Truly yours
J. C. Goosmann

THE
CARBONIC ACID INDUSTRY

A COMPREHENSIVE REVIEW OF THE
MANUFACTURE AND USES OF CO_2

THE COMMERCIAL PRODUCTION OF CARBON DIOXIDE.
DESIGN AND CONSTRUCTION OF APPARATUS AND
MACHINERY. EFFICIENCY FOR REFRIGERATING
PURPOSES. MINERAL WATERS AND OTHER
BEVERAGES. METHODS OF CARBONATING
AND BOTTLING. UTILIZATION
OF FERMENTATION CARBONIC
ACID GAS—ITS COLLECTION
IN THE BREWERY.

BY

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PREFACE.

The manufacture of liquid carbonic acid and its application to the needs of various branches of trade has grown to immense proportions in a comparatively short period of time. Twenty-five years ago carbonic acid and its liquefaction was of interest only to the scientist, and a knowledge of its peculiar properties was possessed only by the instructor upon scientific subjects and the experimenter. The fact that it could be changed from a gaseous to a liquid state was an interesting scientific phenomenon, but it was not regarded as having much practical value in the industrial world.

About the time that the wholesomeness of natural mineral waters containing carbonic acid was recognized, the question of imitating them by artificial means arose. In a very few years thereafter this resulted in the production in large quantities of artificial mineral waters compounded of the same constituents as the natural product. The necessities of the mineral water trade, therefore, gave the first great impetus to the manufacture of carbonic acid.

The very rapid strides made in the growth of the brewing industry during the same period also increased materially the demand for this product. Many other industries as well have since been constantly increasing their demands upon the resources of the carbonic acid manufacturer.

Up to this time no treatise or book of a practical nature covering the entire field occupied by the carbonic acid industry has been published. Most of the available information concerning it is found in short contributions and paragraphs scattered through a wide range of periodicals and pamphlets, and for this reason it has been extremely difficult to obtain correct data which could be applied to practical use in any one of the branches of the industry.

After a search for information bearing upon this subject in all its phases extending over a period of ten years, the author of this volume determined to alter this condition of affairs by collecting all available reliable data, and, after carefully analyzing and comparing same, publish the result in a systematic and concise review of the whole subject that would be of value to all who are engaged in producing and dispensing this product. Much of the information and data contained herein, which is of particular value to those actively engaged in the business, is a record of the actual experience of the author and others who have devoted years to its study. The advantages and disadvantages of all apparatus and machinery used in the various branches of the industry are treated upon thoroughly and impartially. In this connection the investigations and inventions of German scientists and engineers, especially those of Dr. Luhmann, Mollier, Lorenz and Stetefeld, have been of material assistance to the author. The chapter on fermentation gas records the actual practical work and experience of the writer in this particular line of work, and it is hoped that the suggestions contained therein will prove of value to the reader interested in this branch of the industry.

A part of the matter incorporated in this work appeared first in a series of articles in *Carbonic Acid and Carbonated Beverages,* while considerable of that pertaining to the subject of the manufacture of CO_2 has been reprinted from articles which were written by the author and published in *Ice and Refrigeration.*

An effort has been made to take up and treat every distinct feature of the entire subject in a careful and systematic manner under separate chapter heads and subdivisions, so that the reader may be able to readily find any particular information or facts he is in need of. Nevertheless, inasmuch as this is the first attempt ever made to collect and compile into one volume all the information of practical value extant upon this industry, so extensive and important in all of its ramifications, it is felt that omissions and imperfections necessarily will be discovered. It is therefore earnestly desired by the author and the publishers that corrections and suggestions be freely submitted in order that this work may be improved and perfected as much as possible in future editions.

J. C. Goosmann, M. E.

Chicago, Ill., May, 1907.

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CHAPTER I.

ORIGIN AND DEVELOPMENT OF THE INDUSTRY

EARLY DISCOVERIES.

A retrospective glance over the field during the past century shows the great indebtedness which the technical branches of science owe to the study of nature. Many of the recent triumphs in the industrial world had their origin in the quiet study of a scientist, or in the laboratory of an experimenter, long before the constructor was called upon to give it the form and substance in which it finally started on its tour of conquest around the earth, revolutionizing the mode of living of many races of people. The carbonic acid industry is one of the phenomenal achievements which has resulted from this research in nature's realm. Up to the year 1780 the chemical combination of carbonic acid gas was unknown; it was a mysterious gas until then and the honor of its discovery belongs to the famous physicist, Lavoisier, who gave it the chemical designation by which it is known today. Little did he think at the time that this gas was destined to become of important commercial value, and nearly a century rolled by before the far-seeing physicist and chemist, Karl Friedrich Mohr, recognized (about the year 1870) the significant importance of liquid carbonic acid in the commercial and industrial world.

TECHNICAL DIFFICULTIES EXPERIENCED.

Most prominent technical men looked upon the successful liquefaction of gases in large quantities as an idea little short of preposterous even at that time, and it was nearly ten years later before a patent on the liquefaction of carbonic acid gas of any desired pressure by heating of bicarbonates in closed retorts was granted.

The lucky inventor was a Hollander by the name of Hendrik Beins, and it was he who opened the way for a number of similar inventions, so that in less than two years the eminent chemist, Dr.

W. Raydt, was enabled to produce large quantities of liquid carbonic acid for the first time. Walter N. Hill, of the United States torpedo station located at Newport, R. I., published a pamphlet in 1875 which explained in detail his invention for the purpose of liquefying CO_2 in large quantities. It is not recorded, however, that this invention was ever used for this purpose and it is therefore assumed that the first quantities of liquid carbonic acid commercially used in the United States were imported from Germany by Bruennler in 1884; so that the advent of the "Carbonic Acid Industry" in America dates back to that year. In 1879 an experiment to raise an anchor of nearly 30,000 pounds weight from a depth of forty feet below the surface of the water by means of carbonic acid gas was successfully made at the Imperial wharf in Kiel, Germany. This was the first actual chronicled use of liquid carbonic acid.

The fact that a steel cylinder full of liquid carbonic acid represents a power reservoir which is easily transported and which is ready to give up its stored energy by merely opening a valve is well known and is especially made use of for elevating fluids, as may be observed in almost every liquor saloon in America. It is, furthermore, a well known fact that large quantities of heat are rendered latent by the transition of carbonic acid from the liquid into the gaseous state, thereby producing a powerful refrigerating effect. Millions of pounds of liquid carbonic acid are consumed yearly in the production of carbonated beverages of various description, and the quantities consumed for drawing beer reach enormous figures. The world-famous steel works of Krupp in Essen, Germany, have used liquid carbonic acid as a means for compressing the fluid steel since 1880 and it has become useful as a motive power as well as a fire extinguisher. Owing to its neutral character, it is used for the purpose of applying counter pressure in a multitude of apparatuses.

ITS PLACE IN THE REALM OF NATURE.

If we investigate more fully the characteristic features of carbonic acid, especially those which led to its discovery, we find that it is a gas that wields a most important influence in the realm of nature itself. Every process of regeneration in the mineral, the vegetable and the animal kingdoms requires this gas as the fundamental agent.

It changes the carbonates of the metals and of the alkali earth into bicarbonates so that they become soluble in water. In this condition they are carried to and deposited in other localities, where they create new formations of chalk and other carbonates, sometimes reaching gigantic proportions.

The existence of the vegetable kingdom is almost entirely due to this gas. The roots of every plant absorb the gas in its watery solution, and when it reaches the foliage it is transformed by the chemical action of the sun into the useful material that builds the new cells.

The animal body, like all organic creation, consists of four elementary substances, namely: carbon, oxygen, hydrogen and nitrogen, but unlike the vegetable, the animal organism can not use for its existence these elementary substances. They are suitable for creative as well as regenerative work in the animal world only after they have been made by the vegetation into organic matter; hence it follows that besides water and ammonia carbonic acid is the indirect producer and conservator of animal life through its direct creation of the vegetable kingdom.

At the moment of extinction of vegetable as well as animal life the process of putrefaction sets in and the organic matter is destroyed by separation into the original elementary substances of carbonic acid, water and ammonia, which are again introduced into the creative and regenerative cycle of life to perform the same work over again.

During the development of knowledge, culture and civilization, man has used his best endeavors to make the products emanating from the three kingdoms of nature subservient to his manifold needs, and as soon as the importance of carbonic acid as one of the main factors of existence had been realized, all the skill and ingenuity available was set to work to produce and apply this gas to numerous hygienic as well as industrial purposes.

Its discovery was principally due to the fact that it attracted the attention of scientists by phenomena for which they were unable to find a satisfactory explanation. It was known that certain stones would show a violent chemical reaction and gas generation when saturated with acid; and that the flame of a candle would die out in some cavities of the earth, but no one was able to offer a plausible reason for these mysterious occurrences. Finally it was discovered that the same gas which caused the above phenomena was especially prevalent in the atmosphere of extensive forests, that it was generated by the decomposition of the carbonates of alkali, as well as during the combustion of coal, and also in the course of all processes of fermentation. After a great deal of careful examination, Lavoisier became more intimately acquainted with the nature of this gas and finally established, by means of a series of experiments, that two atoms (thirty-two parts by weight) of oxygen and one atom (twelve parts by weight) of carbon in chemical union form carbon dioxide, or carbonic acid, as it is commonly called.

Carbonic acid of all the gases was the first to be successfully liquefied, which was accomplished in 1823 as a result of the efforts of Davy and Faraday.

NATURE AND ATTRIBUTES OF THE GAS.

The various valuable attributes of carbonic acid soon became widely known and the rapid growth of the brewing industry, as well as the mineral water trade, created for it an enormous demand. The properties of this gas, commonly known by its chemical symbol, CO_2, are now probably better understood than those of all other gases. Almost everybody knows that it is responsible for the sparkle of champagne, beer and aerated waters, and that it exists in all waters as well as in the atmosphere. In its natural state it is a colorless, odorless gas, and at a temperature of 32° F. and a pressure of thirty-six atmospheres, it can be converted into a colorless and odorless liquid. The specific gravity of carbonic acid gas is 1.529 at atmospheric pressure and it becomes a liquid at 110° below zero at that pressure.

When carbon is burned in oxygen CO_2 is formed, but if the supply of oxygen is insufficient, carbonic oxide, CO, an extremely poisonous gas, is also produced. The latter will burn with a blue flame, and by its combustion produce CO_2, but pure CO_2 will neither originate nor support combustion. A flame will be immediately extinguished if brought into an atmosphere highly saturated with CO_2; it is a peculiar characteristic of CO_2 that the oxygen contained in this chemical combination is closely bound to the carbon and not available for purposes of oxydation under ordinary circumstances. CO_2 is contained in the atmosphere to the extent of about 0.04 per cent, but the average is somewhat influenced by surrounding conditions, the time of the day, the condition of the weather, temperature of the atmosphere and the extent of vegetation. The air over great stretches of land contains a greater percentage of CO_2 than the air over the sea, and while the percentage decreases during the day on land it increases over the sea. Rain decreases and snow increases the amount of CO_2 in the air; during foggy weather the percentage is greater and when the atmospheric conditions are clear it is smaller. The summer season produces the maximum, and cold, wintry weather the minimum percentage. Active vegetation removes the CO_2 in great quantities from the air during its assimilation process, but each respiration of man and beast, and each process of combustion and fermentation restores a considerable amount. Volcanic formations, abysses of the earth, fountains, and especially the sea constantly emit large quantities of CO_2, so that its relative percentage of the atmosphere remains nearly the same.

Carbonic dioxide is produced in chemically pure form by means of combustion of coal, coke, chalks, magnesite, etc., or by means of the decomposition of bi-carbonate of soda, and a number of CO_2 gas wells gush out the natural product from the interior of the earth at a high pressure. Liquid CO_2 may be liberated at such low temperatures that a white crystalline mass is retained, which slowly evaporates through the absorption of atmospheric heat. The fact relating to the higher specific gravity can be ascertained by throwing the above crystalline mass into a basin of water; it will then be observed that the CO_2 rises in white clouds and slowly sinks down over the rim of the basin. CO_2 does not possess a great affinity for water, but it will dissolve in about its own volume, forming carbonic acid (H_2CO_3). The solution has a sharp acid taste, and it will turn blue litmus paper red. The volume of CO_2 that water is capable of absorbing decreases as the temperature rises and all of it can be expelled if the water is brought to the boiling point.

The major part of the carbonic acid gas used in Germany for commercial purposes is obtained from wells, and it seems that the German Empire is especially favored by nature in this particular. Large numbers of natural CO_2 wells are found wherever the sedimentary stratum is frequently broken by volcanic formation, and basalt as well as phonolite veins form in most cases the channels between the interior and the surface of the earth through which the gas travels. These volcanic formations are very porous, which allows the surface water to filter slowly through them into the earth, while the natural CO_2 gas works its way upward through the same porous formations, when it is partly absorbed by the incoming water, forming H_2CO_3, while the balance of the gas escapes into the atmosphere. Natural carbonic acid gas wells have been found, especially in locations where the earth's crust has been split and broken in numerous directions by volcanic disturbances, as, for instance, throughout the entire mountainous district east of the Rhine, as well as in the Suabian Alps. In the summer of 1895 a party of men were at work sinking a shaft in the neighborhood of Sondra, Thuringia, when suddenly at a depth of 650 feet a gas stream broke forth with such force that the heavy drilling apparatus was blown bodily out of the shaft. It was ascertained that this gas was pure CO_2 and the pressure of this well ran up to 16.5 atmospheres, or 242 pounds per square inch. The amount of gas furnished by this well alone averages over 1,000,000 pounds every twenty-four hours, and after many unsuccessful efforts the flow of the gas was finally controlled by means of a special apparatus, built similar to a large stuffing box and packed with several sets of rubber rings.

Science and its most learned devotees have not been able to explain how and why such immense quantities of CO_2 are generated in the interior of the earth. The gas can not be separated from the carbonates of the alkali earth by means of high temperature, because the pressure obtaining at great depth prevents it. Strong acids are not present in the interior of the earth and the only plausible explanation remaining is that CO_2 in a free, compressed condition forms a component part of the deeper strata, and the Sondra well may be cited in proof of this argument, as it is located in a dry and water-free stratum. The gas obtained from this well needs only to be cleaned, compressed and filled into CO_2 cylinders. It is cleaned in a simple water-spray apparatus, the moisture is then absorbed by forcing the gas through a chloride of calcium tower, and from here it is conducted by its own pressure to compressors of double-stage type; after compression the gas is cooled in ordinary high pressure condensers and is changed into the liquid state, ready to be drawn off into the steel cylinders.

The manner of obtaining the gas from wells where it is mixed with water is nearly as simple. It is much more difficult to obtain CO_2 by artificial means and the various means used for this purpose will be fully described in the following chapters.

It is well known that large quantities of CO_2 are liberated during the fermentation process in the manufacture of beer, etc., and the obtaining of the gas as a by-product during this process has been looked upon with great favor, especially so in the United States, as a large proportion of the American breweries are establishments of a magnitude hardly ever reached in any other country. During the last few years a number of breweries have adopted the plan of absorbing a certain amount of fermentation CO_2 from a particularly rich wort, purifying and storing the same and re-saturating the beer with this gas before racking off. The beer so treated does not need "Kraeusen," and as this is of special commercial advantage to the brewer the process has rapidly increased in favor. Numerous plants of this character have already been installed and the results are said to be most satisfactory.

Carbonic acid liquefying plants in breweries are no longer infrequent. In Chicago the Schoenhofen Brewing Company has a complete plant, also the Pabst brewery of Milwaukee. The William J. Lemp Brewing Company, St. Louis, and three brewers in New York have followed the example of the first named institutions. An idea may be gained of the vast quantities of CO_2 arising from the fermenting tubs, when it is remembered that one pound of liquid CO_2 is given off by every five to six gallons of wort during the period of fermentation.

ITS USE IN VARIOUS INDUSTRIES.

Manufacturers of mineral waters, aerated waters and other beverages consume CO_2 in large quantities for carbonating purposes. They assert, however, that fermentation CO_2 very often is unfit for the carbonation of waters and fancy drinks on account of a very undesirable odor which it frequently possesses, and as this odor would be transferred to the product carbonated with such gas, they prefer to produce their own gas by means of the decomposition of bi-carbonate of soda with acids, if gas produced by combustion can not be obtained in the locality.

The truth of these assertions can not be doubted. CO_2 has a great affinity for flavors, desirable as well as undesirable, and acquires them readily. In order to prevent the absorption of objectionable odors by the gas, the machinery and apparatus used for the production of CO_2 should be kept scrupulously clean; they should be washed and purified frequently; the water used for washing the gas should be fresh and pure and special attention should be given to the development of the gas in the fermenters; all air should be expelled from same before drawing the gas and the latter should be tested as to its richness before starting the suction and compression machinery. The gas then obtained will have for carbonating purposes all the qualities to be desired from a pure, odorless CO_2.

Attention has already been called in a former paragraph to the fact that during the evaporation of liquid CO_2 a considerable amount of heat becomes latent. This is especially noticeable during the evaporation of crystalline CO_2, which requires considerable quantities of heat, and as air is a poor conductor, the crystalline CO_2 is unable to obtain the necessary heat fast enough from the atmosphere surrounding and therefore requires considerable time before it is fully dissolved. To the study of this condition is due the invention of CO_2 ice and refrigerating machinery.

Within the last few years there has been a marked inclination to use CO_2 in breweries. Every brewer is acquainted with the fact that this gas is given off in immense quantities from the vats during the process of fermentation; and as it is peculiarly suitable for carbonating the finished beer, on account of the aromatic flavors of the malt and hops used in brewing, which they contain and which are invariably lost during fermentation, it is now frequently used for that purpose.

A very efficient outfit of machinery for the collection, compression and storage of this fermentation gas in connection with a carbonating and refrigerating system is now in use in many breweries. This gas is collected from the fermenters, purified and compressed and is then used for carbonating the finished beer. In connection therewith a part of the gas is prepared to serve as the refrigerating agent in the ice machines. The surplus of the gas may be liquefied by means of the refrigerating equipment and put into steel cylinders ready for the market.

In the sugar industry carbonic acid gas is used for saturation purposes, *i. e.,* the decomposition of sugar-chalk combinations, producing a non-soluble carbonate of calcium and clarifying the liquid sugar. Carbonic acid gas is also used for chemical decomposition in the manufacture of white lead, and it serves the same purpose in the production of sodium of ammonia.

Carbonic acid is a well known preservative and its use in fighting fire is highly estimated. For medicinal purposes the CO_2 water and gas bath is considered very valuable, especially in the treatment of nervous diseases, as there is nothing else known that acts upon the entire nervous system with the same mildly stimulating and at the same time pleasant effect. Medical authorities state that the most important agent in the famous German waters is CO_2, and it is to its action that the healing power of carbonic acid waters used externally is attributed.

CO_2 is a staple article and is sold in steel cylinders of great tensile strength containing either fifty or twenty pounds of the liquid, and its use is so universal that it can be readily obtained even in the smallest towns. The annual output of CO_2 in the United States is over 50,000,000 pounds, and as new branches of usefulness are discovered almost yearly the demand increases so rapidly that the producers of the marketable article find it difficult to keep pace with it.

CHAPTER II.

VARIOUS METHODS OF PRODUCING CO_2.

VALUABLE ATTRIBUTES.

It has been shown that the discovery of CO_2 was due to its silent, but nevertheless extremely effective work in the domain of nature. Human knowledge and research revealed the valuable attributes of the gas, and commercialism combined with inventive genius made it applicable to a number of existing industries, improving the product of the latter. In the course of time new fields of usefulness were found for the gas; it made possible the creation of new products, bringing into existence new industries. Thus its value has been demonstrated beyond peradventure and it has grown to be a material of the greatest importance, the production of which has developed into a business of magnificent proportions.

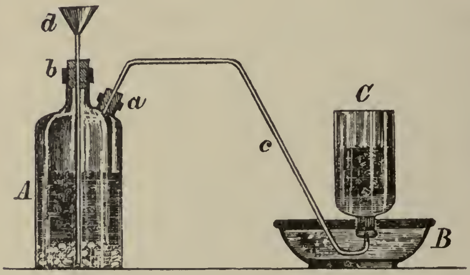

FIG. 1.—LABORATORY APPARATUS FOR PRODUCING CO_2.

Small quantities of pure carbonic acid gas may be obtained in any laboratory in the following manner: A small quantity of crushed marble is placed in a bottle, *A* (Fig. 1), so that the bottom of same is covered to a height of about two inches. The bottle is then filled with sweet water about half full. Marble and water must be well shaken in order to remove all air that may adhere to the crushed marble. The bottle has two outlets, both of which are closed by means of a cork. A glass tube with funnel extends through the cork into the bottle and another S tube, *c*, connects the bottle, *A*, with another receptable, *C*, as shown. Funnel, *d*, admits a small quantity of chloric acid, and immediately a production of gas takes place. This gas escapes through tube, *c*, into bottle, *C*, and as the latter is filled with water and sealed by means of water in the basin, *B*, the gas fills the upper part of the receptacle, *C*, and expels the water from the same. The first gas so produced contains air and this mixture of gas and air is allowed to escape until the pure gas is formed. The product of this decomposition is carbonic acid gas, chloride of calcium and water, which, expressed by the respective chemical symbols, is: $Ca\ CO_3 + 2\ HCl = CO_2 + Ca\ Cl_2 + H_2O$.

In order to ascertain the freedom of the gas from atmospheric air it is tested in the following manner: Fill a small test glass to about one-fifth of its volume with caustic potash lye and fill up with CO_2 gas under water. The liquid and gas must be thoroughly mixed by shaking and if there be no air mixed with the gas the latter will be completely absorbed by the lye, so that the glass will fill itself with water, when slightly opened below the surface of same. If any gas remains, it indicates by the volume which it occupies the amount of air mixed with the CO_2.

PRODUCTION OF CO_2 BY COMBUSTION.

The combustion of carbon in any form produces carbonic acid gas. Carbon burns in an atmosphere of oxygen or in air because of its power to unite with the oxygen contained in the same. The atmospheric air is a mixture of nitrogen and oxygen, 23 per cent, by weight, of which is oxygen; during the process of combustion this oxygen joins the carbonic oxide produced during the primary stage of combustion and forms carbon dioxide.

Considerable misconception exists as to the difference between carbon oxide, the poisonous, and carbon dioxide, the comparatively harmless gas. The products of combustion where pure carbon is consumed are carbon monoxide (CO), and carbon dioxide (CO_2); the monoxide is extremely poisonous and is formed only when there is insufficient air to render the combustion complete; it has therefore a decided tendency to absorb another equivalent of oxygen, is very inflammable, burns with a blue flame, and changes into CO_2 as soon as sufficient oxygen is added to complete the combustion.

Owing to the fact that carbon monoxide—carbon oxide—or CO, decomposes the blood, it acts as a strong poison when inhaled into the lungs. Carbon dioxide, on the other hand, does not assist in any combustion and a flame will be immediately extinguished when brought in contact with this gas. CO_2 does not deteriorate the blood when inhaled, at the same time the oxygen contained in the carbonic acid gas does not substitute the oxygen of the atmospheric air and the result will be the suffocation of any living creature for want of oxygen when placed within a room containing a high percentage of this gas.

The respiratory organs, and as a natural consequence the blood, are always subjected to the CO_2 contained in the air, and even a considerable amount may be inhaled without any deleterious effects, so long as the mixture of gas and air contains the requiste amount of oxygen.

CO_2 produced during the combustion of carbon also contains the unconsumed balance of the oxygen in the air admitted during the process, as well as the nitrogen of the whole volume. These latter gases constitute the undesirable elements and it is necessary to separate and expel them from the crude CO_2. Any materials containing carbon, such as oil, wood, anthracite and bituminous coal, may be used for the generation of CO_2, but for commercial purposes only such material as contains carbon in its purest form can be used; all other carbon-containing substances are not suitable for this purpose, because they furnish large quantities of ill-smelling gases in combination with the CO_2, and as the latter has a great affinity for flavors it will absorb same to such an extent as to make it unfit for domestic purposes. Of the various grades of coal, anthracite or hard coal, is the richest in solid or fixed carbon, sometimes containing as much as 97 per cent of pure carbon. Such coal, as well as charcoal, and the porous coke, furnish the purest CO_2.

The formation of CO from one pound of carbon produces 4,275 B. T. U. and as soon as the higher stage of oxidation is reached by admitting more air, we secure 10,260 additional B. T. U. together with the formation of CO_2. It is generally assumed that the actual amount of air required for a complete combustion—or the formation of CO_2—approximates twice the theoretical amount, for the reason that it is impossible to get an intimate mixture of the air with the heated fuel.

In order to obtain the highest percentage of CO_2, the material burned must be dry; the temperature in the furnace must be high—for the reason that the oxygen unites with the carbon monoxide produced during the primary stage of combustion only at high temperatures; the admixture of air through the fire bed should not exceed 150 to 160 cubic feet per pound of coal or coke; the thickness of a scrupulously clean fire-bed must not exceed five inches, and the fire must show a white heat above—no flame—and an incandescent glow on the grate bars. Attention to these details will lead to the richest yield of CO_2 gas.

CHEMICAL GENERATION OF CO_2.

The watery solution of carbonic acid (H_2CO_3) is of a very mild acidulous character, which proves to the chemist that it is easily possible to expel the pure CO_2 from its chemical combinations by means of stronger mineral or organic acids, such as sulphuric, chloric, hydrochloric and nitric acids. Carbonates which are frequently so treated in order to eject the CO_2 contained in same are:

Marble—Not soluble in water, contains 48 per cent CO_2, decomposes when treated with any of the stronger mineral or organic acids. Marble dust forms into a nearly insoluble product of sulphate of calcium (gypsum) when treated with sulphuric acid.

Calcit—Which has nearly the same characteristics as marble, contains 44 per cent CO_2 and is frequently mixed with other metallic oxides.

Aragonit—Which is of the same chemical combination as calcit and differs only in its higher specific weight and density.

Chalk, powdered—Nearly insoluble in water, gives off its CO_2 when treated with any of the acids.

Dolomit, powdered—Contains 48 per cent CO_2, consists of 58 per cent carbonate of calcium ($Ca\ CO_3$) and 41 per cent carbonate of magnesium ($Mg\ CO_3$).

Carbonate of Zinc—Contains 35.5 per cent CO_2 and is readily decomposed by means of chloric or sulphuric acid.

Strontianit—Contains 30 per cent CO_2, is easily soluble in chloric acid and is frequently used to precipitate sugar from the molasses.

Carbonate of Lead—Which, when pure, contains 16.5 per cent CO_2, dissolves readily when treated with chloric acid.

Owing to the fact that carbon monoxide—carbon oxide—or CO, decomposes the blood, it acts as a strong poison when inhaled into the lungs. Carbon dioxide, on the other hand, does not assist in any combustion and a flame will be immediately extinguished when brought in contact with this gas. CO_2 does not deteriorate the blood when inhaled, at the same time the oxygen contained in the carbonic acid gas does not substitute the oxygen of the atmospheric air and the result will be the suffocation of any living creature for want of oxygen when placed within a room containing a high percentage of this gas.

The respiratory organs, and as a natural consequence the blood, are always subjected to the CO_2 contained in the air, and even a considerable amount may be inhaled without any deleterious effects, so long as the mixture of gas and air contains the requiste amount of oxygen.

CO_2 produced during the combustion of carbon also contains the unconsumed balance of the oxygen in the air admitted during the process, as well as the nitrogen of the whole volume. These latter gases constitute the undesirable elements and it is necessary to separate and expel them from the crude CO_2. Any materials containing carbon, such as oil, wood, anthracite and bituminous coal, may be used for the generation of CO_2, but for commercial purposes only such material as contains carbon in its purest form can be used; all other carbon-containing substances are not suitable for this purpose, because they furnish large quantities of ill-smelling gases in combination with the CO_2, and as the latter has a great affinity for flavors it will absorb same to such an extent as to make it unfit for domestic purposes. Of the various grades of coal, anthracite or hard coal, is the richest in solid or fixed carbon, sometimes containing as much as 97 per cent of pure carbon. Such coal, as well as charcoal, and the porous coke, furnish the purest CO_2.

The formation of CO from one pound of carbon produces 4,275 B. T. U. and as soon as the higher stage of oxidation is reached by admitting more air, we secure 10,260 additional B. T. U. together with the formation of CO_2. It is generally assumed that the actual amount of air required for a complete combustion—or the formation of CO_2—approximates twice the theoretical amount, for the reason that it is impossible to get an intimate mixture of the air with the heated fuel.

In order to obtain the highest percentage of CO_2, the material burned must be dry; the temperature in the furnace must be high—for the reason that the oxygen unites with the carbon monoxide produced during the primary stage of combustion only at high temperatures; the admixture of air through the fire bed should not exceed 150 to 160 cubic feet per pound of coal or coke; the thickness of a scrupulously clean fire-bed must not exceed five inches, and the fire must show a white heat above—no flame—and an incandescent glow on the grate bars. Attention to these details will lead to the richest yield of CO_2 gas.

CHEMICAL GENERATION OF CO_2.

The watery solution of carbonic acid (H_2CO_3) is of a very mild acidulous character, which proves to the chemist that it is easily possible to expel the pure CO_2 from its chemical combinations by means of stronger mineral or organic acids, such as sulphuric, chloric, hydrochloric and nitric acids. Carbonates which are frequently so treated in order to eject the CO_2 contained in same are:

Marble—Not soluble in water, contains 48 per cent CO_2, decomposes when treated with any of the stronger mineral or organic acids. Marble dust forms into a nearly insoluble product of sulphate of calcium (gypsum) when treated with sulphuric acid.

Calcit—Which has nearly the same characteristics as marble, contains 44 per cent CO_2 and is frequently mixed with other metallic oxides.

Aragonit—Which is of the same chemical combination as calcit and differs only in its higher specific weight and density.

Chalk, powdered—Nearly insoluble in water, gives off its CO_2 when treated with any of the acids.

Dolomit, powdered—Contains 48 per cent CO_2, consists of 58 per cent carbonate of calcium ($Ca\ CO_3$) and 41 per cent carbonate of magnesium ($Mg\ CO_3$).

Carbonate of Zinc—Contains 35.5 per cent CO_2 and is readily decomposed by means of chloric or sulphuric acid.

Strontianit—Contains 30 per cent CO_2, is easily soluble in chloric acid and is frequently used to precipitate sugar from the molasses.

Carbonate of Lead—Which, when pure, contains 16.5 per cent CO_2, dissolves readily when treated with chloric acid.

Carbonate of Copper—Which is a chemical combination of oxide of copper, carbon dioxide and water; contains 20 per cent of CO_2 and is dissolved by means of chloric acid.

In consideration of the fact that the commercial CO_2 is used for domestic purposes in various waters, fancy beverages, for the raising of beer to the faucets, etc., it must be of absolute purity; and in order to produce a pure and odorless CO_2 the material used for its production must be faultless. A careless selection of the raw material will surely spoil the gas; the slightest by-odor, or other impurity, will make it unfit for carbonating purposes.

For this reason many of the carbonated water factories produce their own gas, and the process used by them is based upon the principle of the chemical decomposition of any of the bases containing CO_2 by means of strong acids. The carbonates and bi-carbonates of the earth have been found especially suitable for this purpose, as their treatment is comparatively simple, while at the same time they yield a high percentage of gas. Marble dust, bi-carbonate of soda, powdered chalk or whiting are used mostly, and sulphuric or chloric acid serves the work of decomposition. Pure marble contains 48 per cent of CO_2, and requires for its decomposition about 230 pounds of chloric acid of 20° Beaume for every 100 pounds of marble. Bi-carbonate of soda is very frequently used; it is manufactured from the crystalline soda and being a bi-carbonate, contains a high percentage of gas, usually 46 per cent. About 100 pounds of hydrochloric acid (vitriol) are required to decompose 150 pounds of the bi-carbonate, and the amount of gas manufactured from this quantity of soda and vitriol averages 560 to 600 cubic feet.

Whiting (powdered chalk) is one of the cheapest materials available and sulphuric acid is used for the decomposition of same. The sediment enters into a chemical union with two molecules of water and it is good practice to use four quarts of water to every quart of acid in order to prevent the hardening of the mass of gypsum. It is advisable to heat the water before using.

The apparatus used for the above purposes is called a "generator" and, ordinarily, consists of a horizontal cylindrical, lead-lined vessel, which is provided with an agitating device operated by means of pulley and belt. The bicarbonate of soda is filled into this cylinder, a fixed quantity of water is added and thoroughly mixed with the soda by means of the agitator. Mounted horizontally or vertically above the cylinder is another cylindrical receptacle, called the acid pot. This acid pot or cylinder contains the acid and is connected with the generator body by means of a lead pipe. A valve actuated by the movements of the gasometer regulates the flow of acid into the generator vessel. The decomposition of the soda takes place immediately and the gas escapes with effervescence through a suitable connection into several purifiers. These purifiers which are connected to the generator and located in any suitable place, are filled with water and connected in series. The gas inlet extends nearly to the bottom of the purifiers, so that the gas is forced to pass through the water. Any acid or other impurities carried over from the generator will be absorbed by the water. After leaving the purifiers the gas may be dried in a simple chloride of calcium tower if desired. It will be readily understood that this process necessitates the employment of special help, it is slow and tedious, consumes considerable

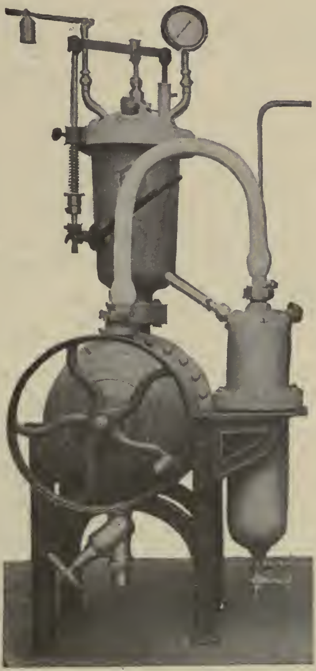

FIG. 2.—GENERATOR FOR CARBONIC ACID GAS.

power and is generally discarded in localities supplied with liquid CO_2 of a pure character.

SOURCES AND METHODS OF PRODUCING CO_2 IN CHEMICALLY PURE FORM.

Carbon dioxide is produced principally (outside of the chemical process, which furnishes CO_2 only in limited quantities):

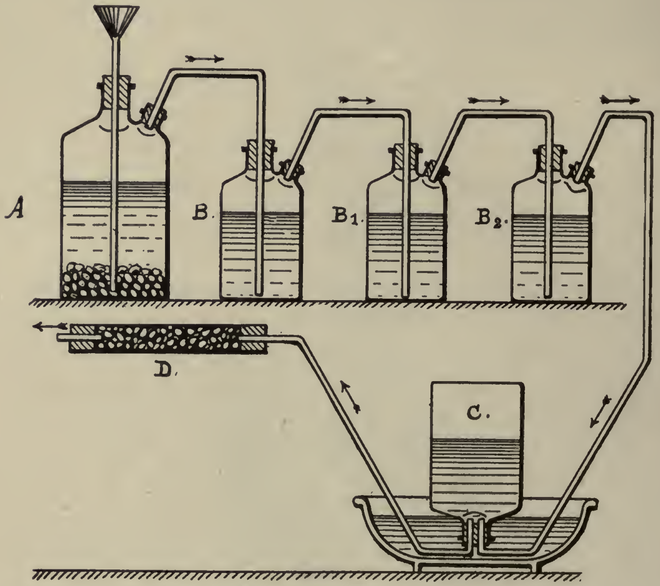

FIG. 3.—LABORATORY METHOD OF DEVELOPING, PURIFYING, COLLECTING AND DRYING CO_2 GAS.

A, Developer; *B*, B_1 and B_2, Purifiers (Washers); *C*, Gasometer, and *D*, Dryer (Chloride of Calcium).

1—By nature; *a,* in gas form; *b,* in a watery solution.

2—By heat; *a,* heating of carbonates in closed retorts; *b,* heating of carbonates in closed retorts and admission of live steam; *c,* heating of carbonates in a kiln and admission of live steam.

3—By means of combustion; *a,* combustion of carbon; *b,* generation of CO and the burning of same in a kiln filled with carbonates.

4—By means of fermentation.

SOURCES OF THE NATURAL PRODUCT.

Carbonic acid gas wells eject enormous quantities of CO_2 from the interior of the earth, especially in localities where volcanic disturbances have so affected the earth's crust as to allow the surface water to penetrate to great depths. This surface water absorbs part of the CO_2 contained in the humus soil and carries it along into the deeper strata. It is now prepared to act as a mild acid, decomposes great layers of the alkali earth and builds up in the course of time new formations. Many of the earth's volcanic localities contain free carbonic acid gas at great depths, and whenever this gas is reached by the penetrating surface water it will saturate the latter in accordance with the hydrostatic pressure prevailing at such depth, and it appears at another place as a sparkling and foaming spring. Many of the bottled mineral waters are the natural product which is generated in this way.

Germany is favored with an abundance of these carbonic acid springs (it is said more than one thousand). Some of them are famous the world over. The most noted are: Wiesbaden, Schwalbach, Selters, Homburg, Soden, Schlangenbad, Ems, Nauheim, etc. The "sprudel" of Nauheim furnishes seventy-one cubic feet of carbonic acid gas every minute. France possesses a number of such springs in the Auvergne and in the midst of the Vivarais. The Saratoga Springs in New York also are well known.

The percentage of CO_2 contained in such springs can be tested, according to Fresenius, by means of a graduated glass cylinder. This cylinder is used as a receiver of a certain quantity of gas obtained from the spring. Caustic potash lye is then introduced and so manipulated that the CO_2 will be absorbed by it. The remaining gas that can not be absorbed by the lye indicates the volume of the air and other gases which were mixed with the CO_2 in the spring water. Sometimes the value of the spring is destroyed by the presence of sulphuretted hydrogen gases in quantities. This gas is well known on account of its bad odor, and if it can not be expelled the value of the spring shrinks considerably.

The most valuable wells are those which furnish the CO_2 gas in a practically pure condition under pressure. A number of such wells are known to exist in various localities; one of the most noted is at Kaiser-Franzensbad, which furnishes 5,760 cubic feet of gas every twenty-four hours. The gas is nearly pure and has only a very slight by-mixture of sulphuretted hydrogen (H_2S) gases.

The method of absorbing the carbonic acid gas from a carbonic acid spring is comparatively simple. The water reaches the surface by means of its own pressure. As soon as it comes in contact with the atmosphere the gas escapes with effervescence. In order to collect the gas the mouth of the well is surrounded by a large basin in which a certain height of water is always maintained. An ordinary gasometer is used to cover the center of the basin, the rim of the gasometer extends into the water forming a seal in the usual manner. The gas is drawn off through a suitable connection and the surplus water is carried away after it has given off the gas. A similar outfit is used to collect the gas from CO_2 gas wells.

PURIFICATION OF THE NATURAL PRODUCT.

Sometimes the gas when obtained from the earth in a free and dry condition contains considerable nitrogen, air and other gaseous and organic substances. The pure gas must be separated from such impurities before compressing and liquefying, which is successfully done by an apparatus designed for the purpose by Dr. Luhmann. Its basic idea is that of absorption by water under pressure. The pure CO_2 gas is absorbed by water, which takes up but very little of the impure gases. The latter are then expelled from the solution by passing a current of pure carbonic acid gas through it, which absorbs the undesirable gases and carries them with it from the solution.

The apparatus is shown in Fig. 4. *A* is the absorption tower, which is filled with clean lumps of coke resting upon a perforated plate, *s*. The gas containing the impurities is admitted below *s*, through pipe *c*, under pressure. As it rises through the coke column it meets a stream of water which enters through spray, *e*, and percolates downward. The water absorbs the pure CO_2 plus a small volume of the impure gases, the balance of the undesirable gases escaping through atmospheric connection, *k*. Gauge, *d*, shows the pressure in the tower.

The saturated water then enters the lower part, *B*, of the tower, a water gauge showing the height of its level within. The lower part of *B* is provided with several perforated discs, *t*, while the upper part of the same compartment contains an additional coke column, as shown. Pure carbonic acid gas enters at the bottom of *B* through pipe *i*; it travels upward through the saturated water and is spread repeatedly over the whole area by the perforated discs, *t*. The impurities are then absorbed by the pure carbonic acid gas in accordance with the law of Dalton, according to which the pressure exerted on

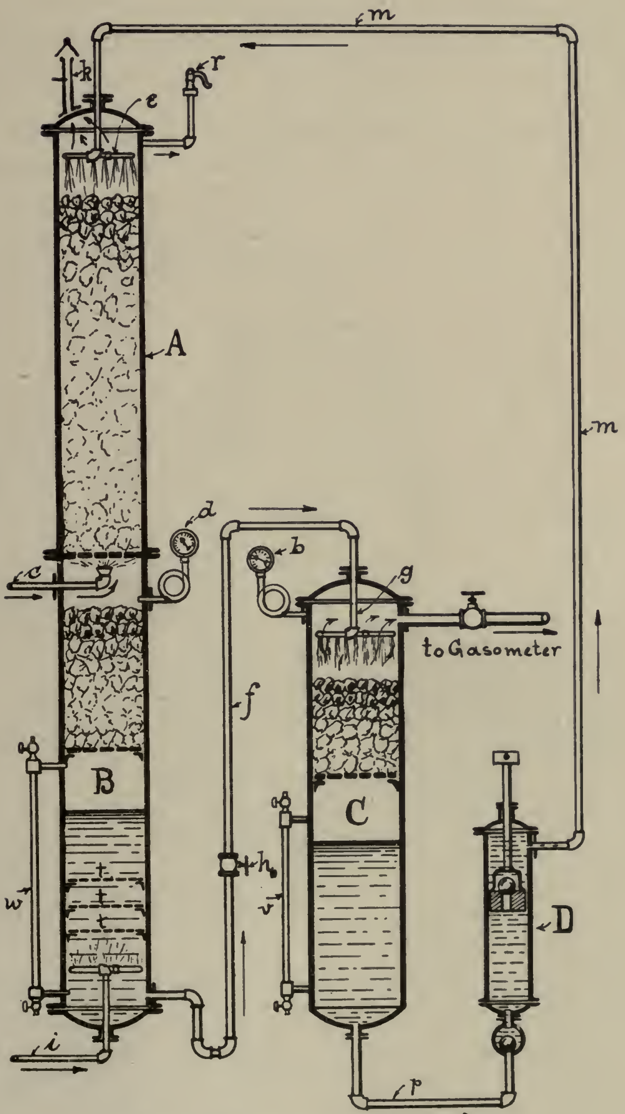

FIG. 4.—PURIFIER FOR NATURAL CO_2.

the interior walls of a vessel containing a mixture of gases is equal to the sum of the pressures which would be exerted if each of the gases occupied the vessel alone, and are carried from the solution into the atmosphere. If the gas contains odorous organic substances it is well to dissolve in the solution a small percentage of permanganate of potassium, by which means such gases will be oxidized and destroyed. The solution is then forced by the pressure obtaining in *A* into vessel, *C,* through pipe line, *f,* and the pressure is reduced by means of valve, *n.* The solution is then sprayed over a third coke column and the gas is liberated, owing to the decrease in pressure, and escapes through pipe, *v,* into a gasometer. The water collects in the lower part of *C* and is forced again into *A* through pipe line, *m,* by means of a pump, *D.* It will be seen that the process is continuous and that the power required is only that consumed by the pump. In the case that the impure gas is obtained at very little or no pressure

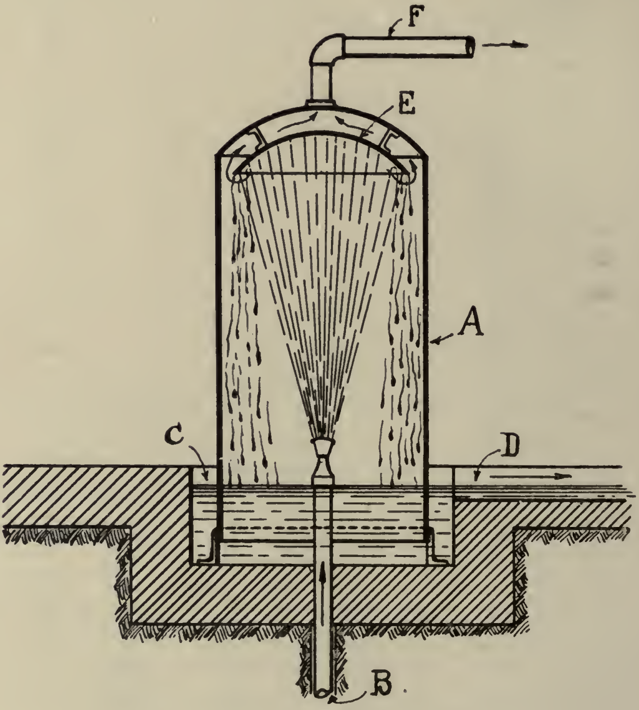

FIG. 5.—HOOD FOR NATURAL GAS WELL.

it must be forced into *A* by means of a compressor. This equipment is also successfully used for the purification of fermentation gases.

In the majority of cases the carbonic acid reaches the surface of the earth in the watery solution, but it is often present in such large volumes that the spring gushes forth because of the boiling of the gas at great depths, with considerable force. As soon as it comes in contact with the atmosphere the gas is released, owing to the termination of the pressure which existed in the interior, and largely escapes, the water retaining only the small volume of gas which it can hold under atmospheric pressure and its respective temperature.

In Saratoga Springs, N. Y., the gas arrives at the surface under a pressure of three pounds, but there are springs in Germany which reach the atmosphere under hundreds of pounds' pressure.

The gas is obtained from the water as shown in the illustration, Fig. 5. The spring is set in a large basin, *G,* by means of pipe, *B,* and covered by a high hood, *A*, the height of which is governed by the pressure at which the water is forced from the earth. It splashes against a shield, *E*, liberates its gas and falls back into the basin, from which it is drained off through a gutter, *D*. The liberated gas leaves the hood through pipe connection, *F,* which conducts it to a gasometer.

One of the small "sprudels" at Saratoga Springs, N. Y., which the Natural Carbonic Gas Company allows to flow for exhibition, is shown in Fig. 6.

CALCINATION OF MAGNESITE.

The simplest process of obtaining carbonic acid gas by means of heat consists of the calcination of magnesite in closed retorts. Calcined magnesite is a valuable product in the manufacture of fireproof material of various kinds. In its powdered form it is used as a filler for paper, etc., and it is therefore readily disposed of at a good price. This fact, in connection with the simplicity of the outfit required, seems to be responsible for the continued use of the retort system. Fig. 7 represents a simple furnace, which is so constructed that it can be fired from both ends. Cast iron retorts are imbedded in the brickwork and the smoke and gases pass around the retorts into the smoke box and out through the chimney. In order to produce the maximum amount of heat possible a fireproof damper is placed in the chimney directly above the furnace, and the admission of air into the firebed is so regulated as to produce a white-heat combustion without draft.

Magnesite loses its CO_2 at a temperature of about 600° F., and the gas is drawn off through simple pipe connections attached to the rear cover of the retorts. Water traps are interposed to collect the condensation of any moisture which may have been absorbed by the magnesite before calcination. No further purifying apparatus is used, and the gas is discharged directly into the gasometer, from

FIG. 6.—FLOWING NATURAL GAS WELL, SARATOGA SPRINGS, N. Y.

where it is drawn into the suction of a two- or three-stage compressor to be compressed and liquefied.

This system does not always furnish gas of the desired purity; sometimes it contains considerable volumes of air, and at other times the presence of moisture in quantities depreciates its value, particularly for refrigerating purposes. Its greatest drawback lies in the inefficiency of the process; the waste of heat is enormous, the lifetime of the retorts is very limited and the cost of the gas production is from four to five times higher than in any up-to-date combustion plant. It has been suggested that the combustion gases, which are wasted in the ordinary retort furnace, be saved and absorbed and the CO_2 gas so obtained added to the gas produced from the magnesite. At a glance this plan seems to be very feasible; however, in carrying the same into practice a complete purifying outfit must be installed, and as this purifying apparatus constitutes the chief investment of a good combustion plant, it is far better to abandon the retort furnace altogether and operate with combustion gas only.

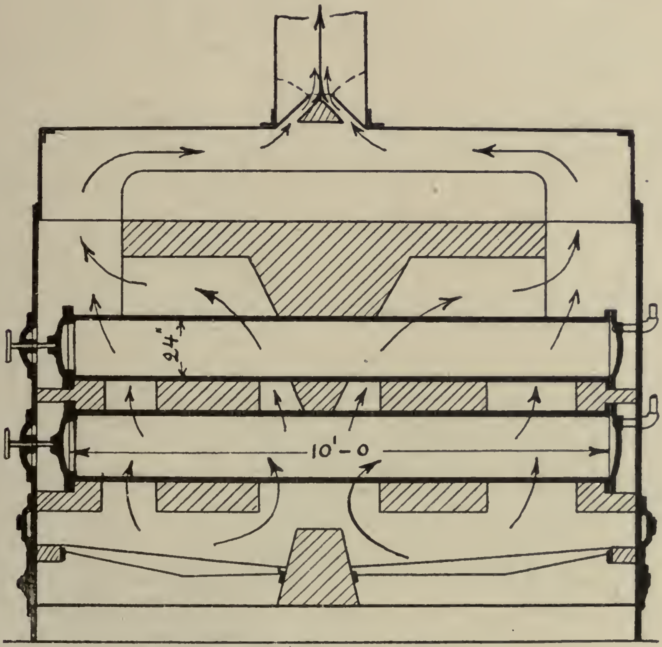

FIG. 7.—SIMPLE FORM OF CLOSED FURNACE.

The magnesite used in the eastern and southern parts of the United States is imported from Greece and is laid down in any of the eastern and southern seaports at the average price of $8 per ton. The Grecian magnesite is a nearly pure carbonate of magnesia; it has a very fine crystalline grain and is ordinarily nearly snow white—sometimes almost transparent—and at other times yellow, gray or without any color. A chemical analysis usually gives the following result:

Magnesia	44.214
Carbonic acid	51.351
Oxide of iron	.970
Insoluble remnants	3.465

The State of California possesses mountains of magnesite, which is usually of a somewhat darker color and coarser grain than the imported material.

CALCINATION OF LIMESTONE.

The calcination of limestone furnishes considerable quantities of CO_2 gas, but the heat required to expel the gas from limestone is of a much higher degree than that required in the case of magnesite. It is well known that the admission of live steam during the heating process induces the limestone to give off the CO_2 gas much more readily, and the observation of this fact led to the construction of a simple retort furnace, shown in Fig. 8. A cast iron retort is built

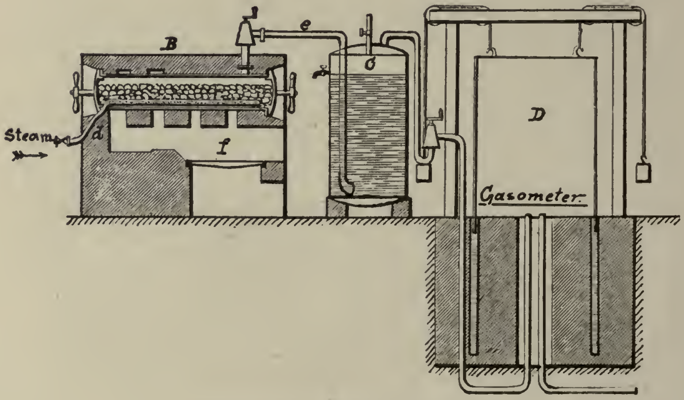

FIG. 8.—SIMPLE RETORT FURNACE.

into a high-temperature furnace, and the limestone contained in same is heated to a red heat by means of the hot fire gases emanating from fireplace *f*. A perforated steam pipe is placed at the bottom of the retort and superheated steam admitted, which discharges into the layer of red-hot limestone. The CO_2 gas is easily expelled in this way and escapes through a suitable connection, *e*, together with the steam vapors, into a large washer, *C*. A continuous supply of cold water condenses the steam while the CO_2 gas escapes into a gasometer. Air and other permanent gases may be drawn off at the top of washer, *C*. The temperature of the off-water from the washer should be not less than about 98° F. in order to prevent the absorption of CO_2 gas by the water.

This process requires a heat of over 1,100° F., and as the specific heat of steam vapor is comparatively low it is necessary to supply large quantities of superheated steam to obtain the temperature and to maintain it during the process. It is also known that carbonic acid gas has a much higher specific heat than steam, so that the same volume of a mixture of carbonic acid gas and steam will create much more heat than steam alone. This method is used in connection with a limekiln in such a way that the CO_2 gas produced in the limekiln is drawn off and forced into a re-generator, where it is mixed with steam, and the mixture of CO_2 gas and steam, returned to the limekiln, saturates the limestone and produces the required high temperature. As soon as the process operates regularly a certain amount of CO_2 gas and steam is absorbed from the kiln into a washer to be purified, while the balance of CO_2 gas and steam is used to be drawn into the re-generator and returned to the limekiln successively.

THE KINDLER FURNACE.

One of the most efficient methods of CO_2 gas production is obtained in the combustion of anthracite, charcoal and coke, and the first apparatus constructed for the purpose is the so-called "Kindler" furnace, illustrated in Fig. 9. A tapering shaft contains the combustion material—coal or coke—and is closed by means of a cover, *b*. The column of coke rests upon the grate bars above the ashpit, and vertical grate bars prevent the falling out of the coke into air opening, *a*. As soon as the fire is started the volume of air necessary for a perfect combustion is properly regulated. The column of coke feeds slowly downward and must be replenished from time to time.

The products of combustion escape through canal *cc* into a large washer, *d*. Attached to pipe *r* is a suction fan, which draws the gases through the washer and discharges them into the purifying apparatus. The space and canal *cc* is filled with crushed limestone, which retains the ashes carried over by the air draft and besides gives up its CO_2 gas as soon as the required temperature is reached. Water pans are placed on top of canal and space *cc*, principally for the purpose of cooling the gases of combustion before they enter the washer. The latter is provided with a manhole for the purpose of admitting a full charge of limestone, which, in combination with the water, is used as a "scrubber" of the gas. A second scrubber, containing soda-lye, is frequently added, both limestone as well as soda-lye acting as an absorbent of any sulphuric acid gas which may be mixed with the CO_2.

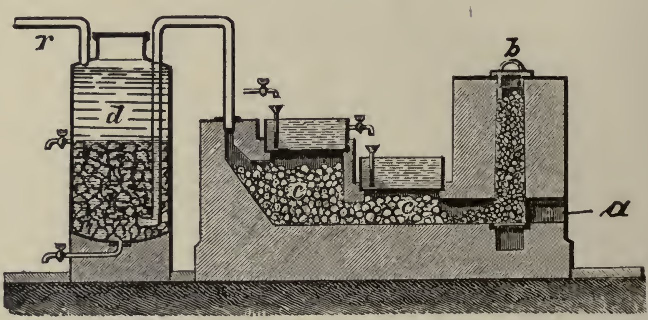

FIG. 9.—THE KINDLER FURNACE.

The atmospheric air contains about 21 per cent by volume of oxygen. This latter gas unites with the carbon during combustion and forms an equal volume of CO_2; it follows that the gases of combustion obtained from the coke can not furnish more than 21 volume per cent of CO_2 gas, the remaining 79 volume per cent constituting the proportion of free or unconsumed air usually present in the gaseous products. This percentage is higher when air is freely admitted during the combustion. The volume and weight of the gaseous products of a complete combustion at 62° F. and atmospheric pressure may be obtained by the following formula: $V = 1.52\ C. + 5.52\ H.$, and the weight can be found by the formula: $W = .126\ C + .358\ H$, when V = volume of gaseous products, in cubic feet;

W = weight of gaseous products, in pounds; C = percentage of constituent carbon, and H = percentage of constituent hydrogen. The volume at any other temperature is governed by the law of the expansion of gases.

Because of the fact that not all of the oxygen gas is consumed during the combustion, it is well to base the calculations for practical results upon not more than 16 to 18 volume per cent of CO_2 gas. Much depends upon a careful and close regulation of the air-draft, too much air being a decided disadvantage for the accomplishing of a thorough combustion.

The character of the coke, as well as the size of the pieces, also is a matter of considerable importance. "Large egg" coke, a thin layer of the burning material, and considerable draft, produce a gas containing large volumes of unused air; on the other hand, small size coke and an insufficient supply of air produce a layer of material on the grates which shows an incandescent glow throughout. This condition is favorable for the reduction of the carbonic acid gas to carbon monoxide and should be carefully avoided. The draft must be so regulated as to produce a complete combustion, together with the best consumption of the oxygen in the air. The most practical sign by which this ideal condition can be ascertained is the action of the combustion itself, which must produce a white heat above the fire-bed and an incandescent glow on the grate bars.

THE WALKHOFF LIMESTONE KILN.

It is well known that limestone contains considerable quantities of carbonic acid gas and that it is possible in most cases to expel the CO_2 from the same by means of heat. A simple kiln construction, which was introduced by Walkhoff, utilizes the heat of the combustion gases to expel the CO_2 from the limestone, which adds a large percentage of the latter to the combustion gases. Fig. 10 shows a cross section of the kiln. The arrangement of fire-place and grate bars is nearly the same as in the Kindler construction. Two shafts, *B* and *D*, are connected by means of canal *C*. The shafts are filled with broken limestone and the heat is supplied from a coke fire at fire-place *A*. All the shafts have the shapes of a self-feeder, the ashes from the coke is removed through an ordinary ashpit door; the calcined lime drops into receptacles *G*, to be taken out from time to time. The heat of the combustion gas drives out the CO_2 from feeds slowly downward and is rapidly calcined by the intense heat created in the lower part of the kiln. Several openings are placed in the brick and iron work to allow an inspection of the process, and to remove any eventual obstructions on the inside. The gases of combustion are conducted through openings, *b,* into large pipes, which lead to washing and purifying apparatus. This method yields a very rich gas, as the CO_2 obtained by the reduction of the carbonates combines with the products of combustion from the gas generator and forms a compound containing about 25 per cent CO_2 when limestone is used, and as high as 35 to 40 per cent with magnesite as the calcined material.

The caustic burnt carbonates fall into the lower part of the kiln, which has a pitch toward the openings provided for the removal of the calcined carbonates. One of the additional advantages of this process is the fact that the carbonates are reduced to nearly a powder, which makes them more desirable for various purposes.

Coke from gas factories, especially such as contains no sulphur in any form, is most suitable for use in this kiln, and furnishes the purest CO_2. Large quantities of CO_2 being required in sugar factories for saturating and other purposes, the above kiln has met with great favor in these establishments.

CHAPTER III.

LIMEKILNS AND COKE FURNACES.

THE SOLVAY PROCESS.

Carbon dioxide is a very important factor in the manufacture of soda, sodium carbonate and ammonia soda, and as the method of producing CO_2 in these establishments is very instructive, using as they do the most practical kiln construction and method of calcining the lime, a detailed description of the process in this place is deemed advisable.

The Solvay process, which is now employed more than any other for this purpose, consists in preparing carbon dioxide from limestone, passing this gas into an ammonia-hydrate solution to form ammonium bicarbonate, mixing said salt solution with the ammonium bicarbonate and producing thereby sodium bicarbonate and ammonium chloride. The sodium bicarbonate is then calcined to form soda ash and the carbon dioxide is again available for use in connection with gas from the kiln. The ammonium chloride is decomposed by milk of lime, the ammonia is set free to be used over again, and the chlorine goes to form calcium chloride.

The limestone used to obtain the carbon dioxide should be as nearly pure calcium carbonate as can be obtained; however, slight impurities are not so serious an objection in this case. A too high percentage of silica, iron or alumina is objectionable, as it causes the limestone to clinker if the temperature is sufficiently high to burn the limestone rapidly. When the lime clinkers it is almost impossible to slake it and is therefore worthless. A high percentage of magnesium carbonate is also undesirable in a limestone, as it lowers the efficiency of the quicklime. The limestone from different parts of the same quarry differs considerably, a fact shown by the following analysis prepared for one of the large United States ammonia-soda works. The analyses were made at regular intervals extending over a period of three consecutive months:

CONSTITUENTS	October Per cent	November Per cent	December Per cent
$Si\ O_2$ (insol. in HCL)..	2.95	5 60	3.95
$AL_2\ O_2$ and $Fe_2\ O_3$.....	.80	.90	.30
$Ca\ CO_3$...............	94.20	83.26	88.39
Mg CO	2.36	10.41	7.75
Total	100.31	100.17	100.39

A hard, compact limestone is the most suitable, for, although it takes a higher temperature and a longer time to burn, it gives a quicklime that is easier to thoroughly slake, and the slaked lime is usually of a better quality. Coke is used mostly in the limekiln, and should be good oven coke and as free from sulphur as possible.

THE SPECIAL FIRE-BOX LIMEKILN.

One style of limekiln has no special fireplace, the coke being simply charged in layers with the limestone; but as the ash of the fuel interferes to some extent in the use of the lime, it is better to construct a kiln with special fire-places, as shown in Fig. 12, which makes a better control of the fire possible. This kiln consists of a shaft twenty-four to forty feet high and tapering both ways to two-thirds the distance from the top. The outer shell of iron is lined with firebrick. In the larger furnaces two rows of bricks are used. The whole kiln is properly supported by pillars and brickwork. The top of the kiln is provided with a cover, one that can be raised to charge the kiln and is then lowered, and rests in a lute of sand or water in *B*. At *D* is shown a 3-inch hole, kept closed with a plug. The hole allows a chance to inspect the process of combustion and to break down the charge should it clinker and stick to the walls. The fireplaces are attached to the kiln at *F*, and removable grate bars, *G*, are located at the bottom of the kiln to support the lime. The ash drops into the lower room and the lime is removed from the kiln by moving or turning the bars. The limestone is elevated to a platform, *C*, and charged into the kiln. The gases are conducted through pipes, *P*, located about four feet from the top of the shaft, and the temperature of the gas at these points averages about 600° F.

METHOD OF BURNING THE LIMESTONE.

The temperature for burning the limestone is from 1,400° to 1,500° F., but if the limestone tends to fuse this temperature should be slightly reduced and the lime burned less rapidly. Damp limestone burns at a lower temperature and better than dry limestone, for the moisture aids the dissociation of the limestone into carbon dioxide and calcium oxide.

One pound of pure calcium carbonate requires about 750 units of heat for its decomposition, and we know that in burning carbon to carbon dioxide one pound of carbon yields 14,500 heat units; therefore 1,000 pounds of calcium carbonate should be burned by about fifty pounds of pure carbon. One thousand pounds of calcium carbonate yields about 50 per cent, or fifty pounds of carbon dioxide. In addition to the above a large amount of heat is required to raise the temperature of the air used in the combustion, which in this case averages at least 200 cubic feet of air per pound of carbon

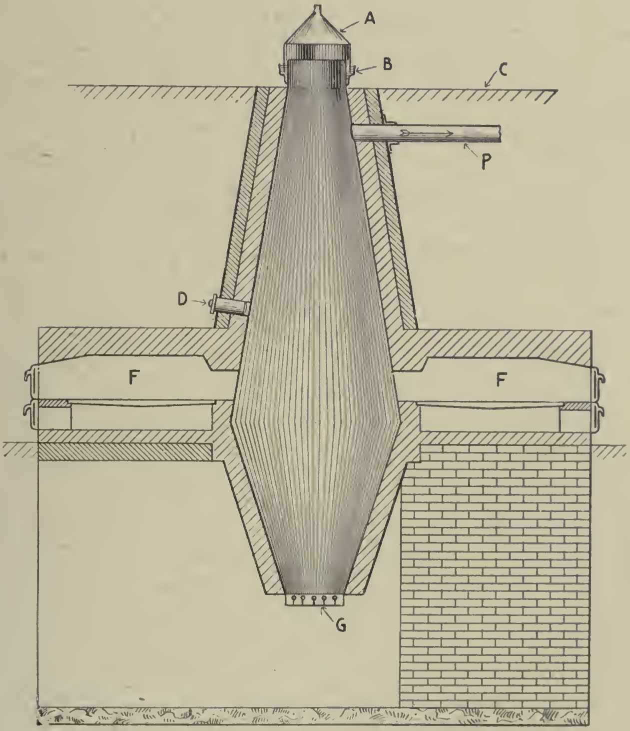

FIG. 12.—LIMEKILN WITH SPECIAL FIRE-PLACES.

burned, so that it is necessary to burn more carbon, which in turn furnishes more carbon dioxide. In addition the loss of heat through radiation from the sides of the kiln and from the quicklime which is not quite cold when removed, and also the heat required to evaporate the moisture in the limestone must be added. Taking all these factors together it has been found that 1,000 pounds of limestone require about 120 pounds of carbon for a complete calcination.

In order to determine the amount of CO_2 obtained from the lime, as well as by the combustion of carbon, we will assume that the lime contained 44 per cent of CO_2 by weight, which is 440 pounds per 1,000 pounds of lime. The above calculation shows that the heat from the combustion of 120 pounds of carbon is required to drive out the CO_2 from every 1,000 pounds of lime, and we know further that the oxygen of the air in chemical union with the carbon forms an equal volume of CO_2. The atmospheric air contains 21 per cent of oxygen, hence we obtain, during the combustion, 21 cubic feet of CO_2 from every 100 cubic feet of air chemically consumed. One pound of carbon requires about 150 cubic feet of air (15.33 pounds) during combustion, consequently 120 pounds would require 120x150, or 18,000 cubic feet, 21 per cent of which, or 3,780, would equal the number of cubic feet of CO_2. We will assume that the CO_2 has a temperature of 300° F. when drawn off, and at that temperature ten cubic feet of CO_2 will weigh just about one pound, hence we obtain 378 pounds of CO_2 gas from 120 pounds of carbon. If we apply the example to coke, which has an average of 90 per cent of carbon, the amount of CO_2 will be 334 pounds instead of 378 pounds; 440 pounds from the limestone, plus 343 pounds from the coal consumed, makes a total of 783 pounds of CO_2 for every 1,000 pounds of lime burned.

After the fire has been started it is necessary in this case, as in all others, to watch the process. The temperature must not go too high so as to fuse or "dead burn" the lime. The air supply must be regulated and if the charge tends to clog it must be broken down. Sometimes it is necessary to allow a part of the limestone to go unburned in order not to "dead burn" the rest.

THE GENERATOR GAS KILN.

During the last few years many of the lime-kilns have been arranged with generator gas fire, as shown in Fig. 11, and the air required during the combustion is led through air spaces in the kiln brickwork, where it reduces the heat in the brickwork and becomes "foreheated" before entering the zone of combustion. This construction saves considerable fuel, practical tests having shown a reduction of about twenty pounds of fuel for every 1,000 pounds of limestone.

Another advantage of the generator gas kiln is the fact that any kind of fuel may be used without impairing the purity of the CO_2 to any extent. Ill-smelling gases, such as sulphur and sulphuretted hydrogen, will be almost entirely consumed, and the products of combustion consist only of CO_2, nitrogen, the unconsumed oxygen of the air, slight traces of sulphuric acid and hydrogen.

THE LATEST IMPROVED KILN.

A kiln construction, which has recently been patented and which produces a more uniform heat throughout the kiln, prevents "dead burning" of the lime and is economical in the use of fuel as well, is shown in Fig. 13. It consists of an apparatus wherein, instead of the ordinary pure-air draft which it is customary to supply to a fire, the combustion of the fuel is conducted by means of an artificially-accelerated draft composed of air and a neutral gaseous diluent, Thus the liberation of the heat units of the fuel is greatly retarded and a long flame of large volume is produced.

The usual method of burning lime under the continuous process with external fires is by the use of wood as fuel. Wood has a comparatively low calorific power, yielding sufficient heat to effect the calcination of the lime-rock without overburning the lime; but its cost as a fuel is high in most localities as compared with that of coal or coke, and the available supply is constantly diminishing. The employment of coke in place of wood as fuel with ordinary methods of conducting combustion results in overburning of the lime. The calorific power of coke being much higher than that of wood, the intense heat developed by its combustion results in the formation of a slag by the melting of fusible impurities in the lime-rock, and there is obtained a product which will not slake thoroughly, or only after a long period, often slaking to some extent after it has been made up into plaster or mortar and applied to buildings or elsewhere, producing the very undesirable effect known as "pitting." The combustion of an ordinary coke fire in a kiln takes place mainly within the fire-box and is expended upon the fire-box walls rather than upon the lime-rock, causing rapid deterioration of linings and producing a short flame of small volume, which is incapable of properly filling the cross-section of the kiln-body, and burning the mass of rock uniformly throughout. Instead it climbs the walls of the kilns where the draft is strongest, and burns the lime at the sides more rapidly than at the center. Any artificial acceleration of a pure-air draft through a coal fire merely tends to intensify the combustion and increase the rapidity with which the heat units are evolved.

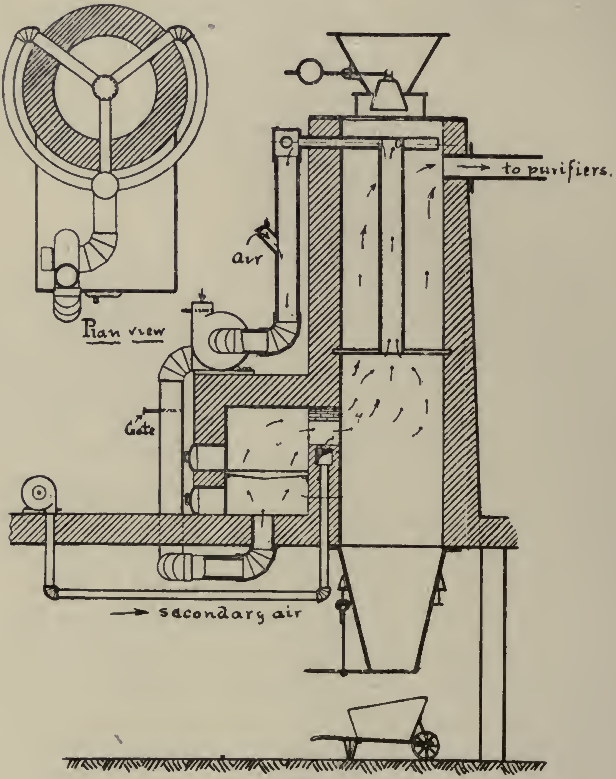

FIG. 13.—AN IMPROVED KILN CONSTRUCTION.

This invention makes possible the use of coke without overburning the lime and obtains practically perfect combustion. In the fire-box carbon monoxide mainly is produced, which is burned in the shaft proper by the introduction of additional air into the kiln, thereby producing a uniform heat throughout the kiln area without "dead burning" or fusing. The CO_2 is drawn off at the top of the kiln.

THE COKE PROCESS.

A number of the largest plants for the production of CO_2 for commercial purposes use the coke process in such a way as to utilize the heat of combustion to raise steam for power purposes. Fig. 14 shows an ordinary horizontal tubular boiler adapted for this purpose. It has been emphasized in a former paragraph that it is necessary to regulate the air supply very accurately, especially when burning coke under an ordinary boiler. The influx of large quantities of air when opening the fire doors is detrimental; the air which can not be used, but increases the percentage of oxygen in the CO_2 and robs the fire of much heat. In order to overcome the necessity of opening the

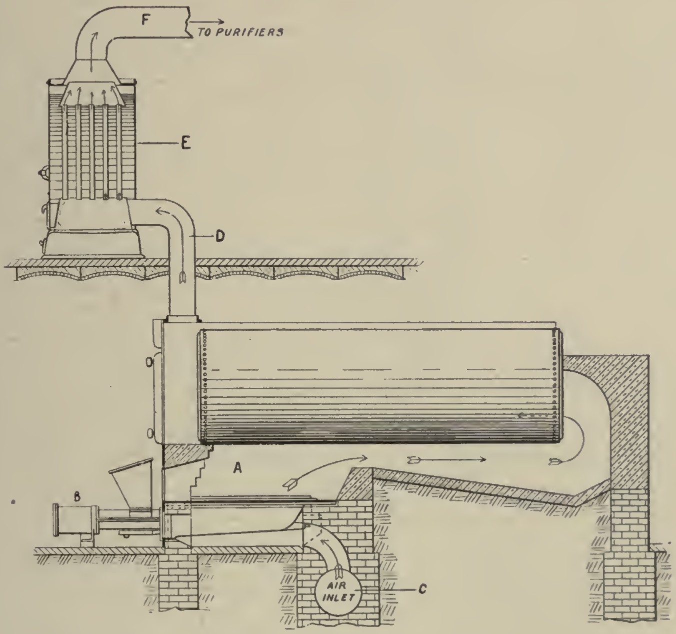

FIG. 14.—CONNECTION OF BOILER TO ECONOMIZER MAKING STEAM AND CO_2 FROM ONE FIRE.

fire doors the Jones underfeed stoker, *B*, has been attached to an ordinary horizontal tubular boiler. The stoker operates in such a way that the fuel is introduced into the furnace beneath the fire line without opening the fire doors. This method, in connection with a forced draft equipment, admits of an absolute control of the volume as well as of the purity of the air supply.

The coke, previous to being introduced into the furnace, is contained in the hopper and is forced into and along the retort by means of a ram plunger operated by steam. The ram, at each fresh charge, carries forward ten to fifteen pounds of coke; the plunger, or auxiliary ram, moving in connection, insures an equal distribution within the retort. The effect of this operation is to give the entire bed of fuel an upward and backward movement, thereby forcing the clinker and non-combustible material to the dead plates on either side of the retort. The refuse is removed every six or eight hours through the fire doors. The air is forced into the air chamber below the grate at *C*, by means of a volume blower, which may be operated by an independent engine, electric motor, or by connection to a line shaft. Entrance to the air chamber in brick-set boilers may be

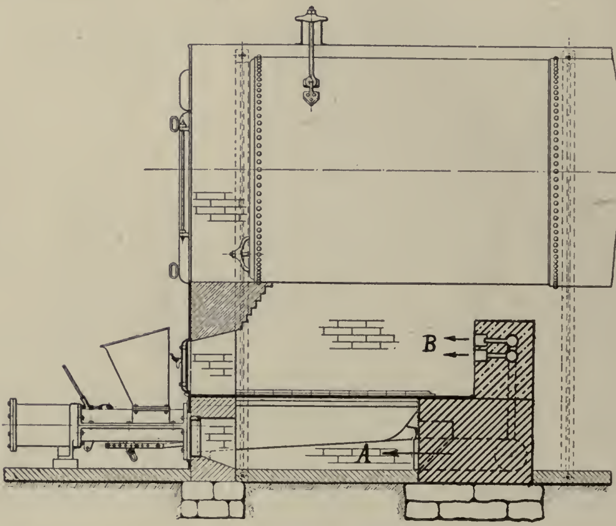

FIG. 15.—JONES STOKER EQUIPMENT, SHOWING PRIMARY AIR ADMISSION, *A*, BELOW RETORT, AND SECONDARY AIR ADMISSION, *B*, AT BRIDGE WALL.

made at any convenient place, and the air can be so conducted as to raise its temperature by means of waste heat from the boiler before entering the combustion chamber. Another obvious advantage of this method lies in the fact that the air used can be taken from the purest available air supply, which increases the possibility of obtaining the purest CO_2. The volume of air to be used, being under positive control, enables the operator to produce a CO_2 nearly free of unconsumed oxygen. The gases of combustion leave the boiler through the smoke connection, *D,* and are admitted into the shell of a vertical economizer, *E.* The latter contains a charge of potash lye, the temperature of which must be heated to about 216° F., for purposes to be explained in a later paragraph. The gaseous products of combustion have a temperature of about 550° F. at point *D;* this heat must be reduced to as low a temperature as possible before the gases reach the purifying apparatus, and as heat is required to raise the temperature of the lye in *E,* the latter is interposed to absorb as much heat from the gases as they may contain. The additional heat required to raise the temperature of the lye to the point at which the CO_2 gas is liberated, is supplied in a special lye boiler by means of exhaust or live steam.

In order to avoid the presence of carbon monoxide in the flue-gases, secondary air is admitted through the bridge wall under the boiler, as shown in Fig. 15, where it is distributed by means of a pipe header and distributing nipples. Any monoxide passing over the bridge wall will be consumed to carbon dioxide, which will be plainly visible if the brick wall of the boiler is provided with an observation window.

PROPERTIES OF COKE.

Coke is the combustible residue left when the volatile constituents of bituminous coal are expelled by heat. Much of the sulphur of the coal is expelled with the volatile hydrocarbons, so that the coke usually contains considerably less sulphur than the coal from which it is made, and this is one of the principal reasons why coke is preferred in the manufacture of CO_2. It burns more readily than coal and usually contains from 85 per cent to 97½ per cent carbon, from ¾ per cent to 2 per cent sulphur and from 1½ per cent to 14½ per cent ash. It weighs about thirty pounds per cubic foot when broken, and the volume of one ton heaped is from seventy to eighty cubic feet. Coke is capable of absorbing from 15 to 20 per cent of moisture. It requires 142 cubic feet of air during combustion, which would be equivalent to about 2.5 pounds of CO_2 as the product of combustion; it is stated, however, that in the practical run one pound of CO_2 is obtained from every pound of coke consumed.

There are three grades of coke, which are eligible for use in the manufacture of CO_2, that is, ordinary gas-house coke, 48-hours and 72-hours foundry coke.

The last named grade is considered the best, as it is nearly entirely free from sulphur and bituminous matter. The West Virginia 72-hours foundry coke is especially favored by the operators of coke carbonic acid gas factories.

THE CONTROL OF COMBUSTION.

The perfect and economic combustion of the coke depends upon three essential points, which are:

1. A sufficiency of air, but not an excess.
2. A sufficiently high temperature in the combustion chamber.
3. A perfect mixture of the air with the carbon of the coke.

The first and second of these conditions are not always fulfilled in ordinary practice and the third condition is seldom recognized as essential by the ordinary fireman.

The supply of air to the boiler furnace is controlled by the fireman, and the tendency is to work boiler fires with a large excess. But excess of air means waste of heat and a diminished percentage of carbon dioxide in the flue gases. With the exit gases at a temperature of 600° F. the losses due to excess air may vary from 13 to 68 per cent of the fuel burned.

When the conditions for a complete combustion, *i. e.,* grate surface and draft, are supplied, it depends upon the fireman to obtain the best results, which means the highest percentage of CO_2 in the flue gases, as well as the highest production of heat for the evaporation of the water within the boiler.

In order to produce combustion, carbon, the vital element in the coal, must unite with oxygen, which it does in certain unvarying proportions. In the first stage of combustion, one part of carbon unites with one part of oxygen, forming a combustible gas, known as carbon monoxide, and in this process about one-fourth of the heat is liberated. In the second stage, the carbon monoxide absorbs another part of oxygen, forming carbon dioxide, and in this process the large balance of the heat is liberated.

The oxygen absorbed by the carbon during combustion is obtained from the atmospheric air, and as the latter contains 21 per cent by volume of oxygen, which is available for combustion, it will be seen that all of it must change to carbon dioxide when united with all of the carbon in the fuel.

From this it will be evident that for each pound of coal, containing a fixed percentage of carbon, a corresponding volume of air is necessary for combustion. Each pound of coal of average composition requires 10.7 pounds, or 140 cubic feet of air, of which the 21 per cent of oxygen or 29.4 cubic feet will be chemically consumed, resulting in the liberating of 14,700 heat units.

This is the ideal condition, but in practice it is impossible to unite every part of oxygen passing through the fire bed with every part of carbon, therefore the amount of air which is allowed to pass through the fire is considerably more than 140 cubic feet per pound of coal.

If too small an amount of air is admitted, combustion becomes imperfect, because the carbon monoxide developed during the first stage of combustion can not find the necessary oxygen to be consumed to carbon dioxide, and this is the most wasteful condition of firing, for the largest part of the heat is given up during the second stage of combustion, which can not be reached because of a lack of oxygen.

This case is seldom met with in practice. As a rule, the average fireman allows too much draft, or permits too much air to pass through the fire bed, which is detrimental to the combustion, because there is a large amount of air of which the oxygen can not be consumed. This surplus air is heated to the temperature of the escaping gaseous products of combustion, thereby unnecessarily robbing the fire of much of its heat.

Aside from excessive or defective draft, loss of fuel may result from faulty grates or wrong proportions of grate surface, and there may be defects in the boiler setting or in the fire and ash pit doors. All these defects are shown by an analysis of the flue gases, and as carbon dioxide is the direct product of the combustion, its presence in per cent by weight or volume in the flue gases is a positive indication of the grade or degree of combustion.

The percentage of carbonic acid in the flue gases is easily ascertained by absorbing this gas from the balance of the products of combustion, using a caustic soda or potash lye as the absorbent.

TESTING OF THE FLUE-GASES.

The gas should be tested before it enters any purification apparatus, and a suitable connection should be made to main line, *F,* Fig. 14. In most cases it is sufficient to determine the percentage of CO_2 only; this can be accomplished by means of a simple testing apparatus, as follows:

A small rubber tube, *l,* Fig. 16, connects a three-way cock, *h,* of the apparatus with the main gas line. The apparatus proper consists of a burette, *b,* which has a scale of 100 equal points. On the top of this burette, above the three-way cock, is mounted a funnel containing a quantity of caustic potash lye, the lower end of the same being immersed in a glass of water to form a proper seal. The height of the water in glass, *g,* is to be so adjusted that it corresponds exactly with the zero point of the scale. The three-way cock, *h,* provides connection with gas tube, *l,* and allows communication between funnel, *k,* and burette, *b,* at will.

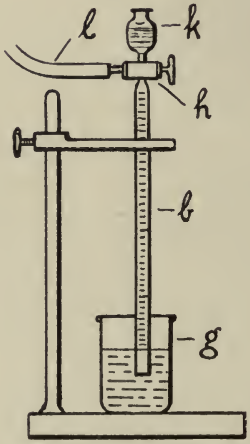

FIG. 16.—FLUE-GAS TESTING APPARATUS.

The first manipulation is to place cock, *h,* in such a position as to permit the gas to enter burette, *b;* this connection remains open a short while, until all atmospheric air is expelled. After this it is necessary to re-establish the height of the water in the burette with the level of the water in the glass by removing rubber tube, *l,* from the nipple of the three-way cock and allowing a part of the gas to escape until the water levels are fixed in line with the zero point of the burette.

The next move is to establish communication between funnel *k,* and burette, *b;* turn the cock slowly and allow the lye to drop into the glass tube; it will absorb the CO_2 contained in the gas immediately, the volume of gas will be reduced and the lye will gradually fill the tube until all CO_2 is absorbed. Close the cock as soon as this condition is reached and note the height of the lye in the tube on the scale of the latter. If the height of the lye shows 18 points out of the 100 on the scale, it is evident that the products of combustion contain 18 per cent of CO_2, and the combustion of the coke, admixture of air, etc., may be pronounced good.

The result obtained by this means is not entirely exact, as the weight of the water column increases the volume of the inclosed gas slightly; therefore this result is a trifle short. In an exact test the weight of the water column should be eliminated, which is accomplished by means of a so-called Winkler gas burette. This latter test requires a little more skill on the part of the manipulator and is for laboratory use only; a so-called work test must be made from time to time by the operating engineer or fireman in order to ascertain the condition of his fire, and for such practical purposes the above test is entirely satisfactory.

If the fire bed does not contain the required thickness, carbon monoxide may be produced in considerable quantities, or large volumes of unconsumed oxygen may be present on account of too much draft. The presence of either one is detrimental, and their quantities must be determined and the corresponding changes in the regulation of the combustion made. Carbon monoxide as well as oxygen may be detected and the respective quantities determined by means of a "Bunte" instrument, as shown in Fig. 17.

It consists of a glass tube, *e,* having a little over 100 cubic centimeter capacity, which is closed at each end by tightly fitting stop cocks *g* and *f.* The stop cock *g* is of the ordinary two-way style, while *f* is of the three-way construction, so that the tube can be placed in connection with the source of the gas through the end of the cock and the rubber tube, *m*, or it can be connected with the cup-shaped receptacle *l*, which is made above *f*. The tube *e* is graduated in one-tenth cubic centimeters for 100 cubic centimeters down from *f*. Frequently the burette is surrounded by a water-jacket to prevent variations of temperature. This is, however, an unnecessary accessory and seriously interferes with the manipulation of the instrument.

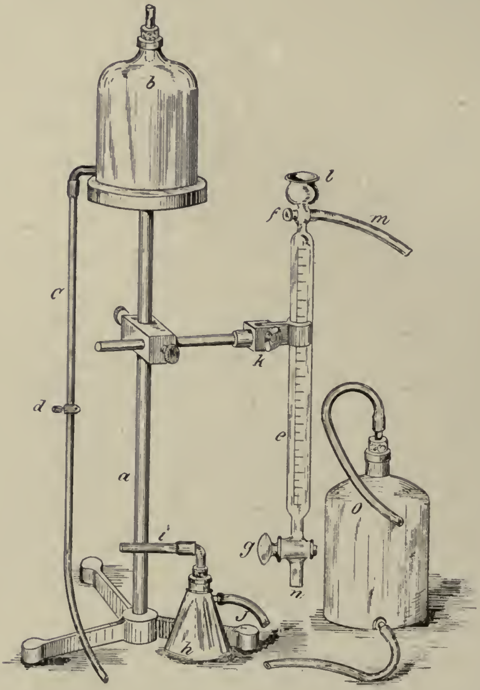

FIG. 17.—BUNTE TESTING INSTRUMENT.

When gas is abundant and under a slight pressure, as is the case in carbonic acid factories, the tube *m* is attached to the main flue-gas line, *f* and *g* are opened, and 2 or 3 liters of gas allowed to pass through the burette, thus sweeping out the air and leaving a good sample of gas. By closing *f* and *g* the gas is enclosed. Having the burette filled with it, the cup *l* is filled with water to a mark that is 1 centimeter above the stop cock *f*; *c* is then attached to *u*, and *d* and *g* opened. Water thus flows into the burette and compresses the gas. When the water reaches the 100 cubic centimeter mark, *g* is closed and *f* is turned to connect the burette with *l*. Gas will escape until that in the burette is under the atmospheric pressure, plus the pressure of 1 centimeter of water; *f* is then closed and the volume of gas read (it should be exactly 100 cubic centimeters). The rubber tube *i* of the suction flask *h* is then attached at *n*, *g* is opened, and, by sucking on *j*, the water is almost completely removed from the burette, leaving a partial vacuum; *g* is then closed and *i* removed from *n*.

For the determination of the volume percentage of carbon dioxide a small beaker containing a suitable solution of caustic potash is brought under *n*, and *g* is turned so that the alkali solution rises in the burette; *g* is then closed. The burette is then grasped at *l*, loosened from the clamp *k*, and after the water is emptied from *l* the burette is thoroughly shaken, so that the gas is well mixed with the caustic potash. The burette is then replaced in clamp *k*, *n* is brought under caustic potash solution, and *g* is again opened. The alkali will rise in the tube and when it has filled as much as it will, *g* is once more closed and the burette shaken as before. This is repeated as long as the alkali solution continues to rise in the burette. Water is then filled to the 1 centimeter mark in *l*, *f* is opened to insure equal pressure, then closed, and the volume of gas read. The difference between this reading and 100 gives the volume percentage of the carbon dioxide in the gas mixture.

For the determination of the volume percentage of oxygen, the caustic potash is removed as far as possible by means of the suction flask *h*, and alkaline pyrogallol allowed to rise in the burette in its place. The same operations as for carbon dioxide are performed until all the oxygen is absorbed. The volume of gas is then read. The difference between this volume and 100 gives the volume percentage of carbon dioxide and oxygen, and deducting the volume percentage of carbon dioxide leaves the volume percentage of oxygen in the gas.

The volume percentage of carbon monoxide is determined by sucking out the alkaline pyrogallol after measuring the oxygen, replacing it with a hydrochloric acid solution of cuprous chloride, and proceeding as in the preceding cases. After the carbon monoxide has been completely absorbed, as shown by the absorbing liquid no longer rising in the burette, the absorbing liquid is sucked out as completely as possible and the gas washed two or three times with water to completely remove the hydrochloric acid. This diminution in volume of the gas gives the volume percentage of carbon monoxide it contains; the remainder of the gas is the volume percentage of nitrogen in the gas.

The re-agents for the Bunte burette are made in the following way: Dissolve 100 grams of solid potassium hydrate in 200 cubic centimeters of water.

The alkaline pyrogallol is made by dissolving 32 grams of potassium hydrate in 200 cubic centimeters of water and 40 grams of pyrogallic acid in 200 cubic centimeters of water. The two solutions are thoroughly mixed and kept carefully guarded from the air in a rubber stoppered bottle. It is even better to keep the two solutions separate and only mix them when needed for use.

The cuprous-chloride solution is made by dissolving 200 grams of cupric chloride in 500 cubic centimeters of water and 500 cubic centimeters of concentrated hydrochloric acid and allowing the solution to stand tightly stoppered in a bottle containing copper turnings or strips of sheet copper until it becomes clear and colorless.

In a carbonic acid gas factory, which obtains its product from the combustion of coke, frequent tests of the flue gases are indispensible, as perfect or faulty combustion can not be recognized in any other way. The foregoing tests require considerable skill in their manipulation and as it is a question of the utmost importance that tests, especially those showing the percentage of CO_2 in the flue gases, be made frequently, stationary instruments have been designed which automatically register the percentage of CO_2 in the flue gases.

VARIOUS TESTING INSTRUMENTS.

Several very ingenious instruments designed for this purpose have recently been placed on the market.

In Fig. 18 is shown an apparatus which consists of a gas pump *A*, receptable *B*, test tube *C* within *B*, absorption vessel *D* and glass cylinder *E*. These five principal parts are connected as shown. The outlets of *B*, *C* and *D* are controlled by hydraulic valves 1, 2, 3 and 4. *C* is graduated into 100 equal parts, preferably cubic centimeters.

Gas pump *A* is provided with a swimmer *S*, which latter is slipped on to rod *T*, and its movements are controlled by lower set screw *p*, and upper set screw p^1. The cylinder is closed air-tight and the cover carries valve *v*, which is controlled by the movement of rod *T* as shown. Counter weight *G* is for the purpose of controlling the weight of valve *v*, and set screw *St* is used to adjust the height of the liquid in line with the highest degree mark in *C*.

Pipe connection *K* is provided with a valve; it connects the apparatus to the smoke-stack or to the flue-gas line.

Cylinder *E* is also provided with a swimmer S^1; the latter is movable on rod *F*, which carries the recording pen.

To prepare the apparatus for use fill glycerine into *A* until *C* is filled to its highest degree mark (100 cubic centimeters), then adjust swimmer *S* in *B*, so that it floats on top of the glycerine without raising the fluid in *C*. Swimmer *S* is now at its lowest point and when in this position valve *v* must be closed. Parts *D* and *E* are disconnected at 1 and 2, valve *v* being closed. The apparatus is then subjected to the chimney draft by opening the valve in pipe connection *K*. The result is that the glycerine in *A* rises, while in *B* and *C* it recedes correspondingly.

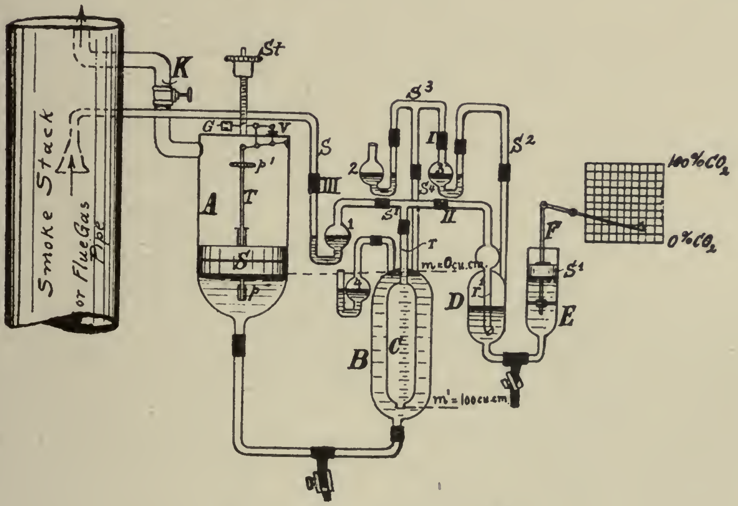

FIG. 18.—FLUE-GAS TESTING INSTRUMENT.

As soon as point m^1 in *C* is reached the chimney valve is closed. *D* and *E* are then connected at 1 and 2. *D* contains a solution of caustic potash and swimmer S^1 in *E* must be so adjusted that the recording pen is in the 100 per cent CO_2 position. As soon as the chimney valve is again opened, swimmer *S* releases valve *v*, atmospheric air enters *A* and the glycerine flows back into *B* and *C*, forcing the air contained in *B* through connection s^4, s^3 and out through hydraulic valve 2. The air in *C* escapes through *r* and s^1 into *D*, passes through the lye, fills the upper part of *D* and forces a corresponding part of lye into *E*. This raises swimmer S^1 and pen *F* records a vertical line up to 0 per cent, if set right.

The glycerine in *C* has reached point m^1 at the same time. If correct, establish connection between *s* and the smoke-stack at 3. Swimmer *S* in *A* will then again rise, the glycerine leaves *C* and *B*, and *C* will be filled with flue gas. When the glycerine leaves *E* it relieves the pressure of air enclosed in the upper part of *D*, and this volume of air passes through s^2, 3 and s^4 into *B*. Should the volume of air contained in *D* be insufficient to fill the space in *B* vacated by the receding glycerine, additional air enters through 4. As soon as point m^1 is reached, *C* is completely filled with flue gas and pen *F* must then be at its lowest point. By this time swimmer *S* will release valve *v*, and the incoming atmospheric air forces the glycerine from *A* into *B* and *C*. The air contained in *B* escapes through valve 2, while the flue gases enclosed in *C* will be forced through *r* and r^1 into *D*. The caustic lye absorbs the CO_2, and the nitrogen as well as the unused air passes into the upper part of *D*, forces a corresponding part of lye into *E* and pen *F* rises until point *m* in *C* is again reached. The highest point obtained by pen *F* records the percentage of CO_2 contained in 100 cubic centimeters of flue gas.

The apparatus makes the successive determinations rapidly. It is very handy, easily manipulated, and is reliable in its record of a satisfactory or unsatisfactory combustion.

The instruments shown in Figs. 19 and 20 are known by the name "Econometer"; they are designed in two styles, one for determining the percentage of carbonic acid by volume, the other by weight. In the apparatus, Fig. 19, the volume per cent of carbonic acid gas is ascertained by first absorbing the gas in a caustic solution and then measuring the amount absorbed by the pressure of the atmosphere, which forces the fluid in the indicator tube to a height corresponding to the volume per cent of CO_2 absorbed.

To make an analysis of the gases with this instrument, a ⅜-inch gas pipe is inserted into the boiler flue and a ¼-inch or ⅛-inch gas pipe run from there to a point conveniently situated for operating the instrument, which can be hung on the wall by means of the hangers. Connection is then made with this pipe by means of rubber tube 1.

The lever 2 is now raised to a vertical position; the absorbing body 3 is slightly raised, and then the chamber 4 is filled to within ¼-inch of separator 5 with caustic solution of a specific gravity of 1.26 to 1.28. Pour solution slowly through filling-tube 9. The stopper 8 is then pressed tightly into tube 9, and the separator 5 is also pressed firmly into its resting place in chamber 4.

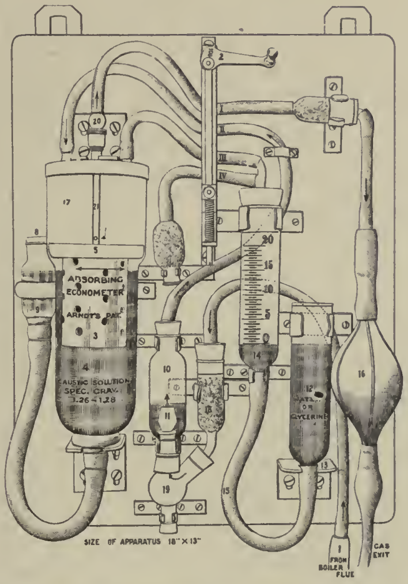

FIG 19.—"ECONOMETER" FOR DETERMINING PERCENTAGE OF CO_2 BY VOLUME.

Bulb 10 is now filled with water to a point slightly above the vent 11, and the tube 12 being placed on rest 13 is filled with water until the level is on the zero line in tube 14, to which the water flows by means of tube 15.

The pump 16 is now pressed about fifteen times and the gas is drawn into chamber 17. In its passage thereto the soot and dust are removed by means of cotton filter 18, passing through bulb 19, which is sealed with water at the vent 11.

When the chamber 17 is filled with gas, the lever 2 is lowered to an angle of ninety degrees, closing tubes I, II and IV, and opening tube III. The separator 5 is now raised by means of button 20, which carries connecting spindle 21, and the carbonic acid is brought into contact with the caustic solution. Absorption begins immediately, and as the CO_2 is taken up in the caustic solution, a rarification occurs in the chambers 17 and 4. These chambers are connected with glass 14 by means of tube III, and the pressure of the atmosphere forces the water in this tube 14 high enough to offset the rarification in the chambers 17 and 4. To facilitate absorption, separator 5 should be raised and lowered two or three times, and if the water then ceases rising in tube 14 the tube 12 should be raised until its water line corresponds to that in tube 14, and the volume per cent of CO_2 can be read on the scale.

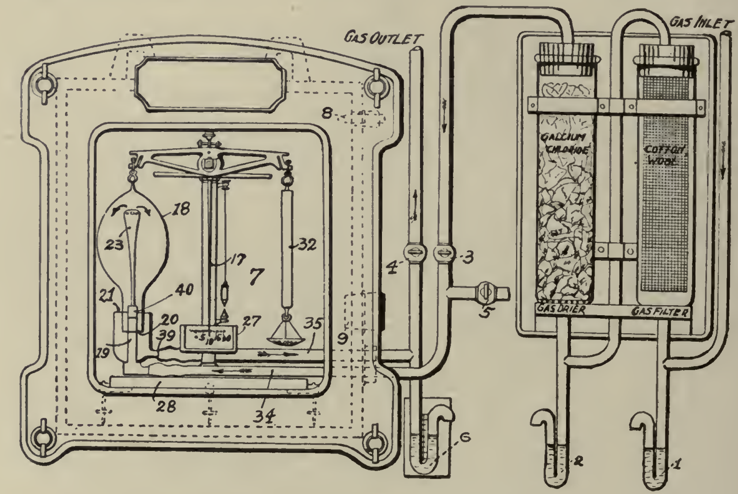

FIG. 20.—"ECONOMETER" FOR DETERMINING PERCENTAGE CO_2 BY WEIGHT.

When lever 2 is raised again to a vertical position the remaining gases in chamber 17 are drawn out by the action of the pump through the little hole in the lower part of the hollow spindle 21. New gases enter immediately and another analysis can be made.

To have all the joints perfectly air-tight all rubber stoppers must be well pressed home. The cotton wool should be renewed from time to time. The caustic solution is good for about 300 analyses. If the apparatus begins to work slowly, the caustic solution should be renewed. To have spindle 21 work freely, it must be greased regularly with vaseline, not with oil.

The second instrument, Fig. 20, is a gas weighing machine on an entirely new principle, fixed in an air-tight case 7 with a plate of glass in front. In the case 7 there are two connecting joints, 39 and 40; 40 is connected by a pipe of about ¼-inch bore to the flue of the boiler between the latter and the damper, and 39 is connected by a similar pipe to a small aspirator in the flue between the damper and the chimney, or the chimney itself, and which is worked by the draught of the chimney. In the interior of the Econometer case 7, the joint 40 is connected with the ascending pipe 23, and the joint 39 with the descending pipe 22 by India rubber tubes 34 and 35.

The gas weighing machine itself consists of a very finely adjusted, highly sensitive balance, to which is fixed the pointer or index 17. On one end of the balance is suspended an open gas reservoir 18, with a capacity of about a pint, and in the opposite end a compensating rod 32, to which is affixed a scale with a number of glass beads, by which the gas holder can be balanced. The knife edges of the balance are steel gilded, and the caps are agate. The whole balance works on a pillar screwed on a cast plate 28. The latter has adjusting screws by which the balance is finely adjusted, both horizontally and vertically. For this purpose a small pendulum is attached to the supporting pillar. Further, a frame 27 is fixed on the pillar in which is inserted the scale.

The gas-ascending pipe 23 reaches into the gas holder or reservoir 18, which has a neck 20 open below and surrounded by the outgoing connecting joint 21, open above. The neck 20 has free play round the pipe 19, as well as around the connection 21, so that the gas balance can swing free from resistance and therefore works with extraordinary exactness.

The combustion gases having to pass through filters and drying chambers enter the weighing globe thoroughly cleaned and dried.

As carbonic acid is about 50 per cent heavier than atmospheric air and the other gases contained in the gaseous smoke, so the gaseous smoke which continually fills the reservoir must be heavier in proportion to the amount of carbonic acid contained therein. The scale 27 is so divided that the movement of the pointer 17 of the gas-balance from one dividing line to another corresponds with the volume per cent of CO_2 in the fuel gases to be weighed. The amount of carbonic acid in the products of combustion can therefore be read off at all times. See the following table:

TABLE SHOWING LOSS OF FUEL WITH FROM 2 TO 15 PER CENT CO_2 IN THE COMBUSTION GASES.

If the "Econometer" shows......	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Per cent carbonic acid.
Then the quantity of air passing through the flues is....	9.5	6.3	4.7	3.8	3.2	2.7	2.4	2.1	1.9	1.7	1.6	1.5	1.4	1.3	Times the theoretical requirements.
With a surplus supply of air of 30% or about 166 cubic feet of necessary air per pound of fuel, there will still be a further excess of about......	1977.6	1212.5	960.5	606.3	536.8	395.5	310 8	197.8	169.5	113	84.8	56.5	28.3	0.0	Cubic feet of superfluous air heated to a temperature of usually 518° F.
And the loss of fuel at 518° F. amounts to	90	60	45	36	30	26	23	20	18	16	15	14	13	12	Per cent.

The proportion of air actually used to the amount required is, in the case of coal combustion (according to Bunte) "18.9 divided by "K," the latter symbol representing the amount per cent of carbonic acid in the gases.

The loss of heat, as calculated in the foregoing table and proved by ascertaining the amount of carbonic acid, can be caused in various ways. In most cases the grate is not the right size for perfect combustion; it is generally too large. This can be determined by the aid of the Econometer. If by properly manipulating the draft, thickness of fire, etc., until the Econometer shows the desired percentage of CO_2, an excessive amount of steam is produced, it may then be taken for granted that the grate is too large and should be shortened.

A common source of loss of energy in the combustion of fuel is to be found in allowing the fire to burn in holes, so permitting the air to pass through without combustion; this will at once be shown by the Econometer, and enables the stoker to recognize the faults and remedy them at once.

By comparing the amount of carbonic acid at the entrance and exit of the boiler flues, which can easily be done by fixing the apparatus to the corresponding places, one may discover any defects in the brickwork admitting air and causing loss of heat and fuel, often of considerable amount.

The instrument can be obtained at a slight cost. By using it properly and making the required corrections until the best possible combustion (showing not less than 18 per cent in the coke carbonic acid gas process) is obtained, it will be worth its weight in gold.

The foregoing test of the flue gases is of as great importance as the use of an indicator card in determining the efficiency of an engine. The former is just as necessary, because it offers the only means to regulate the process of combustion in such a way as to obtain the best efficiency, *i. e.,* to produce the largest quantity of CO_2 and to avoid the presence of oxygen as well as carbonic oxide in the products of combustion; the test of the gas shows the quality of the same; it indicates irregularities and points out the proper way to avoid them.

REMOVAL OF IMPURITIES FROM THE FLUE GASES.

The composition of the gas as to its relative percentage of CO_2, CO, O and N having been established, CO and O must be avoided by means of a better combustion. N is easily expelled in the purifying apparatus, but there are still other impurities mixed with the gas which are especially undesirable, namely, sulphur dioxide from the sulphur in the coke and considerable dust. These impurities must be removed by thoroughly washing and scrubbing the gas before sending it to the absorption tower. A suitable scrubber for washing and cooling is shown in Fig. 21. The gas enters the scrubber through pipe connection, *a,* which, inside of the apparatus, is perforated its entire length so that the gas will be uniformly distributed. The gas rises through the spray of falling water to the first plate, *c,* where it must bubble through a solid sheet of water, then again through the

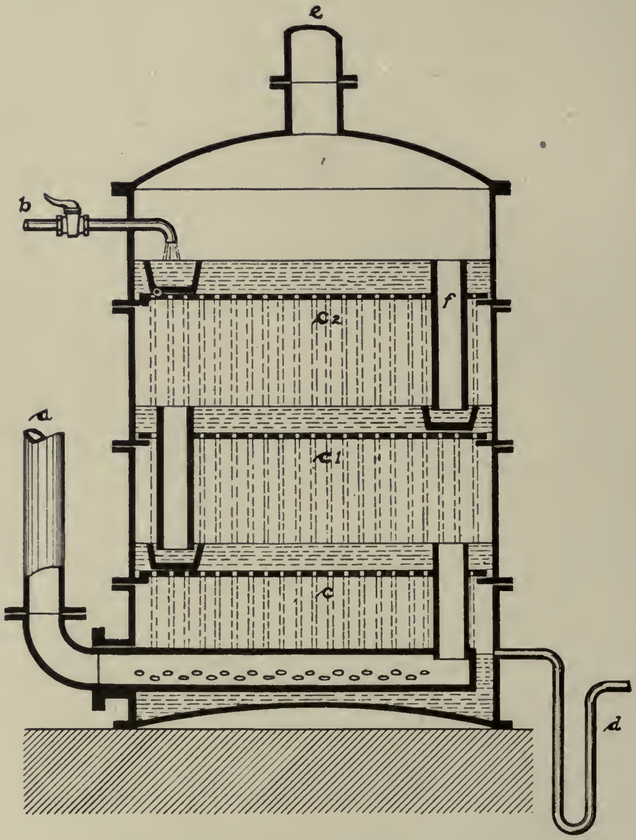

FIG. 21.—SCRUBBER FOR WASHING AND COOLING.

spray to the second plate, c_1, and so on until it passes out through *e*, to a second scrubber. Meanwhile water is admitted through *b* in such quantities that it stands at a suitable height on each plate. Each plate has a tube, *f*, leading to the next lower one, so that if the water enters too fast, or the holes in *c* become clogged, the water can overflow through this pipe. The water collects in the bottom of the washer and siphons off through *d*. The temperature of the "off" water must be maintained at or near 104° F. At this temperature the water absorbs very little CO_2, but removes all the dust and binds most of the sulphur dioxide. The thorough removal of the latter gas is very essential; if this is not done in the scrubber it will be carried into the absorption tower and will deteriorate the lye used for absorbing the CO_2 by forming potassium sulphate. Limestone neutralizes the SO_2 very effectively and it is therefore advisable to fill the lower compartment of the washer with broken limestone; the gas will then be absorbed by the carbonate of lime and in connection with the so-formed calcium it will be dissolved by the water and carried off.

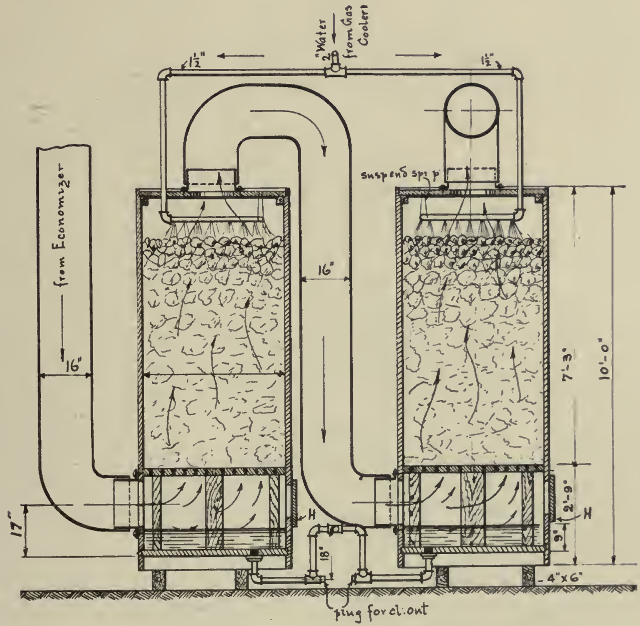

FIG. 22.—SCRUBBER CONSISTING OF WOODEN TANKS.

A simple scrubber consisting of wooden tanks connected in series has been found very practical and durable and is illustrated by Fig. 22.

Should it appear desirable to remove the very last traces of the sulphuric acid, a small scrubber may be used through which soda-lye, as the purifying medium, is made to circulate continuously. Fig. 23 represents a scrubber which may be used for that purpose to good advantage. In this apparatus the lye enters at *c* and slowly overflows through corresponding pipes until it finally runs out at the bottom, to be forced back into the scrubber at *c* by means of a small circulating pump. The gases enter at *a* under the cap, which causes the gas to spread out and pass through the lye before going to the next section. The gas finally passes out at *d*.

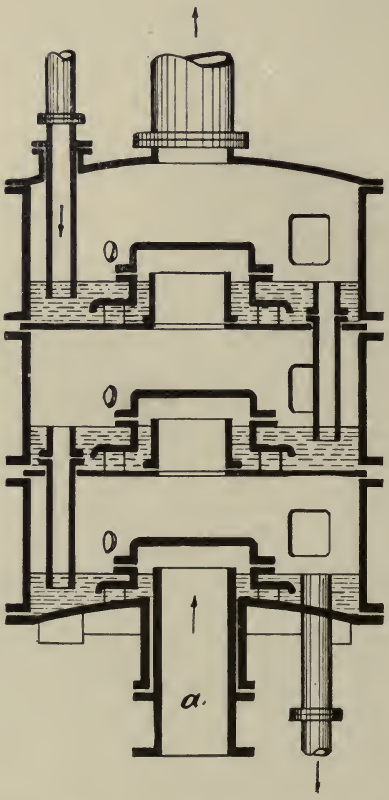

FIG. 23.—SCRUBBER WITH SODA LYE.

The gases of combustion are moved by a simple exhauster, which is interposed in the gas line after the excessive heat of same has been removed by the first scrubber. The exhauster can be used in all cases where the gas passes through the cooling, scrubbing and absorbing liquid without pressure; should it be necessary to force the gas through the liquid then a rotary blower, and at still higher pressure, a gas pump must take the place of the former.

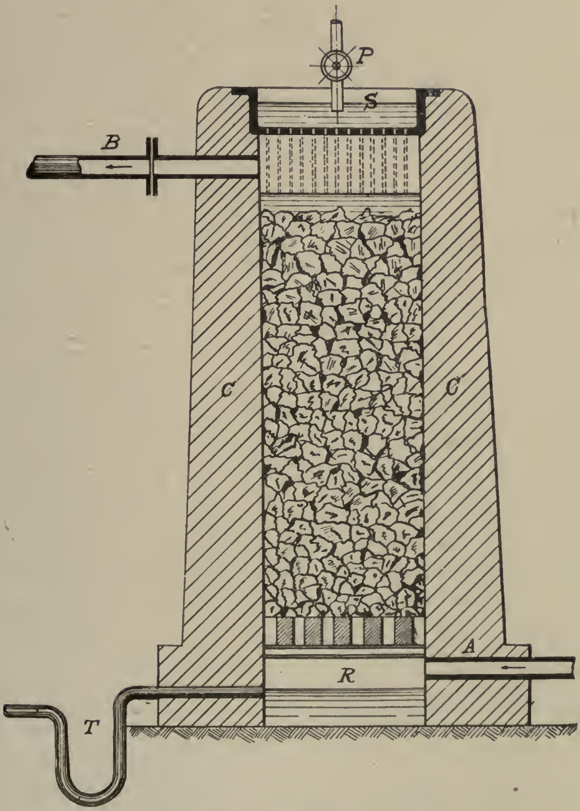

FIG. 24.—DR. LUHMANN'S SCRUBBER.

The scrubber used by Dr. E. Luhmann, who is the foremost German authority in all matters relating to the manufacture of CO_2, consists of a cylinder about fourteen feet high by four feet in diameter, built of concrete. Cylinder *C,* Fig. 24, has a grate, *R,* at the bottom, constructed of hard burned brick. A column of limestone, in lumps, rests upon the grate. The top of the cylinder is closed with a lead lined iron plate, *S*, which forms at the same time a water receptacle about 8 inches high. Numerous small holes in this cover allow the water to enter the scrubber and the water supply at *P* is so regulated that a height of about 5 inches of water is maintained, which forms the necessary seal against any escape of gas at the same time. The products of combustion enter the scrubber at *A* and on their upward course through the small spaces provided by the irregular form of the limestone, they are thoroughly cleansed by the spray of water and escape through pipe connection *B*. The water leaves the scrubber through goose-neck *T* at a temperature of above 100° F. Space *R* is accessible through a manhole through which the solid impurities, such as dust and ashes, are removed from time to time.

The gas is now thoroughly cleaned and cooled; during its passage through the scrubber it has taken up a small quantity of water which must be separated again from the gas by means of a simple mechanical separator.

ABSORPTION OF THE GAS.

It has been shown that the gas produced by a well-regulated combustion contains about 18 per cent of CO_2, the remaining 82 per cent constitutes impurities, principally nitrogen, and must be expelled. Water absorbs CO_2 to a limited extent, but its capacity for absorption may be increased by a reduction in the temperature and an increase of the pressure at which the gas enters the water. Salt water absorbs a greater quantity of CO_2 than sweet water, and a solution of such carbonates of the alkali earth as contain the gas has the greatest absorbing capacity.

Ozouf recommended the use of a solution of sodium carbonate in water (soda lye), but as the solubility of the soda in water does not exceed 10 per cent, it is not capable of absorbing as much CO_2 as a solution of potassium carbonate (potash lye), which forms a lye of a much higher concentration. During the absorption of the CO_2 by the lye, the latter is converted into a bicarbonate, but as the carbonic acid gas is only loosely bound it is easily expelled by means of heat.

A soda lye of a concentration higher than 10 per cent will precipitate the salt at increased temperatures and as in practice it is not possible to form a full bicarbonate, the volume of CO_2 absorbed does not exceed one pound for each cubic foot of lye of 8 per cent concentration, hence the amount of lye that must be handled to absorb a given volume of CO_2 and afterward heated to expel the same is large. It requires large pumps for handling and cuts considerably into the coal pile for the heating of the lye. One hundred parts of water at a temperature of 86° F. dissolve 30.58 parts of potassium carbonate; the latter is known by the chemical symbol K_2CO_3 and is commonly called potash. It does not readily precipitate even from a highly concentrated lye of, say, 30° Beaume.

The following table gives the specific weight and with the same the percentage of pure carbonate of potassium:

TABLE OF WEIGHTS AND PERCENTAGES OF K_2 CO_3

Spec. weight	Degrees Beaume	Percentage of K_2 CO_3	1 cu. ft. contains K_2 CO_3 in pounds	Spec. weight	Degrees Beaume	Percentage of K_2 CO_3	1 cb. ft. contains K_2 CO_3 in pounds
1,075	10	8.1	5.4	1,142	18	15.0	10.7
1,083	11	9.0	6.0	1,152	19	16.0	11.3
1,091	12	9.8	6.7	1,162	20	17.0	12.3
1,100	13	10.7	7.3	1,172	21	18.0	13.2
1,108	14	11.6	8.0	1,180	22	18.8	14.0
1,116	15	12.4	8.6	1,190	23	19.7	14.6
1,125	16	13.3	9.3	1,200	24	20.7	15.2
1,134	17	14.2	10.0	1,210	25	21.6	16.2

The above table represents the values used in practical work. However, there is no objection to a lye of a still higher concentration for the reason that during the absorption the lye is being converted only into a one and one-half carbonate, but not into a full bicarbonate, because the CO_2 is highly mixed with indifferent gases. A highly concentrated lye has the advantage of a greater absorbing capacity, and as that diminishes its quantity per pound of CO_2 it requires less coal for heating the same.

It has also been recommended to add about 8 per cent of soda to a potash lye that is already of a high concentration because of the faculty of a concentrated lye to absorb still another salt, but as the potash lye may be as highly concentrated as desirable it is unnecessary to use soda in addition. A good potassium carbonate should be from 95 to 98 per cent pure. The impurities consist of potassium chloride, potassium sulphate and sodium carbonate.

100 parts of water dissolve.......19.61 parts of K_2CO_3 at 32° F.
100 " " " " ....23.21 " " " " " 50° F.
100 " " " " ....26.91 " " " " " 68° F.
100 " " " " ....30.58 " " " " " 86° F.
100 " " " " ....34.15 " " " " " 104° F.
100 " " " " ....37.92 " " " " " 122° F.
100 " " " " ....41.35 " " " " " 140° F.
100 " " " " ....45.21 " " " " " 158° F.

A solution of 25 per cent is used ordinarily in practice.

After the lye has been used for a certain length of time it is necessary to regenerate same in order to expel any sulphate of potassium which may have been produced by traces of sulphur in the products of combustion. Potassium sulphate precipitates as soon as the lye reaches a high concentration produced by steaming, and these precipitations can then be collected and expelled.

In practice the temperature of the lye should be kept at about 100° to 105° F., because the absorption of CO_2 by the lye is a chemical process and as such has given the best result at above temperatures.

CHAPTER IV.

ABSORPTION AND LIBERATION OF CO_2.

ABSORBERS

The proper absorption of the CO_2 from the mixture of the purified gaseous products of combustion by the lye, is accomplished by means of suitable mechanical contrivances called absorbers, which are so constructed as to provide an intimate mixture of the gas with the lye. A fine layer of lye, spread over a large surface, affords the best opportunity for absorption, and numerous apparatuses have been invented to accomplish this operation, giving more or less satisfaction. Owing to the fact that the products of combustion from which the CO_2 is to be absorbed are mixed with large volumes of indifferent gases it is not possible to convert the potassium carbonate in the lye into a full bicarbonate. In most cases only the one and one-half stage of a carbonate is reached unless the gases are exceptionally rich in CO_2, as for instance in kiln gases. Nor is it possible to re-convert the one and one-half carbonate into a simple carbonate during the boiling process unless the solution is boiled a long time, which is not economical. It follows that the solution fluctuates as a 1.1 to a 1.5 of a carbonate between absorption and liberation of the gas.

It is not a simple carbonate when it enters the absorption tower and not a full bicarbonate when it leaves it, which explains the low efficiency of absorption.

In practice only the volume of CO_2 above 9 per cent in the combustion gases is absorbed unless machinery specially constructed for this purpose is used during the process of absorption, hence, a flue-gas containing 16 per cent of CO_2 will give up only 7 per cent to the lye, the balance escaping with the indifferent gases into the atmosphere. Among the apparatuses used for absorption purposes only those that have come into general use will be described here.

The simplest absorber is the co-called mixer, which is generally used in mineral water factories for carbonating purposes. It consists of a horizontal cylinder, with a shaft extending through same. Fastened to this shaft at right angles are a number of perforated paddle wheels. A simple stuffing box closes the cylinder at each end around the shaft, and a pulley provides belt connection to a line shaft. The lye, as well as the gas connection to the cylinder is made at opposite points, which forces the lye and gas to travel in opposite directions to their respective outlets. The paddle wheels take up very nearly the whole diameter of the cylinder, with only a small clearance at either end, so that a thorough mixture of gas and lye is obtained. As many absorbers of this construction as may be required are connected in series, and the connections are so made that lye and gas travel in opposite directions from absorber to absorber until the outlet is reached. This arrangement requires the employment of force pumps for both gas and lye.

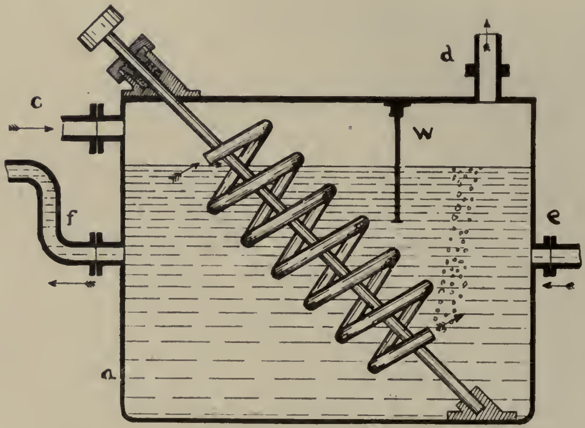

FIG. 25.—ABSORBER WITH REVOLVING SPIRAL COIL.

Another absorber, which is used to some extent, is provided with a revolving spiral coil, as shown in Fig. 25. The coil is placed within the receptacle, *a,* in a diagonal position; both ends are open and as the receptacle is filled with the lye only to two-thirds of its height, the balance of the space being occupied by the gas, the upper end of the spiral takes at each revolution first a small quantity of gas and on its turn through the lye a portion of the latter, thereby enclosing the gas with the coil and forcing same to travel through the coil and out at outlet, *s,* from whence it is forced to bubble through the body of the lye into space, *w*, which latter is divided from the gas by a partition. On its way through the spiral coil lye and gas are thoroughly mixed, and the balance of the CO_2 is absorbed from the gas when same passes through the body of fresh lye entering at inlet, *e*. The saturated lye passes out at *f*, while the fresh gas enters at *c*; outlet, *d*, disposes of the remnants of the gas and leads same to the next absorber. The spiral coil revolves at a speed of not less than 100 revolutions per minute.

The mechanical sprayer, used sometimes, consists of a closed receptacle provided with a paddle wheel. The lye reaches a height just sufficient to enable the spoon-shaped paddles to dip into same, take up a small quantity of lye at each revolution and throw same with considerable force through the upper part of the receptacle which is filled with the gas. The velocity of the paddles must be sufficiently high to keep up a continual rain of lye through the gas, each drop absorbing a fractional amount of CO_2.

Force sprinklers are used. These usually consist of an upright cylinder containing the gas at a slight pressure. The sprinkler is at the bottom. A small stream of lye is forced into the sprinkler which scatters the lye so that the latter shoots through the gas space in small drops. Each drop again absorbs whatever CO_2 it can on its flight through space and the saturated lye is carried off at the bottom.

Revolving wire sieves, the next apparatus, are mounted on a revolving vertical shaft; these divide the gas into very fine bubbles, while the lye passes through the cylinder in a solid body, entering at the top and leaving same at the bottom. The gas enters at the bottom and each mesh of the revolving wire sieve carries with it a bubble of gas, disposing of same by means of centrifugal force. Provision is made to carry the gas back to the center between each section of sieves, so that the gas is divided into small bubbles time and again until it finally passes out at the top. On account of the weight of the column of lye it is necessary to force the gas through same by means of a blower.

ABSORPTION TOWERS.

The cascade tower, which is used also for other purposes, for instance, feed water heating, and in chemistry for the absorption of hydrochloric gases, has also been tried for the absorption of CO_2, but owing to the large body of lye, which did not offer a sufficiently extended surface, the volume of gas absorbed per pound of lye was small, even in towers of considerable height; the cascade-tower was found ineffective and therefore abandoned.

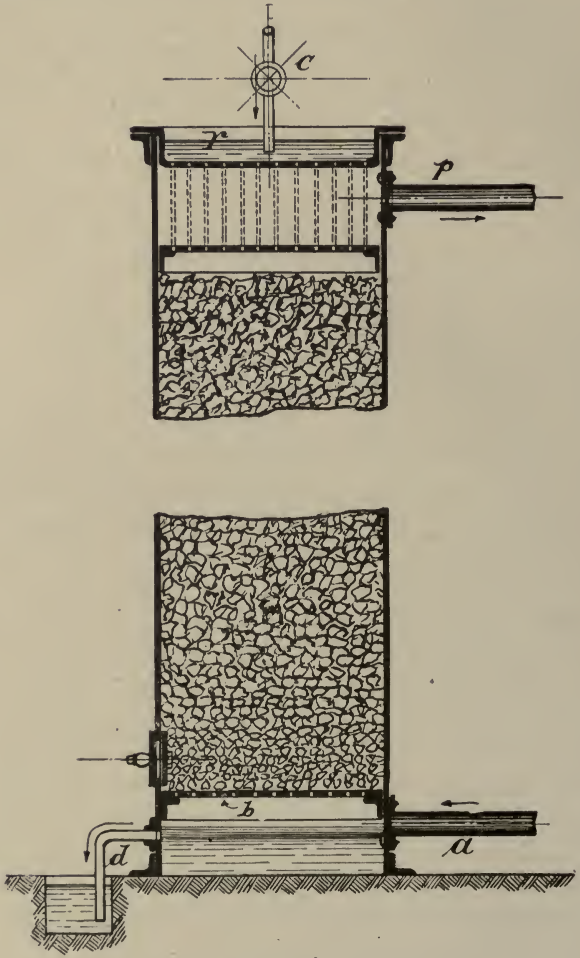

FIG. 26.—DR. LUHMANN'S COKE TOWER.

The coke tower, introduced by Dr. E. Luhmann, is considered one of the most efficient apparatuses for the purpose. The construction is in principle nearly the same as that of the scrubber shown in Fig. 24. The tower is constructed of steel plate and is usually between 75 and 100 feet high by about 4 to 5 feet in diameter, see Fig. 26. A wooden construction surrounds the tower, giving it additional stability and affording opportunity to reach every part of same by means of a stairway. A substantial false bottom, *b,* supports the column of coke with which the cylinder is filled. The lye enters the tower through the pipe connection, *c;* after passing through the tower it gathers under the false bottom, and, leaving through gooseneck connection, *d,* seals the same against escape of gas. The coke filling stops at a height of about 5 fet from the top of the tower and as the gas enters through *a,* below the false bottom, *b,* it rises gradually in the tower, gathers in the room above the coke filling, passing out through pipe connection, *p,* into the atmosphere. The coke filling, consisting of lump coke, divides the space within the tower into very small air spaces. Directly below the cover of the tower is placed a perforated pan, *r,* which divides the lye into numerous little streams; the coke breaks up the streams and covers its irregular surface throughout with a thin sheet of lye. The gases upon passing upward find a large surface of thinly spread lye so that the absorption of the CO_2 is effected in the most thorough manner. Gases and lye pass through the tower in counter-current fashion so that the nearly spent gases meet the fresh and more vigorously absorbing lye in the upper part of the tower, while the nearly saturated lye passes the richest gas at the bottom, so that a nearly full saturation of the lye is accomplished. A damper in the air connection, *p,* may be used, either to increase or to moderate the speed of the gas through the tower.

An absorber of large diameter and of proportionate height facilitates the proper absorption of the CO_2. Good results have been obtained with absorbers of 10 cubic feet volume for each pound of CO_2, hence a plant of 250 pounds CO_2 per hour capacity will require absorbers of not less than 3,000 cubic feet volume. Should one absorber be of too large proportions to conveniently locate it on the premises, it is advisable to use two in parallel connection. The gas and lye is then divided so that equal volumes of gas and lye pass through each tower. If the surrounding conditions permit, it may be advisable to connect the two absorbers in series; in this case the lye and the gas pass first one absorber and then the other; the advantage gained would be a more thorough absorption of the CO_2 from the gas, because the distance traveled in opposite directions for the

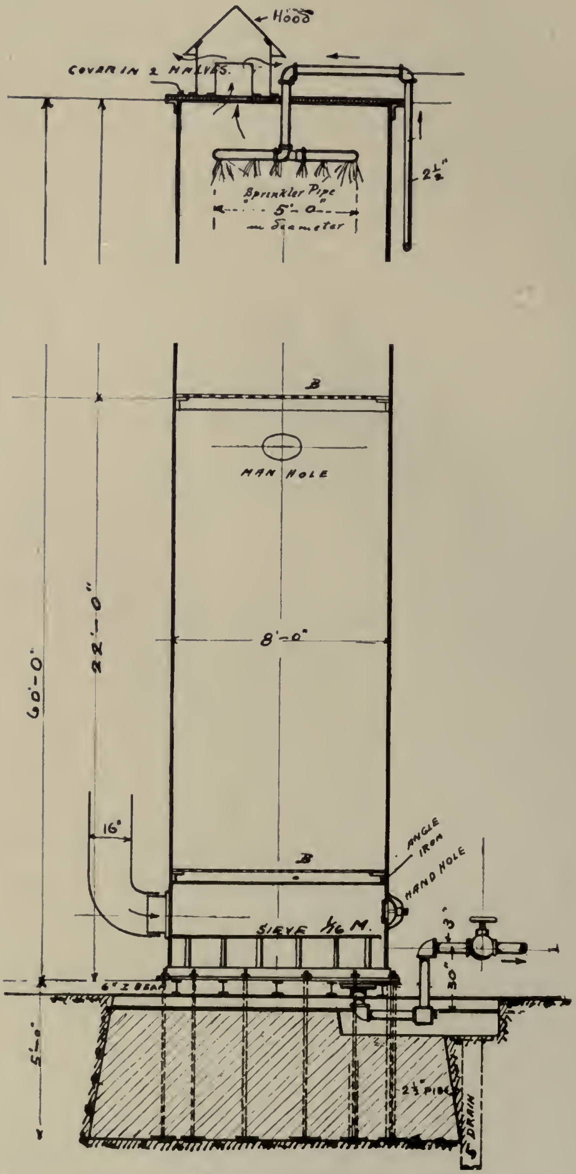

FIG. 27.—ABSORPTION TOWER SHOWING SPRAYING APPARATUS AT TOP.

two is twice as long. The disadvantage lies in the fact that two pumps for the moving of the lye would be required.

In ordinary practice the lye is admitted into the tower through a spray pipe bent in circular shape, as shown in Fig. 27. The lye is forced through the perforations in the spray pipe and is distributed over the coke surface in a fine rain. The cover contains a hood through which the indifferent gases are expelled. The lye passes from the tower through a trap into the saturated lye tank.

If the proportion of the volume of the absorber to quantity of lye and volume of gas is large it will permit the use of small coke pieces, which in turn provides a greater surface than coke of a larger size. There is, however, the danger, with the use of small coke, of clogging up of the tower, especially in its lower part, owing to the weight of the coke column; such clogging seriously interferes with the passage of the gas through the tower, which reduces the output in gas of the plant, increases the quantity of lye to be heated and handled per pound of CO_2, which in turn increases the expense of production materially.

A tower provided with numerous perforated shelves and manholes for the purpose of cleaning it out when clogged permits a more thorough control of the same within. Fig. 28 indicates the construction of such a tower. Each section thereof between the shelves may be cleaned and refilled without the necessity of removing the whole charge in case of trouble. Before filling the tower remove all dust, grit, etc., from the coke by thoroughly screening and washing same. The coke must be as free from sulphur as can be made, yet the best grade contains slight traces of same, and as this sulphur is transferred to the lye and acts destructively upon the lye boiler, it is advisable to treat the coke, before filling, with a diluted solution of muriatic acid. This acid decomposes the sulphur and removes it in the form of sulphuretted hydrogen. After this the coke should again be thoroughly washed with water to remove all traces of the acid, and it is well to mix a small amount of soda lye with the water, toward the end of the procedure.

Many additional constructions have been tried to improve the efficiency of absorption towers. Among others the converting of the absorbing solution into a foam by means of revolving sieves, for the purpose of increasing the surface of the lye. The practical gain, if there is any, is entirely offset by the increased mechanical complication of the absorber and by the increase in power required to revolve the sieves.

Absorption under pressure has the advantage of being increased in efficiency. The tower must, however, be built much stronger, the gas must be moved by large compressors and the power required to operate the lye pumps is increased. The net result of the considerations for and against the pressure absorption system is, that while it increases the efficiency of absorption and decreases the requirements in

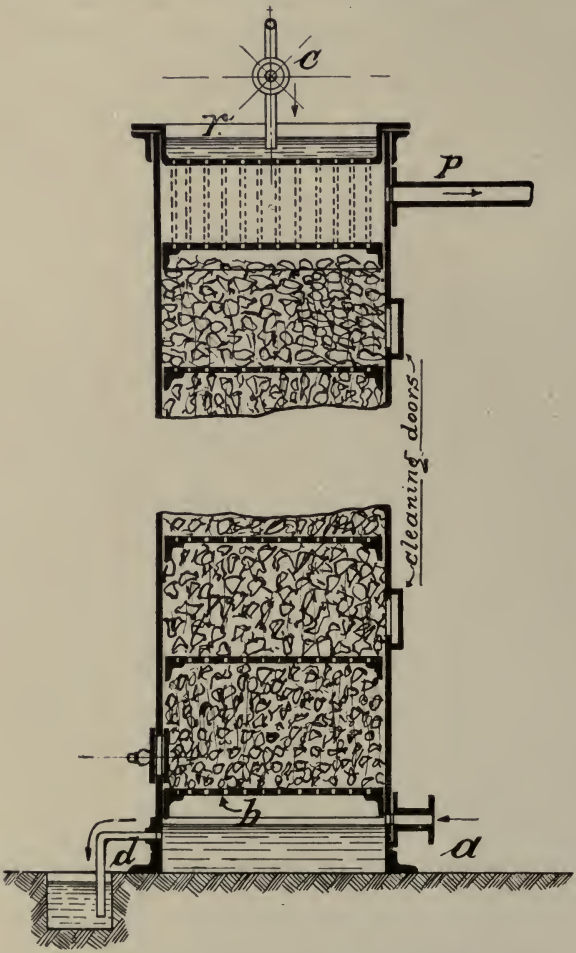

FIG. 28.—ABSORPTION TOWER FITTED WITH PERFORATED SHELVES.

heat for purposes of boiling the lye, it is possible to effect this gain only by complicating the system, sacrificing its simplicity and increasing the amount of power required as well as the risk, therefore its adoption in preference to the simple percolating tower can not be recommended.

LIBERATION OF CARBONIC ACID GAS FROM THE LYE.

The liberation of the CO_2 gas from the alkali solution is accomplished by means of heat, and as the second molecule of CO_2 is only loosely bound with the mono-carbonate, a temperature of 214° F. is sufficient for this purpose. One cubic foot of potash lye of 20° Beaume contains in its solution 12.6 pounds K_2CO_3 and is capable of absorbing two pounds of CO_2. In order to expel this two pounds of CO_2, the heat of 1.7 pounds of coke or of 25 pounds of exhaust steam at 5 pounds back pressure is required. A lye of a higher concentration—for instance, 30° Beaume—absorbs fully three pounds of CO_2, yet its requirements in heat for the purpose of gas liberation remain the same, hence it is clear that a lye of a high concentration is the most effective in the absorption of the CO_2, while at the same time it is economical in the requirements of heat.

The lye is heated in an ordinary shell boiler and the heat is obtained from the fuel, which furnishes the CO_2 as a product. Whenever this method is used it is necessary to operate a second boiler to raise steam for power.

Instead of heating the lye in this manner, live or exhaust steam may be used. In the majority of cases surrounding conditions should be carefully considered and a competent engineer engaged to design the plant, so that the wasteful application of unsuitable methods may be avoided, while any advantages offered by peculiar existing circumstances should be properly applied to secure economical operation.

VARIOUS TYPES OF LYE BOILERS.

If steam, live or exhaust, is used to liberate the CO_2 from the lye, it is customoray to employ a cylindrical tank (see Fig. 29), place it in the upright position and provide it with steam coils. The temperature of the lye is about 120° F. when entering the boiler, and as the steam has a temperature above 212° F., an active exchange of heat between the two will take place. The cylinder must not be filled to the top with the lye, as a chamber for the collection of the liberated CO_2, as well as some steam evaporated from the lye, is needed. CO_2 gas and steam mix, until drawn off into a condenser, where the steam is condensed and is allowed to flow back to the lye collecting basin, while the CO_2 escapes into a gasometer.

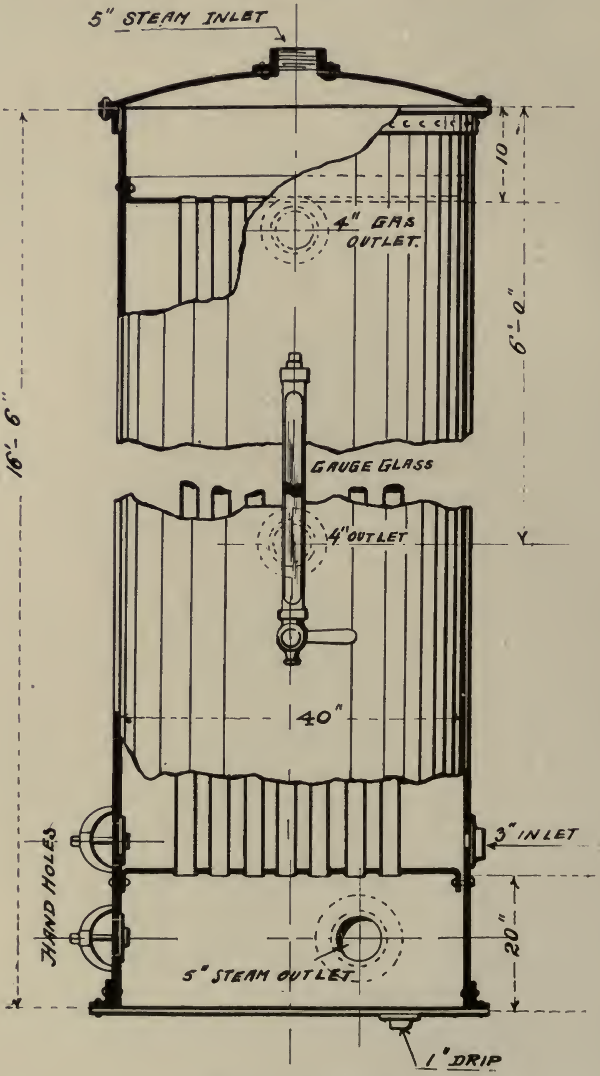

FIG. 29.—LYE BOILER.

This above described boiler has a heating surface of not less than 300 square feet for the boiling of about fifty gallons of lye per minute, and the liberation of between 250 and 300 pounds of CO_2 per hour.

As it is very desirable to save as much heat as possible, an apparatus, as shown in Fig 30, was designed to absorb the heat from the liberated CO_2, as well as from the steam accompanying it, by the cold lye from the absorber. The boiler, *A*, is filled with lye high enough to completely submerge a steam coil. The CO_2, with some steam, escapes from the boiler through opening, *f*, which connects the lye boiler with tube heater, *C*; it leaves the latter through pipe connection, *g*, and thereupon enters cooling coil, *h*, which latter is submerged in water contained by tank *D*. The saturated lye, pumped through *a* into the tube heater, *C*, surrounding the latter's tubes, leaves it through pipe connection, *b*, and is then sprayed through the tubes into basin, *B*. On the passage through the tubes the finally sprayed lye absorbs the heat from the gas passing upward and condenses the steam mixed with it, carrying this condensation with it into basin, *B*. The lye, which is now thoroughly fore-heated, passes through pipe

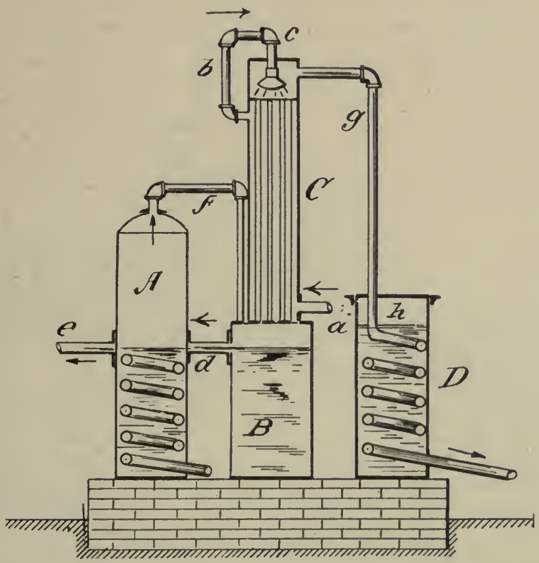

FIG. 30.—APPARATUS FOR ABSORBING HEAT FROM LIBERATED CO_2.

connection, *d,* into the boiler, where its temperature is raised to the point required for the liberation of the gas. The boiled lye passes out of the boiler through *e*, to be cooled to about 100° F. in order to be fit for the absorption of another volume of CO_2.

Frequently an apparatus constructed similar to a horizontal tubular boiler is used for heating the lye. Fig. 31 illustrates a boiler of this kind, having numerous tubes set into the end plates in boiler-tube fashion. The lye enters at *a,* surrounds the tubes and leaves through pipe connection, *b*, while the steam passes into the boiler at *c,* fills the horizontal tubes and imparts its heat to the lye until it condenses, which condensation is carried off through goose-neck. The mixture of CO_2 and steam collects in the dome, leaving it through *e,* passing into a condenser, where the steam is separated from the CO_2 by means of condensation.

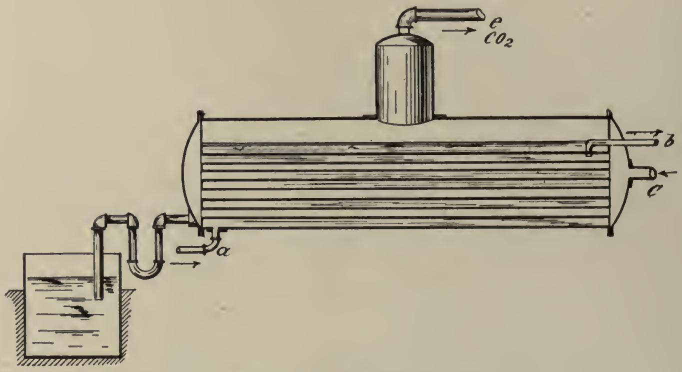

FIG. 31.—HORIZONTAL BOILER FOR HEATING LYE.

A lye boiler which utilizes the heat produced directly from the combustion of the coke that has to be consumed in order to furnish the requisite volume of CO_2 as a product of the combustion is illustrated in Fig. 32. A simple cylindrical boiler, properly bricked and provided with a special fire-place for burning the coke, is fitted with a dome, so constructed that it can be used as a fore-heater of the lye passing into the boiler, acting at the same time as a condenser of the steam evaporated from the lye with the liberation of the CO_2. The boiler is of a rather exceptional length compared to its diameter, so as to furnish sufficient surface in proportion to the quantity of lye to be heated. The heat from the fire passes around the boiler and as much of the surface as possible should be subjected to its action. The dome is constructed either as a special tubular cylinder, as shown in Fig. 33, or as a simple cylindrical receptacle, having a perforated bottom upon which rests the filling of the dome, consisting of coke in pieces about the size of a fist. The lye enters through *l* and is broken up by the uneven surface of the coke into a rain, trickling down on the same and coating the latter's surface. During this passage it meets the liberated CO_2, as well as some steam, absorbs their heat and enters the boiler in a fore-heated condition. The steam mixed with the CO_2 condenses and runs back into the boiler, while the CO_2 passes out through connection, *g*. A continual stream of lye is furnished and passes out through *m*, as fast as supplied, thereby maintaining the same level in the boiler. The other construction of a dome is based upon the same principle as explained under Fig. 30.

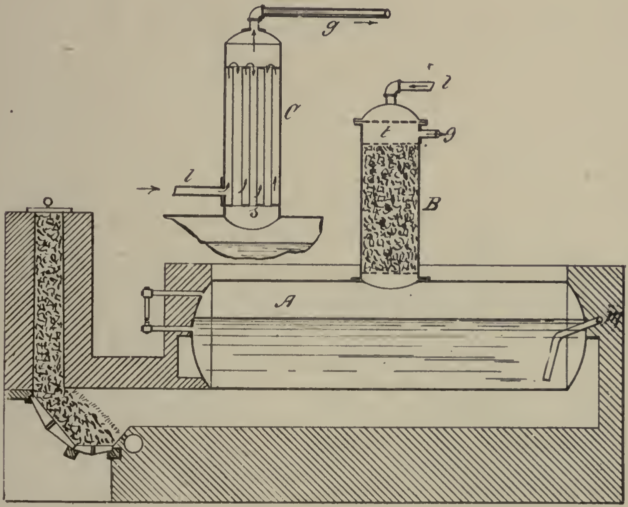

FIG. 32.—LYE BOILER WHICH UTILIZES HEAT DIRECTLY FROM COMBUSTION AND (FIG. 33) DOME FOR SAME

In Fig. 34 is shown a lye-boiler which receives its heat through a steam coil placed inside, as well as from a coke fire maintained under it. The boiler is separated into two parts, *A* and *B*. Connection, *n*, provides a communication between the two. The lower part, *A*, is bricked in, the heat from the fire passing under and then around it. Lye is pumped into compartment *A*, where it is heated from the coke fire; it then passes through communication, *n*, into *B*, where it remains until the necessary temperature, supplied by the steam coil, *g*, is reached. CO_2 and steam leave the boiler through *d*, and the boiled lye overflows by means of pipe, *o*. On account of its deficient heating surface it consumes a disproportionate quantity of steam and therefore is expensive in its operation.

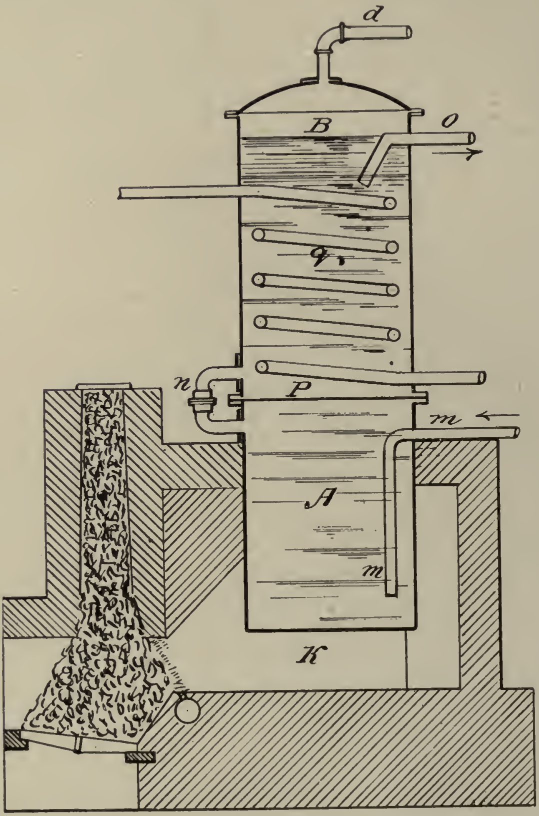

FIG. 34.—LYE BOILER FITTED WITH STEAM COIL.

The latest and most economical lye boiler uses the heat of the flue gases on the economizer principle; it is calculated in the same manner and should contain about 45 per cent of the heating surface of the boiler used in connection with it. The boiler furnishes steam for power purposes and its size is calculated in accordance with the amount of coke that must be consumed to furnish the desired quantity of CO_2. Assuming a production of 250 pounds of CO_2 per hour as the desired quantity, it is necessary to burn about 250 pounds of coke to obtain the result. The heat from the combustion is equivalent to the evaporation of about 2,000 pounds of water per hour, or seventy horse-power in round figures, basing the horse-power on thirty pounds of water evaporated. There would then be available in the flue gases a heat of about 1,000,000 B. T. U. per hour for the heating of the lye in the economizer. A heat exchanger, and, in addition, an exhaust steam heater, have previously been used to raise the temperature of the lye to nearly 200° F. before entering the economizer, so that the only work remaining to be done by the flue gases is the raising of the temperature of the lye about five degrees more, as well as the evaporation of a part of the water. The latent heat of the steam is then used to heat the lye upon its entrance into the economizer, which latter re-condenses it, carries it back into the economizer and prevents, as much as possible, any loss of heat.

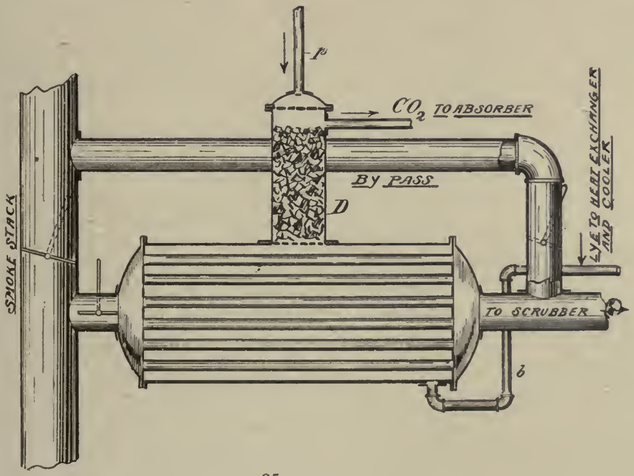

FIG. 35.—ECONOMIZER.

THE ECONOMIZER.

In Fig. 35 this economizer and its connections are shown. The shell which is four feet in diameter, contains forty-six steel tubes 2½ inches in diameter by 14 feet long. The dome contains a coke filling, which breaks up the stream of lye entering same through connection, *p*. Lye overflow, *b*, is so arranged that the economizer is kept filled. The latent heat of the steam passing upward with the CO_2 heats the lye, condenses and runs back into the boiler, while the CO_2 passes out at the top; the gas is then led to proper coolers, which reduce its temperature and condense any moisture which may still remain in it The liberation of the gas from the lye is greatly facilitated by means of an exhauster connected to the CO_2 gas line leading

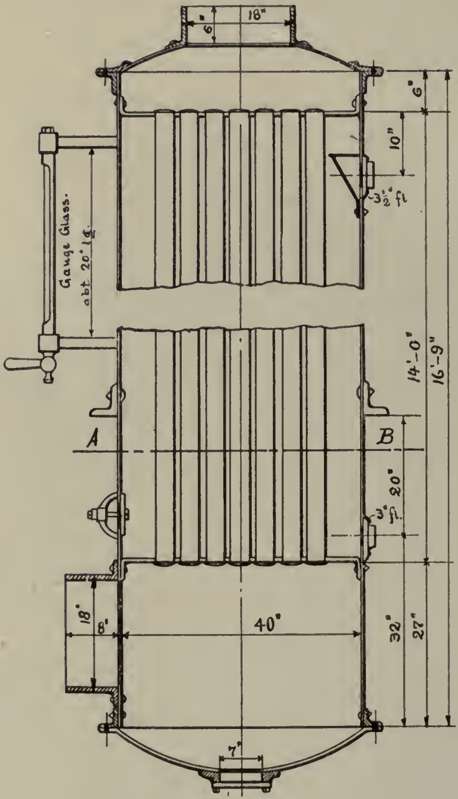

FIG. 36.—VERTICAL ECONOMIZER.

to the gas cooler. This exhauster produces a partial vacuum in dome *D*, and draws off the gas at a temperature considerably below the boiling point, which also prevents the necessity of evaporating quantities of water from the lye, which means a further saving of heat.

A vertical economizer is shown in Fig. 36. Same is of an identical construction as the horizontal type, with the exception that the gas dome is omitted. It is used simply to absorb as much heat from the flue gases as possible.

THE GENERATOR AND ANALYZER.

The balance of the heat necessary to liberate all of the CO_2 from the lye and reconvert the latter into a mono-carbonate is supplied in a generator and analyzer as shown in Fig. 37. This apparatus has been developed in the refrigerating industry—absorption system—where the conditions are nearly identical.

The generator consists of a horizontal cylindrical body about 34 inches in diameter by 10 feet in length. Its rear head made of steel is concaved and riveted in place, while the front head is flanged to the body. This body is provided with six independent coils of 2-inch pipe aggregating 320 square feet of heating surface. The ends of these pipe coils extend through suitable stuffing boxes in the front head and are joined together by large steam headers. The analyzer is flanged to a saddle nozzle, which is riveted to the body. It is about 39 inches in diameter by 4 feet in height. The dished head, containing a 4-inch gas outlet flange, is flanged. Six suitable analyzer trays are arranged within to handle fifty to sixty gallons of lye per minute conveniently.

The gas and steam passes out through the head into the gas cooler—or rectifier—which may be of pipe or of sheet metal construction; the condensed steam is returned to the analyzer, while the CO_2 passes to the gasometer.

Economy in operation is the dominating factor of the whole equipment and for that reason the requirements in steam for power purposes must not exceed the quantity of water that can be evaporated from the fixed amount of coke, the combustion of which is required to furnish as its product the desired gas, CO_2.

GAS COOLERS.

Gas coolers of various construction are used to reduce the temperature of the carbonic acid after its liberation. The same rules which apply to steam condensers apply, with slight modification, to those that are to serve this purpose. Temperature, surface and volume, are the three factors that fix the size. Coolers with large surfaces and least resistance are the most suitable.

The ordinary surface condenser, consisting of a shell, within which are placed a great number of tubes set into end plates, is

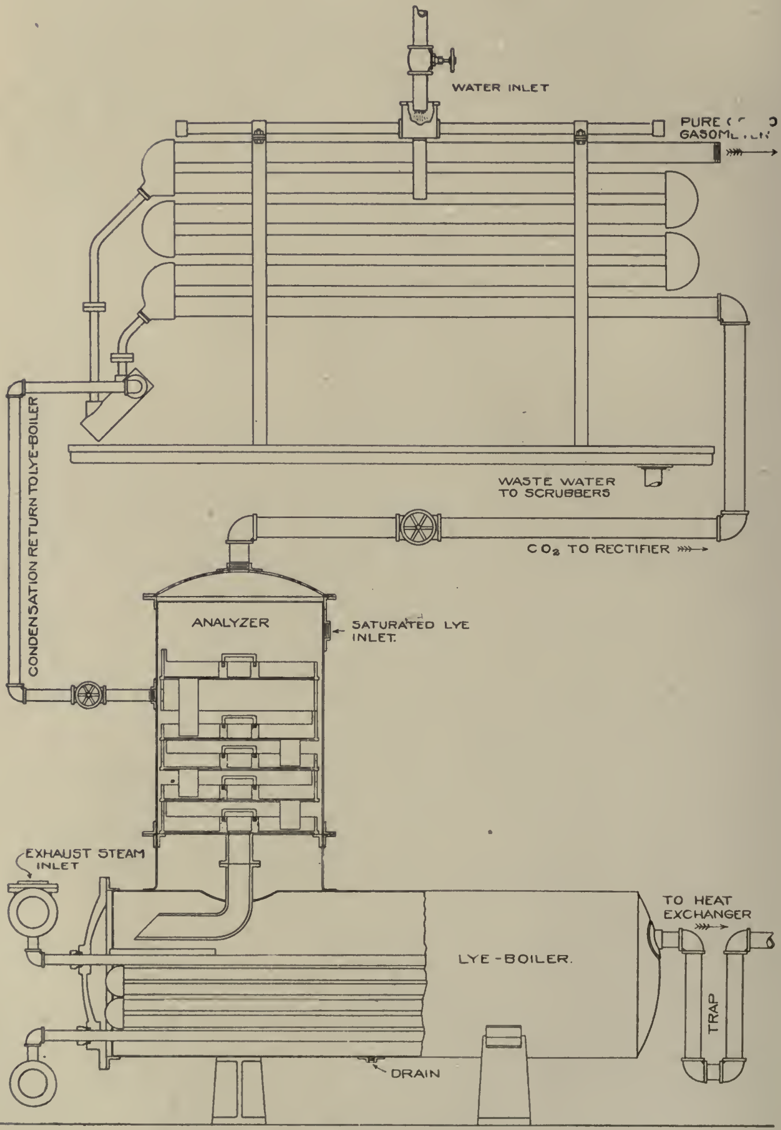

FIG. 37.—CARBONDALE GENERATOR, ANALYZER AND RECTIFIER.

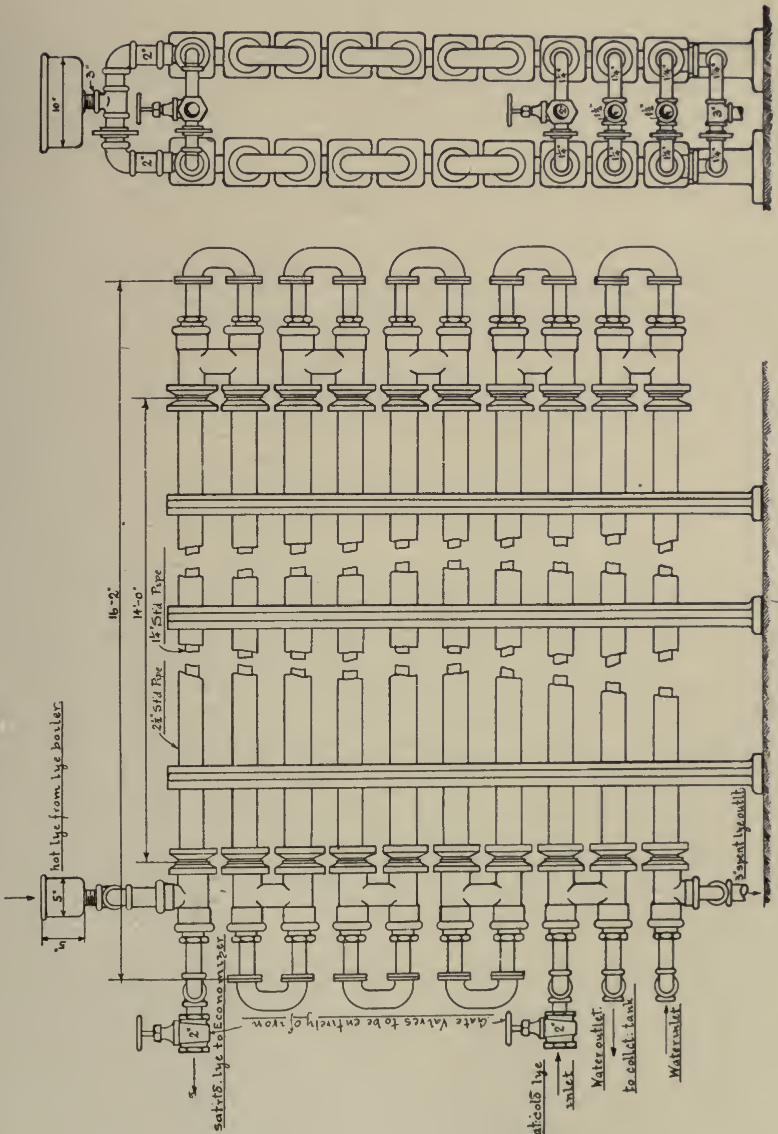

FIG. 38.—DOUBLE-PIPE HEAT EXCHANGER.

giving good satisfaction. The hot gas enters the shell and, surrounding the tubes, is cooled by the water which passes through the tubes. The A-shaped condenser made by the Triumph Ice Machine Company, Cincinnati, Ohio, is also highly recommended for this purpose. This condenser is made entirely of sheet metal, having a large surface which is coated with an even sheet of water when in operation. After the cooling, the gas is stored in a gasometer where it remains until its compression and liquefaction.

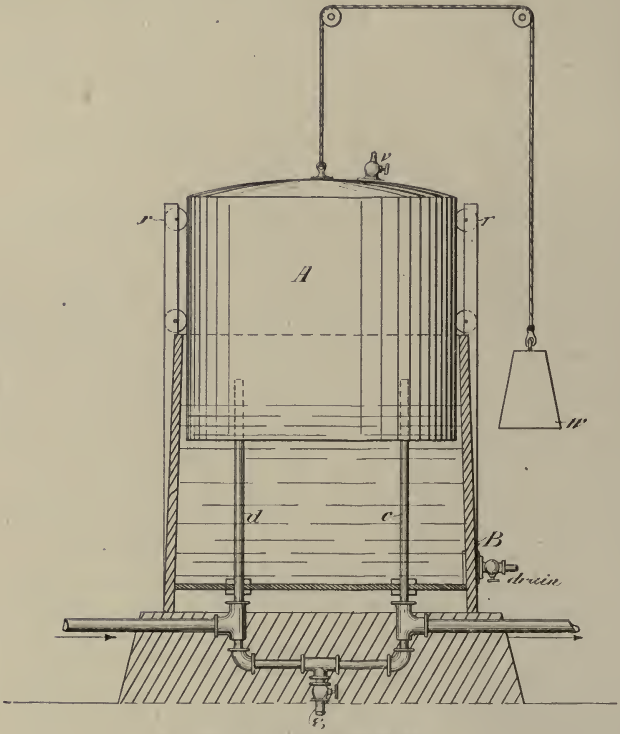

FIG. 39.—THE GASOMETER.

THE HEAT EXCHANGER.

The boiled lye, from which the gas has been liberated, is returned to the weak lye tank. Before it reaches there it passes a heat exchanger in which it parts with its heat to the saturated lye which is on its way to the boiler. The final cooling of the weak lye is accomplished by means of several water pipes in the double pipe heat exchanger, as illustrated in Fig. 38.

THE GASOMETER.

The gas receptacle which is used for the collection of the liberated CO_2 is termed a gasometer. It consists of a large cylindrical vessel closed at one end only. The top is closed and constitutes the head and the open end is set into a tank containing water. This gasometer is illustrated in Fig. 39. *A* is the gasometer bell, which is constructed of light material. Its open end enters the water contained in tank *B*. The gas enters through pipe connection, *d*, and is drawn off through *c*. A trap connects *d* and *c* so that any moisture which collects in the pipe line may be discharged at *e*. The gasometer bell is vertically movable between the rollers, *r*. A counter weight, *w*, eliminates the

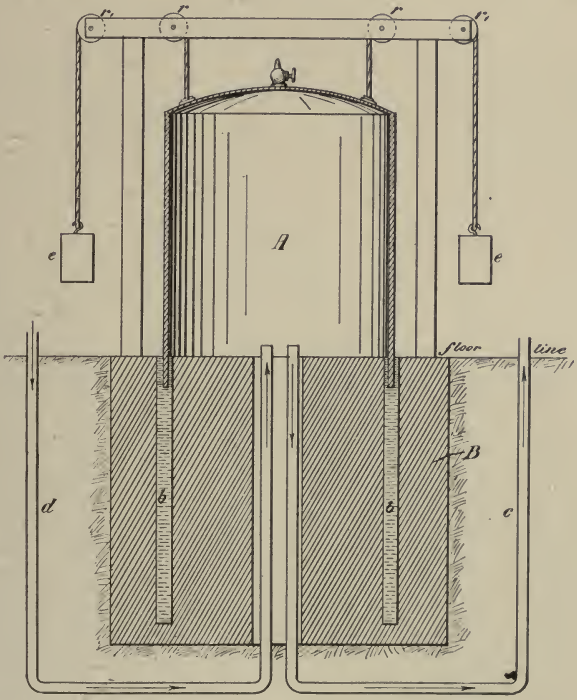

FIG. 40.—GASOMETER WITH CONCRETE TANK.

weight of *A*, and is so adjustable that a slight pressure is exerted upon the gas under the bell. If atmospheric air has entered the gas line it can be expelled through air cock, *v*. The gasometer tank, *B*, is about ten feet in diameter by eight feet high. If it is filled to about three-fourths of its height with water and the lower rim of *A* is permitted to dip into the water about nine inches, it will have a capacity of about fifty pounds of CO_2. This may seem to be small for a plant that produces 250 to 300 pounds of liquid CO_2 per hour; however, it is large enough to allow of sufficient flexibility in the operation of the plant to prevent a vacuum in the gas line.

A gasometer in which *B* consists of concrete, built below the floor line, is illustrated in Fig. 40. In this gasometer the lower rim of *A* dips into a small circular space filled with water as shown.

CHAPTER V.

DRYING, PURIFYING AND LIQUEFYING APPARATUS

THE DRYER.

The gaseous CO_2 stored in the gasometer always contains small quantities of moisture. A pure gas must be dry. Moisture is an impurity which may lead to many disagreeable complications in the use of the gas. Its principal disadvantage is its liability to freeze in the valves, or in the small block-tin conductors used in connection with carbonating equipments, stopping them up and sometimes bursting them. The best absorbent of moisture is calcium chloride, which is used almost exclusively for purposes of drying the gas. The receptacle containing it is called a dryer and is shown in Fig. 41.

A cylinder, *A*, made of ¼-inch tank steel, has a perforated false bottom, *B*. The latter rests upon an angle iron. In its center a 6-inch pipe is screwed through a flange, which pipe is supported by a simple frame *F* at its upper end. The lower end of the pipe is open, while the upper end is closed by means of a pipe cap. The pipe is perforated with ½-inch holes about two-thirds of its height. The space surrounding this pipe is filled with calcium chloride, which is thrown into the cylinder through manholes, *M*. The gas enters through the lower flange, *C*, passes into the pipe and spreads through the chloride of calcium, which absorbs its moisture; the dry gas passes out at flange, *D*, into the line leading to the suction of the compressor. The moisture in the gas dissolves a part of the salt; this concentrated solution collects at the bottom of the tank and must be drawn off through valve *V* from time to time. Fig. 42 represents a dryer constructed for gas under a higher pressure.

THE PURIFIER.

As a further means of purification, more particularly for the purpose of removing the last traces of objectionable odors, a second receptacle called the purifier is interposed in the suction line between the gasometer and the compressor. The nature of this final purification depends upon the character of the odor, and the medium used as a deodorizer varies accordingly.

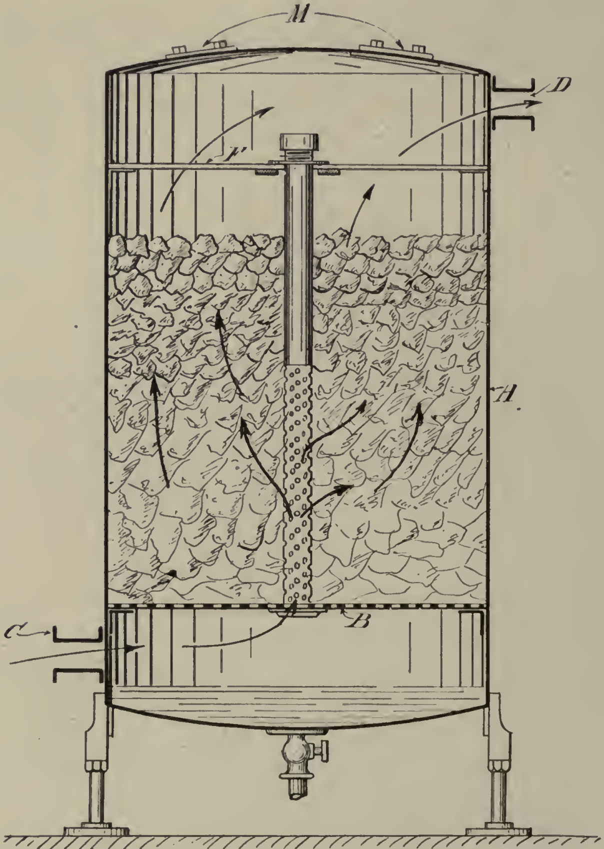

FIG. 41.—CALCIUM CHLORIDE DRYER.

The gas is now ready to be liquefied and the method of liquefaction is subject to the laws which govern the condition of all gases.

LIQUEFACTION OF THE GAS.

All bodies, gases as well as solids, expand and contract with a corresponding change of their temperature, and it has been found that a close relation exists between volume and temperature. With the removal of its heat a gas contracts in volume. Steam has a temperature of 212° F.; upon cooling it its volume decreases, it enters a saturated condition and finally condenses to water. It requires heat to change a pound of ice into a liquid and more heat to produce from liquid the vapor known as steam. In changing back from the steam to a liquid and converting the water into ice, the same number of heat units are given up. This heat is absorbed during the process of fusion; it does not appear sensibly, that is to say, it can not be felt or measured by the thermometer, and it is therefore known as latent heat.

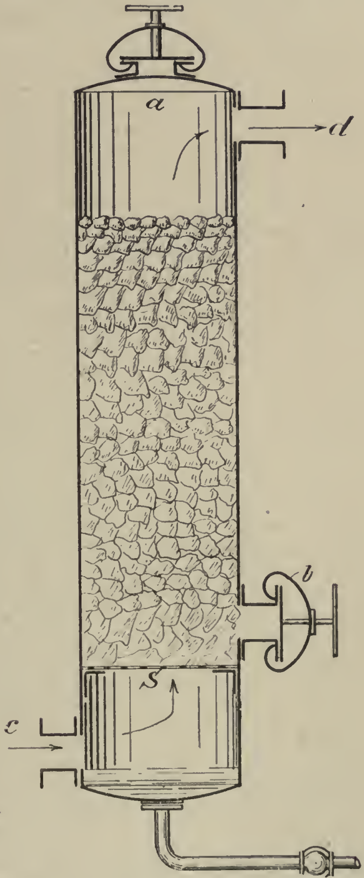

FIG. 42.—HIGH PRESSURE CALCIUM CHLORIDE DRYER.

When a gas, such as carbonic acid, changes from the gaseous into the liquid form the change does not take place through the influence of temperature alone; it is necesary to apply pressure. The relation of pressure and temperature at which a gas changes its condition varies considerably, according to the kind and character of the gas. If the pressure applied to a gas is sufficiently high it is only necessary to reduce its temperature in order to liquefy it. Generally speaking, the saturation of a gas requires a higher pressure when its temperature is higher and a lower pressure at lower temperature.

Each gas has a point on the temperature scale above which it can not be liquefied, below this point it liquefies as soon as the necessary pressure is applied. This pressure, temperature and the volume of a gas measured at the freezing point under atmospheric pressure, are frequently referred to as critical data. Their values for some substances are given in the following table:

SUBSTANCE	Temp. F.	Pressure in atm.	Volume in cu. ft. of 1 lb.
Carbonic acid	88°	75	.035
Water	690°	195	.037
Ammonia	266°	115	.048

The relation between pressure, volume and temperature is graphically illustrated in Fig. 43. The curve representing mixed liquid and vapor is drawn in dotted lines. Each curve represents a fixed temperature. If the gas is operated on at 120° F., the relations between pressure, volume and temperature are not much unlike those for any ordinary gas. If the temperature is lower than this, the deviations shown become greater and greater. Taking, for example, temperatures of 70° F., which correspond with the average temperatures existing in the manufacture of liquid carbonic acid, and, starting with a pressure of fifty atmospheres, increasing it to sixty atmospheres, the volume changes so as to give rise to the curve *BA*; but if the volume is decreased—keeping the temperature of 70° F. constant—the gas liquefies and the pressure keeps constant until it has all become a liquid, which is represented by line *BC*. If the pressure is now increased to 100 atmospheres, very little alteration of volume is produced, and this portion of the curve *CD* is therefore very nearly a straight line. If the operating temperature is as high as 80° F., the straight portion, *BC*, representing the liquefaction line, becomes shorter, and with operating temperatures of 88° F. it vanishes entirely, that is to say, no liquefaction takes place at that temperature. The significance of this is that just below 88° F. the gas changes to liquid without any sensible change of volume, while above this temperature no liquefaction occurs, although the change of volume may be nearly as great as that which results from liquefaction as is shown by the 88° and 96° F. curves. It follows that it is possible to crowd nearly as much gaseous as liquid CO_2 into the same space at temperatures up to 100° F.

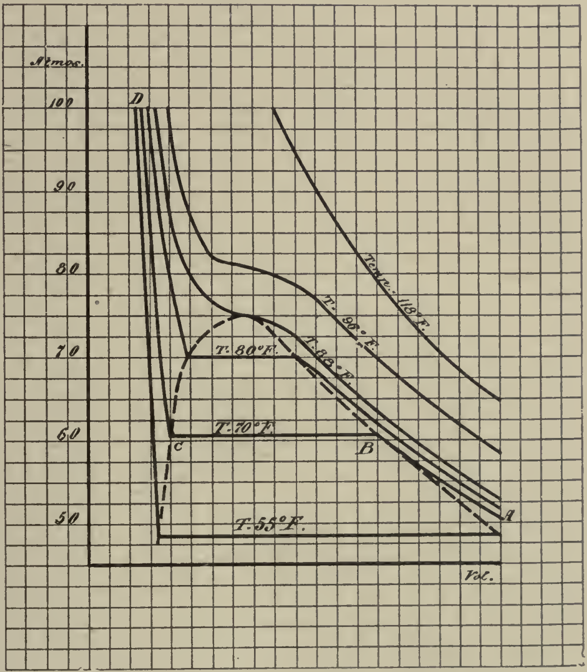

FIG. 43.—DIAGRAM SHOWING RELATION OF VOLUME, PRESSURE AND TEMPERATURE.

The pressures and temperatures of liquefaction of CO_2, shown graphically in curve (Fig. 44), are based upon tables, recently published, prepared by Dr. Mollier. Doubts existed for some years as to the exact properties of CO_2, but these were practically ended by the

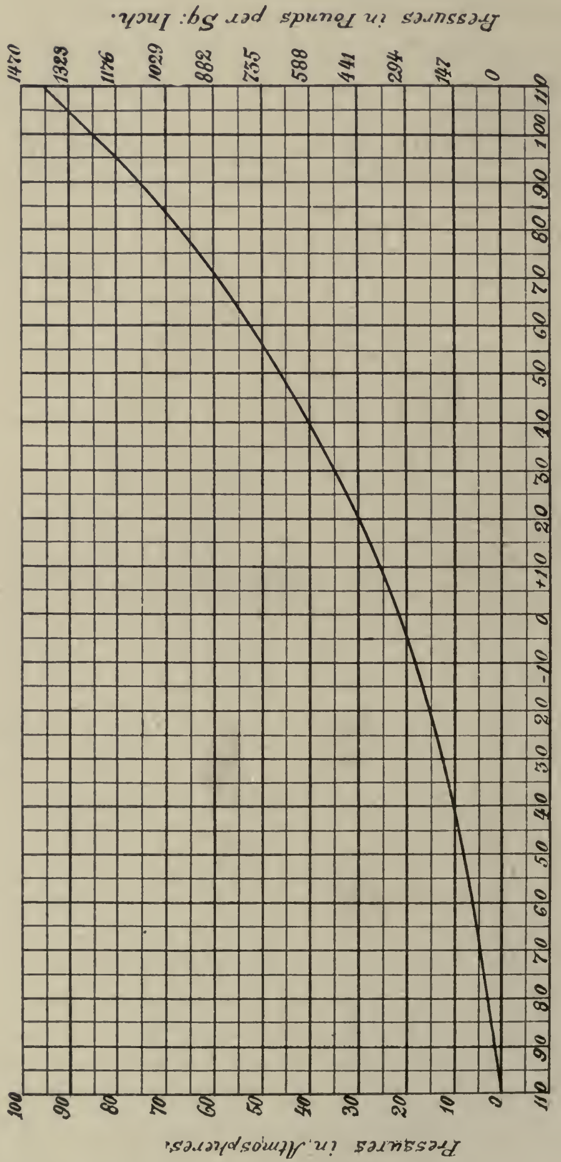

FIG 44.—DIAGRAM SHOWING PRESSURES AND TEMPERATURES OF LIQUEFACTION OF CO_2.

investigations of Professor Schroeter, of Munich, whose findings were but slightly modified in Dr. Mollier's table.

Carbonic acid was the first of the gases to be successfully liquefied, Faraday having liquefied a small quantity of CO_2 in 1823, in a strong glass tube, bent as shown in Fig. 45. In this tube he placed a small quantity of sulphuric acid and carbonate of ammonia. The acid was kept separate from the carbonate until point *c* of the tube was closed by melting. As there was no outlet of escape for the developed CO_2, the pressure increased rapidly and the subsequent cooling of the tube accomplished liquefaction of the gas, the liquid collecting in point *a* of the tube, as shown.

FIG. 45.—TUBE FOR LIQUEFYING CO_2.

EARLY EXPERIMENTS IN LIQUEFACTION.

Thilorier, Mareska and Donny experimented with an apparatus, using Faraday's test on a large scale, and they were enabled to produce several quarts of liquid carbonic acid after repeated filling, generation of gas by means of chemical decomposition and a subsequent cooling. These experiments required much patient labor as well as great care in manipulation, owing to the production of high pressures, which, with such crude apparatus as that used, were difficult to control. However, they had served to show that liquefaction always took place through the combined action of compression and cooling, and as air compressors had since been constructed, it appeared logical to Professor Pleischl in Vienna (1844) to use the latter in the liquefaction process. Under his direction the first compressor for this purpose was constructed by his pupil, Johann Natterer, and this scientist succeeded in producing liquid carbonic acid in quantities with the use of a compressor for the first time. Natterer's machine was of the single-acting compression type and several hours of hard work were required to produce one and one-quarter pounds of liquid carbonic acid.

For a considerable length of time the development in the production of liquid CO_2 made very little progress. Its use was still confined to the laboratory of the scientist, as it had not yet been recognized as a substance of commercial value in the industrial world, until finally an incident occurred which led to important results.

Dr. W. Raydt, in Hanover, Germany, experimented with a Natterer compressor in 1878. At that time one of the German war ships had been accidentally sunk and various methods of raising it had been discussed. Dr. Raydt had conceived the idea of using a balloon filled with carbonic acid gas, attached to a sunken object, for the purpose of raising same to the surface of the water. It appeared to him that liquid CO_2 could be used for that purpose to excellent advantage, but in order to produce the required liquid, it was necessary to construct compressors of larger capacity and greater efficiency than the Natterer machine.

The construction of good-sized compressors, working against pressures such as are required in the liquefaction of carbonic acid, seemed a thing next to the impossible, but Dr. Raydt did not desist and he finally succeeded in constructing a machine of about 30 cubic inches compressor volume, with which he produced nearly 100 pounds of liquid CO_2. This was during the summer of 1879. By special arrangement with the German imperial authorities at Kiel he was permitted to experiment on raising sunken objects from the bottom of the sea. He used a balloon of nearly circular shape, which measured 10 feet in diameter. The cylinder containing the liquid carbonic acid was attached to the balloon and a suitable gas connection to the neck of the latter was provided. The object to be raised was an anchor, weighing 63,000 pounds, lying at a depth of 40 feet. A diver was sent down to fasten the empty balloon to the anchor, after which the liquid CO_2 was made to evaporate into the balloon, and exactly eight minutes after opening the liquid valve the balloon appeared on the surface carrying the anchor with it. The success of this test was duly chronicled and constitutes the first practical use of liquid carbonic acid. As such it marked the beginning of the carbonic acid industry.

Shortly after this, Friedrich Alfred Krupp, head of the world-famous house of Krupp in Essen, proposed to use liquid carbonic acid as a means for compressing fluid steel and Dr. Raydt in 1880 constructed for him a machine with a capacity of ten pounds liquid carbonic acid per hour.

COMPRESSORS.

All of the earlier machines for compressing the gas in order to liquefy it were of the single acting, one-stage type. The modern machine compresses the gas to the required pressure in three to four successive stages, thereby reducing pressure and temperature of liquefaction. This machine is known as the multi-stage compressor. One of the principal advantages of multi-stage compression is found in the reduction of loss due to the heat of compression, and this represents a saving in power, since the resistance due to compression is directly proportional to changes in temperature. Other reductions in losses are found in reduction of clearance and strains and in a more uniform air resistance.

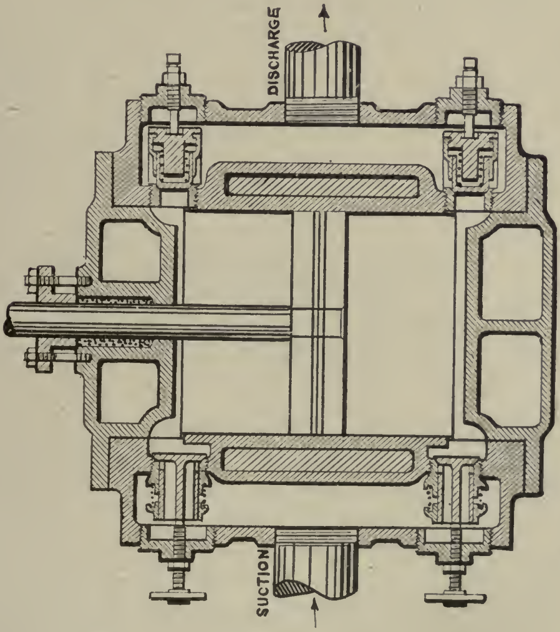

FIG. 46.—CYLINDER OF A DOUBLE-ACTING LOW-PRESSURE MULTI-STAGE COMPRESSOR.

Fig. 46 illustrates a section through the double-acting low pressure cylinder of a multi-stage machine. The suction valves are made large and of light weight, and are so protected by the overlap of the cylinder body that they can not be drawn into the cylinder by the breakage of a stem. The vertical movements of all the valves insures even wear on their seats. The position of the valves enables a full water jacketing of the heads. The cylinder is jacketed as shown.

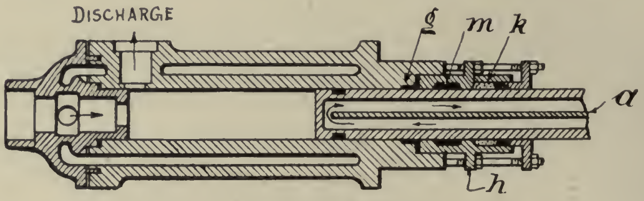

FIG. 47.—SINGLE-ACTING HIGH PRESSURE CYLINDER.

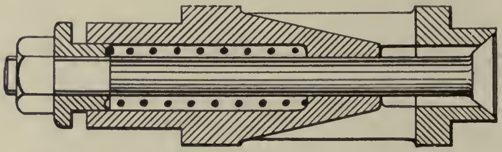

FIG. 48.—SUCTION VALVE MULTI-STAGE COMPRESSOR.

The high pressure cylinder is preferably of the single-acting type, with its suction valve located in the cylinder head and the discharge valve in the vertical position, as shown in Fig. 47. The plunger is made of cast iron, and is hollow, with a metal partition running through its center to permit of water cooling. The packing

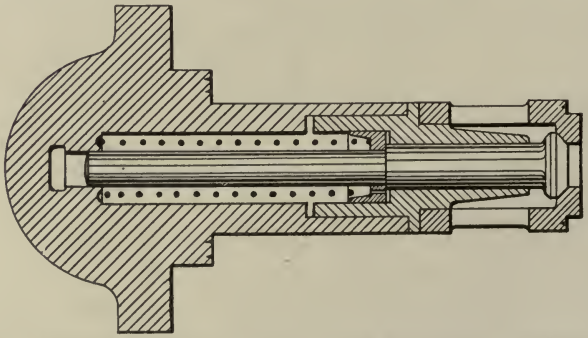

FIG. 49.—HIGH PRESSURE DISCHARGE VALVE MULTI-STAGE COMPRESSOR.

in the stuffing box consists of a tightly fitting leather cup. Chamber, *m,* contains pure glycerine for lubrication. A set of soft packing is placed between stuffing box, *h*, and outer gland, *k,* where it serves to prevent the glycerine from running out at the outer end of the stuffing box.

Fig. 48 shows the suction and Fig. 49 the high pressure discharge valve. Both are of the disc-poppet valve design and are complete in themselves with housing, seat, stem and spring. If a valve requires attention it may be removed and a spare valve substituted. Both valves are cut from high grade tool steel and work on hard Tobin bronze seats, which possess exceptional wearing qualities.

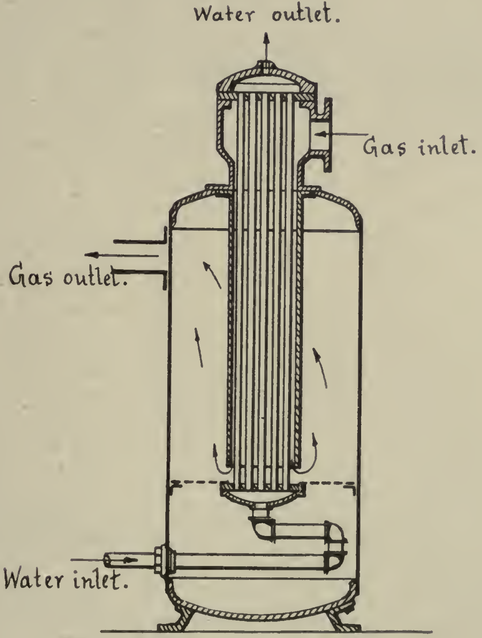

FIG. 50.—DIAGRAM OF INTERCOOLER.

INTERCOOLERS.

One of the most important vessels necessary to the process of compressing gas by stages up to a high pressure is the intercooler. For its best or most economical effect upon the work of a multi-stage compressor, it should cool the passing gas between each of the compressing stages to its normal temperature, and if colder water is available, to a temperature as far below the normal as possible. One of the most efficient intercoolers constructed is illustrated by Fig. 50, in which the heated gas, direct from the compressor, passes into an upper opening, and down between a large number of small tinned copper tubes, held vertically in a large cylindrical flue. The gas finally emerges into the shell portion of the intercooler and is free to travel through the top to the outlet tube. The small copper tubes terminate at either end in plates, into which they are expanded. The cooling water enters through the lower pipe and is forced upward through the cooler tubes, and finally emerges at the water outlet at the top. The water tubes are set so close together that they divide the incoming stream of gas into thin sheets and bring it into very intimate contact with the cooling surface. Gas and water pass through the intercooler in opposite directions.

The submerged intercooler, which consists of a simple pipe-coil under water, is not effective because the gas passes through the pipe too rapidly and on its passage is not brought into the intimate contact with the cooling surface which is necessary for a rapid cooling.

A double-pipe intercooler consisting of 1-inch and 2-inch pipe, the smaller inside pipe containing the water, the gas passing through the annular space between the pipes, both gas and water passing through in counter-current fashion, has given excellent results. It has the further practical advantage that it can be placed at any convenient point in the engine room, away from the compressor, leaving the latter free of access and entirely without obstructions. A receiver should be attached to this style of intercooler to increase the volumetric capacity of the latter.

MODERN MULTI-STAGE COMPRESSORS.

The Norwalk Iron Works (South Norwalk, Conn.) three-stage compressor is frequently employed for liquefying the gas, as it is self-contained and its steam cylinder is on the same bed-plate and in line with the compression cylinders. The steam cylinder is provided with an adjustable cut-off which may be regulated by hand while the machine is in motion. In the gas cylinders a liberal area is given to suction and discharge ports, thus insuring a full supply and easy discharge of the gas even at a high speed of the machine.

The CO_2 is taken from the gasometer and is admitted to the double-acting cylinder in the center of the machine (Fig. 51 *a* and *b*).

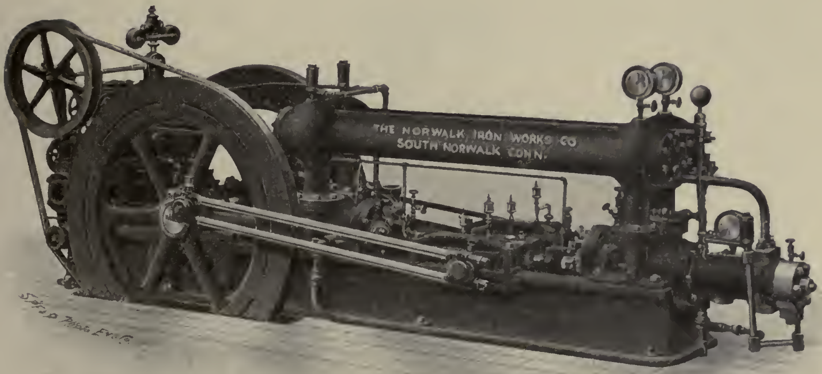

FIG. 51*a*.—STEAM DRIVEN TYPE NORWALK THREE-STAGE CARBONIC ACID GAS COMPRESSOR.

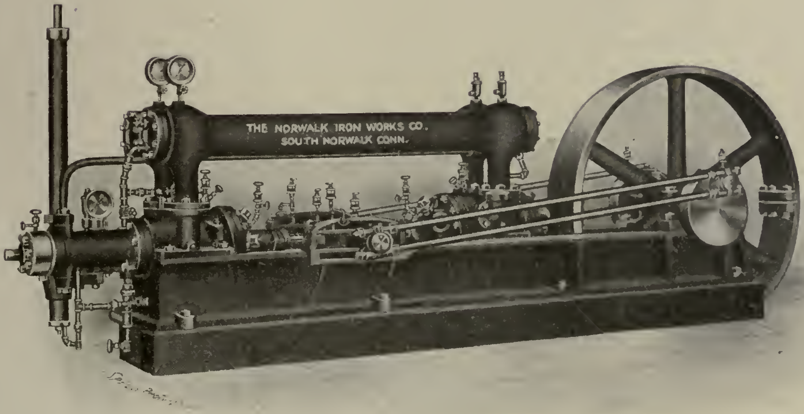

FIG. 51*b*.—BELT DRIVEN TYPE NORWALK THREE-STAGE CARBONIC ACID GAS COMPRESSOR.

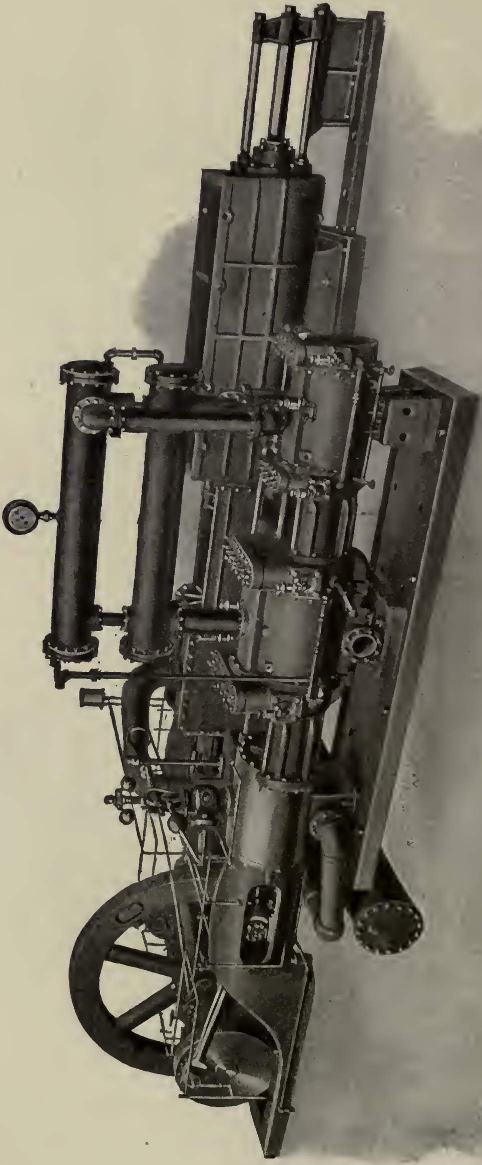

FIG. 52.—FOUR-STAGE COMPRESSOR, CLAYTON AIR COMPRESSOR WORKS, NEW YORK.

Here the first stage of the compression is performed, the gas leaving the cylinder at a pressure of 20 to 25 pounds gauge. The water jacket by which this cylinder is surrounded takes away a share of the heat of compression, after which the first intercooler extracts the remainder, bringing the gas to the second cylinder at or near the temperature of the cooling water. The second cylinder compresses the gas to about 150 pounds gauge pressure, which again raises the temperature of the gas. It is then taken through the second intercooler into the third cylinder in which the compression is completed. The pistons of the second and third cylinders are in direct line with the piston of the first cylinder and the steam piston. All the strain of compression is therefore direct push and pull on a straight steel rod.

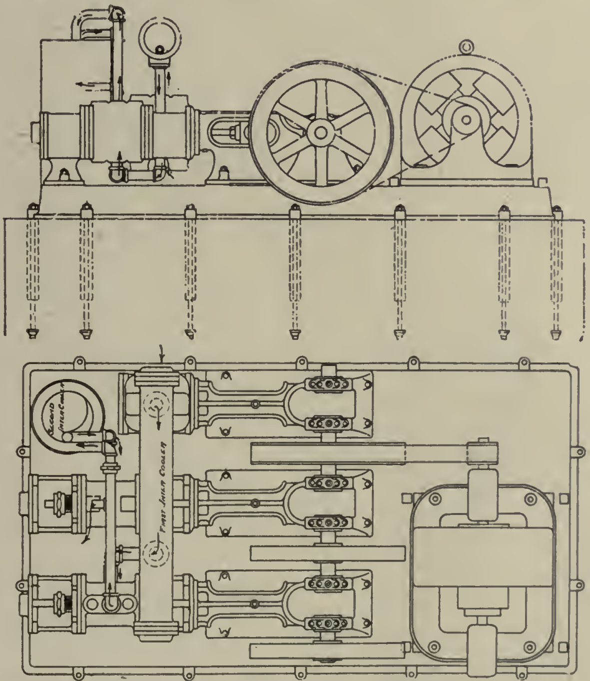

FIG. 53.—ELEVATION AND PLAN OF THREE-STAGE COMPRESSOR, CLAYTON AIR COMPRESSOR WORKS, NEW YORK.

A new four-stage compressor employed for liquefying carbonic acid, possessing some special meritorious features, has recently been introduced by the Clayton Air Compressor Works of New York (Fig. 52). The general construction of this machine is of the duplex

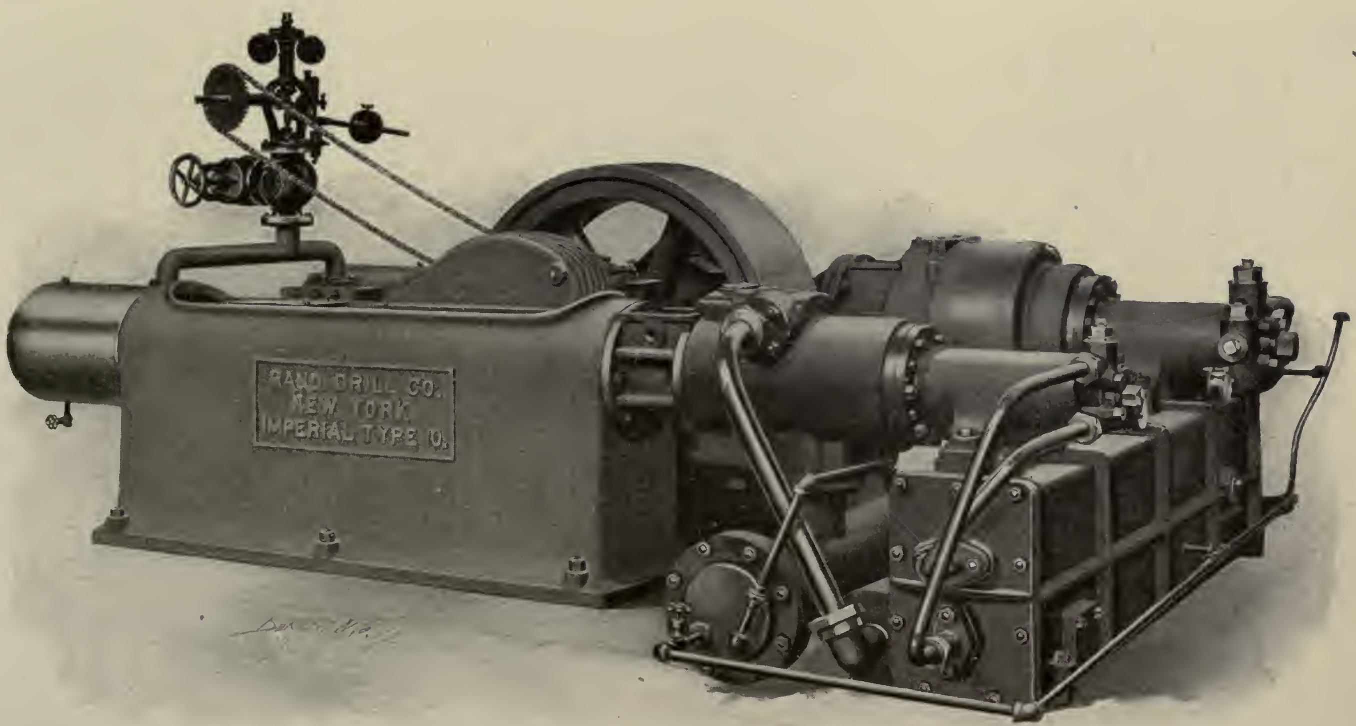

FIG. 54.—FOUR-STAGE "IMPERIAL" COMPRESSOR, INGERSOLL-RAND COMPANY, NEW YORK.

type. It is cross-compounded, with the high and low pressure steam cylinders parallel to each other. The low-pressure and first intermediate air cylinders are of the double-acting type, arranged tandem to the high pressure steam cylinder and fitted with special poppet suction and discharge valves. The first and second intercoolers are arranged above these cylinders. The second intermediate and high pressure cylinders are of the single-acting type and are arranged end-to-end tandem to the low-pressure steam cylinder. The cylinder heads and valves are all of very simple construction and no water jackets are formed in the cylinder castings proper, the construction being such that these castings are submerged in an open-top water-box, which forms, at the same time, the frame for the two cylinders, and in which water-box the third intercooler is also located. This intercooler consists of a copper coil surrounding the cylinders and is submerged in the water. Instead of the usual piston construction, outside end-packed plungers are used in these two cylinders. The result of these various points of construction is that no leakage can occur without being observed and readily corrected.

The Clayton three-stage power driven gas compressor is especially designed for high pressure work and its use is particularly recommended in cases where the compressor load is fairly constant. It is also preferred when the surrounding conditions require economy in the use of the available steam power and when a steady supply of electricity generated by highly efficient machinery is at hand. The compressor frames are grouped in the triplex form and one shaft provided with three cranks extends through the main journals of each compressor. There are two journals for every compressor and the respective crank is rigidly placed between these journals. The low pressure cylinder is placed upon the right-hand frame; it discharges the gas at a pressure of 80 pounds into the intermediate cylinder located on the left-hand frame. There the gas is compressed to 300 pounds' pressure and discharged into the center and high pressure cylinder in which the liquefying pressure is obtained. A large intercooler extends across the frames and three fly-wheels admit of high rotative speed.

The third representative type of a four-stage compressor is built by the Ingersoll-Rand Company. It is designated the "Imperial" compressor (Fig. 54), and is constructed for working pressures up to 1,500 pounds.

The compression of 100 cubic feet of free carbonic acid gas per minute and the work developed in horse-power is given in the accompanying table. The figures given very nearly represent the actual work of compression in first-class compressors, allowing for cylinder cooling, intercooling, and friction. The table shows that the saving in power for 1,000 pounds pressure of a four-stage compression over a two-stage is 18.8 per cent:

POWER REQUIRED FOR COMPRESSING 100 CU. FT. OF CO_2 PER MINUTE.

Gauge pressure in pounds	Two-stage compression developed H. P.	Four-stage compression developed H. P.
60	11.70	10.80
100	15.40	14.20
200	21.20	18 75
300	24.50	21.80
400	27.70	24.00
500	29 75	25.90
600	31.70	27.50
800	34.90	30.00
1000	37.80	31.80
1200	39.70	33.30
1400	41.40	34.50
1600	43.00	35.65
2000	45.50	37 80

THE CONDENSERS.

The final pressure required for the liquefaction of the CO_2 depends entirely upon the temperature of the available water used in the after-cooler, or, in this case, more properly termed the condenser. This cooler is needed to remove the heat of compression of the last stage of compression as well as the latent heat of the gas before it can be changed from the gaseous into the liquid state. The latent heat of compressed carbonic acid is about sixty B. T. U. with the temperature of the available cooling water between 65° and 68° F. The ordinary working pressure at which the steel cylinders are charged is considerably higher, usually between 1,000 and 1,400 pounds gauge pressure, according to the temperature of the water used for condensation. At the temperature stated it requires a pressure above sixty atmospheres before liquefaction takes place. In the following table, prepared by Professor Schroeter and modified by Mollier is given the relation of pressure, temperature and volume in United States measures:

PROPERTIES OF SATURATED CARBONIC ACID VAPOR.

Pressure in lbs. per sq. in. (gauge)	Pressure in atmospheres	Temperature in Deg. F.	Specific volume of liquid in cu. ft. per lb.	Specific volume of saturated vapor in cu. ft. per lb.	Latent heat in B. T. U. per lb.
284	19.3	—5	.0194	.3182	119 86
355	24.1	+9	.0204	.2497	113.26
427	29.0	20.7	.0213	.2028	106 94
498	33.9	31.2	.0226	.1698	100.44
569	38.7	40.5	.0249	.1435	93.76
640	44.2	49 0	.0307	.1232	86.90
711	48.4	56 7	.0161	.1059	79.65
782	53 2	63 8	.0165	.0919	71.73
853	58 0	70.3	.0170	.0795	63.22
924	63.0	76.7	.0176	.0676	52.87
995	67.7	82.6	.0181	.0563	39.29
1066	72.5	88.2	.0188	.0385	10.51

Condensers of various forms are used to liquefy the CO_2. The oldest type is the so-called submerged condenser, which consists of a set of coils properly connected by means of manifolds and submerged in a cylindrical tank filled with water. A submerged condenser of special construction is illustrated in Fig 55. This condenser consists of a tank in which the spiral condenser coils are submerged. A cylinder made of sheet steel is set into the tank as shown. The spiral coils are connected at the bottom by means of a manifold and the outlet from this manifold is connected to a single spiral coil containing the liquefied carbonic acid.

The hot compressed gas from the high pressure cylinder passes through the inlet manifold into the three spiral coils; when the gas has reached the bottom manifold, it has given off its latent heat as well as the heat of compression to the water surrounding it. It has also changed into the liquid form and enters the spiral coil located within the center cylinder as such. The coldest water cools the liquid coil first, passes around the lower opening of the cylinder into the condenser tank proper and runs upward toward the overflow. The result is that both gas and water pass the condenser in counter currents.

In the atmospheric condenser, shown in Fig. 56, the cooling action of the water trickling over the coils is utilized as well as that of the atmospheric currents, to remove the heat from the compressed gas. The liquid enters a large receiver to be drawn off into steel cylinders.

A very efficient condenser which is now extensively used is the double pipe condenser illustrated in Fig. 57. This condenser consists of a 1-inch seamless steel tube within a 2-inch extra heavy wrought iron pipe. The water passes through the 1-inch tube, while the gas is discharged into the annular space between the two pipes. The 2-inch outer pipe is flanged to semi-steel return heads, establishing gas communication, while cast-iron return bends connect the 1-inch tubes thereby forming a continuous passage for the water.

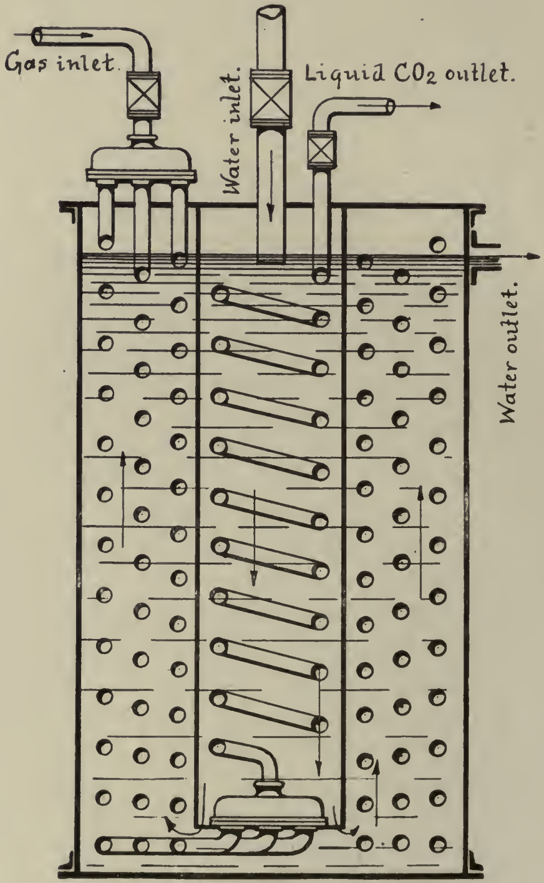

FIG. 55.—SPECIAL TYPE SUBMERGED CONDENSER.

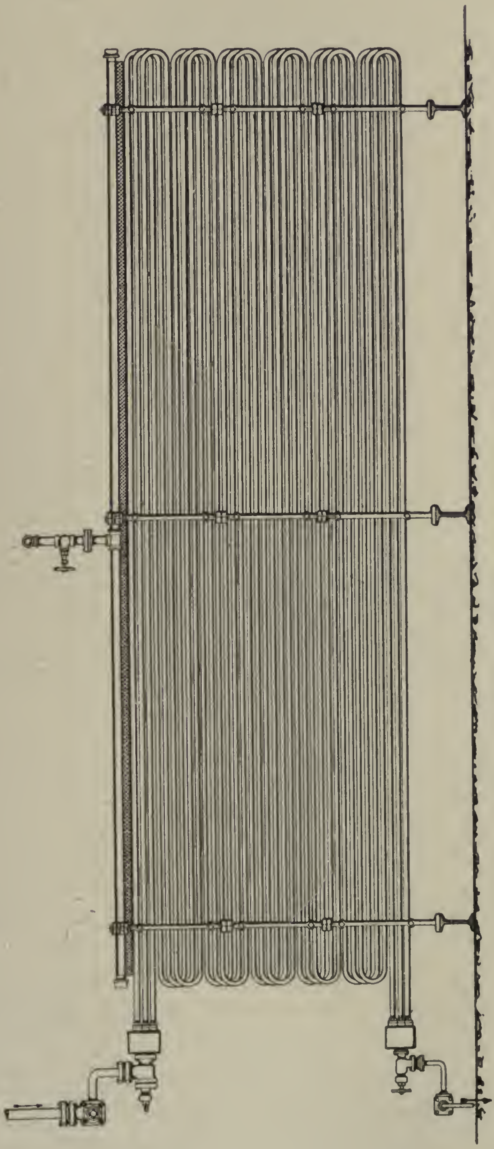

FIG. 56.—ATMOSPHERIC CONDENSER.

The requirements of cooling surface for every 100 pounds of liquid carbonic acid produced per hour, when temperature of cooling water is 65° F., are, for the submerged condenser, 120 lineal feet of 1-inch extra heavy pipe; for the atmospheric condenser, 100 feet of 1-inch pipe, and for the double pipe condenser, 25 feet of 1-inch and 2-inch pipe.

Before the gas enters the condenser it is necessary to remove the lubricating material, which latter would otherwise finally be charged into the CO_2 cylinder, forming an impurity to which every user of CO_2 would strenuously object. A trap constructed as shown in Fig. 58 is used to retain the lubricating material. The trap is filled with pebbles, the uneven surface of which retains the glycerine, and it must be built sufficiently strong to withstand the high compression pressure.

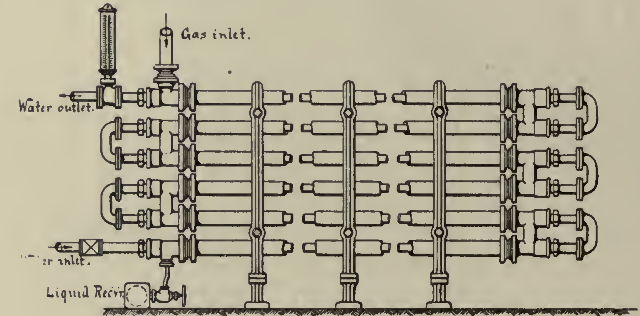

FIG. 57.—DOUBLE-PIPE CONDENSER.

METHOD USED FOR FILLING CYLINDERS.

The liquid carbonic acid is distributed to the trade by means of steel cylinders which are charged with a definite weight of liquid. For filling or charging these cylinders a filling stand is used which is connected with the liquid receiver of the condenser. It has also two or more connections which establish communication between the liquid carbonic pipe line and the cylinders. To prevent an overcharge the cylinders are placed upon a scale. The charging valve is then opened and the liquid carbonic acid is allowed to pass into the cylinder until the required weight is obtained. Fig. 59 illustrates this equipment. The liquefied carbonic acid is conducted through the pipe line into the manifold which constitutes body, *k*, of the filling apparatus. Valves, v and v_1, control connections with the drums to be charged. A gauge, m, indicates the pressure and the filling process must be regulated in accordance with the pressure in

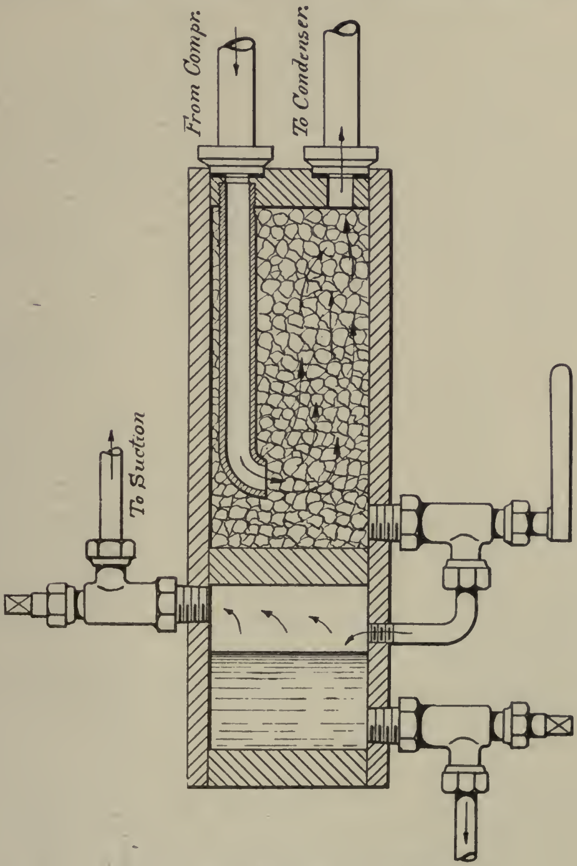

FIG. 58.—TRAP FOR LUBRICATING MATERIAL.

the condenser, which should be maintained as close to the required condenser pressure as possible.

The cylinders, f and f_1, are placed on scales, which, for the sake of convenience in handling the tubes, are set into the floor so that the floor line is flush with the scale platform. The scale is then so adjusted that it will tip as soon as the tare weight of the drum plus the weight of the liquid to be filled into it is reached. When the scale registers the desired weight the valves are closed, the filled

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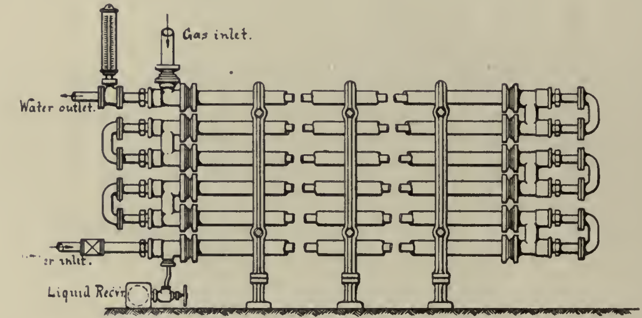

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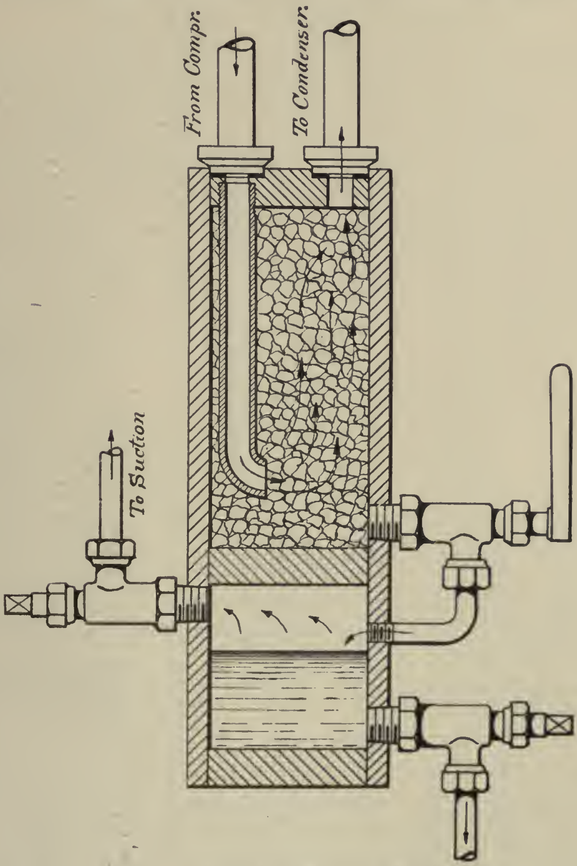

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DESCRIPTION OF CYCLE OF OPERATION.

Diagram Fig. 60 illustrates the connections between the various parts of the apparatus which have been described in the foregoing chapters. The source of gas production may be either the fire box of a boiler, a kiln or any other gas and heat-creating medium. The heat of the gaseous products containing the raw CO_2 is utilized for heating lye (used as the means of absorption) in a special economizer.

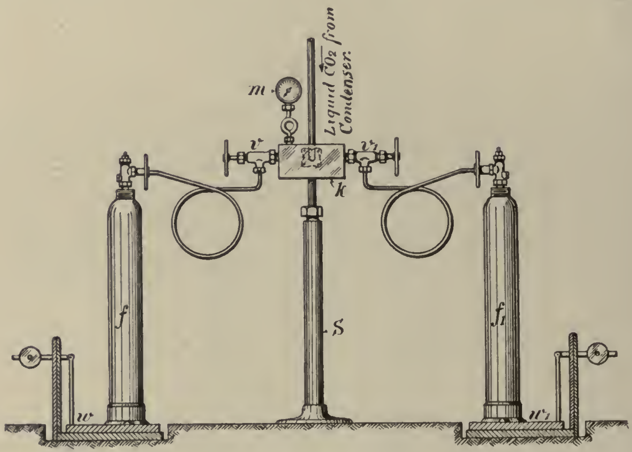

FIG. 59.—APPARATUS FOR FILLING CYLINDERS.

After most of its heat has been spent, it passes through several scrubbers, where it is fully cooled and where the dust, acid, odors and other undesirable ingredients are removed. A suction blower draws the gas and a force blower passes it through the absorption tower under pressure, if desirable. The CO_2 is absorbed either by a sodium or potassium solution and the nitrogen, as well as the unconsumed oxygen of the air is expelled into the atmosphere through the top of the tower.

A pump forces the saturated lye into the economizer. On its way it passes through a double-pipe heat exchanger, where it picks up considerable heat from the weak lye returning from the lye boiler. In the economizer more heat is absorbed from the hot products of

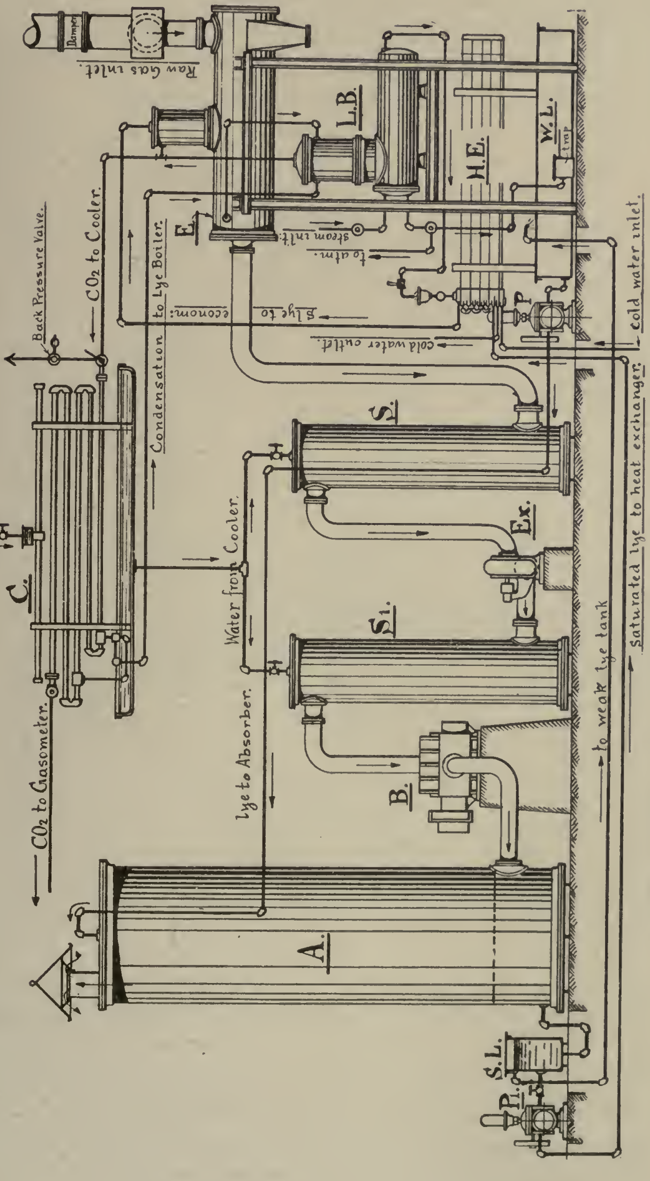

FIG. 60.—DIAGRAM SHOWING APPARATUS FOR ABSORPTION AND LIBERATION OF CO_2.

A., Absorber.
B., Blower.
C., Cooler.
E., Economizer.
Ex., Exhauster.
H. E., Heat exchanger.
L. B., Lye boiler.
P., Weak lye pump.
P_1., Saturated-lye pump.
S. L., Strong-lye tank.
S. and *S_1.*, Scrubber.
W. L., Weak-lye tank.

combustion which pass through it and the lye enters the lye boiler in a highly heated condition.

In the lye boiler the remainder of the heat required to liberate the carbonic gas from the lye is applied either through exhaust steam from the engine or live steam from the steam boiler. The liberated gas rises through the dome of the lye boiler into a cooler, where its

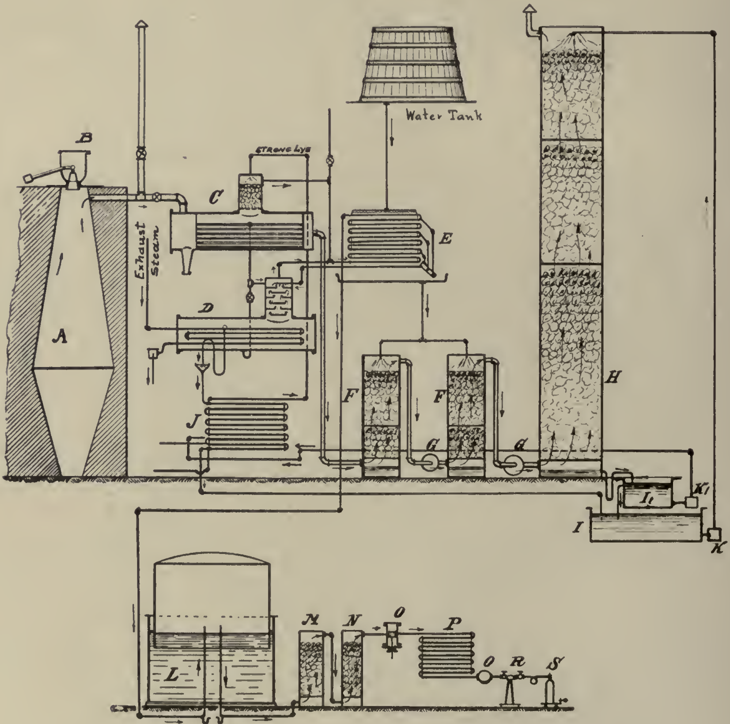

FIG. 61.—DIAGRAM OF NATURAL LIMEKILN AND CONNECTIONS.

temperature is reduced by the use of cooling water. The steam which left the lye boiler with the CO_2 is here condensed and the condensation flows back into the boiler, while the carbonic gas is conducted into the gasometer. The suction connection to the compressor also leads into the gasometer, the gas being passed through a drier before it enters the low-pressure cylinder of the compressor, where it is compressed and liquefied as described.

If a natural limekiln is used, the connections are made as shown in diagram, Fig. 61. The kiln is provided with a special hopper, *B,* through which limestone and coke, mixed in proper proportions, are fed. The gases from the kiln enter economizer *C,* passing through it, most of the heat being absorbed by the lye within. Dust, ashes and other solid impurities carried over from the kiln are withdrawn through dust trap, *c.* The gases pass to scrubbers, *F,* and after having been thoroughly cleansed, they are forced into the absorption tower, *H,* by blowers, *G.* In *H* the carbon dioxide is absorbed by a potash lye, while the indifferent gases pass out into the atmosphere at *h.*

The lye is prepared in weak lye tank, *I.* Pump, *K,* forces it up to the absorption tower, entering the latter through a sprayer and percolates downward through the mass of coke with which the tower is filled. On its way it absorbs the carbon dioxide from the kiln gases and runs out at the bottom through a trap into saturated lye tank I_1. K_1 forces it through a heat exchanger, *J,* into economizer, *C.* From the latter it runs through an overflow pipe into lye boiler, *D.* Here its temperature is raised to about 216° F, it liberates the pure CO_2 and is re-converted into a mono-carbonate, passing out of the boiler through a trap into funnel *j* of the heat exchanger, in which most of its heat is absorbed by the saturated lye which is on its way to the economizer. Finally its temperature is reduced to about 100° F. by cooling water and it returns to weak lye tank *I* to start the cycle over again. The pure carbonic acid gas passes into gasometer *L,* where it remains until drawn into compressor *O.* In the suction line a deodorizer, *M,* and dryer, *N,* is interposed. The dryer is filled with chloride of calcium, which absorbs any moisture which may be carried in suspension by the gas. The deodorizer is not needed in most cases, but if required, it is filled with a strongly oxidizing solution which destroys undesirable odors.

After compression in *O* it enters condenser *P* at high pressure, collects in the liquid form in receiver *Q,* from which it is filled into cylinder *S* by means of filling stand *R.*

Fig. 62 is a diagram illustrating the coke system of manufacturing CO_2 as it is installed and is now in operation in the plant of the Crescent City Carbonate Company, New Orleans, La. In this drawing the course of the flue gases from the smoke stack through the economizer and the scrubbers into the absorption tower is clearly apparent. The saturated lye leaves the bottom of the absorption tower, enters the saturated lye tank and overflows into the weak lye tank.

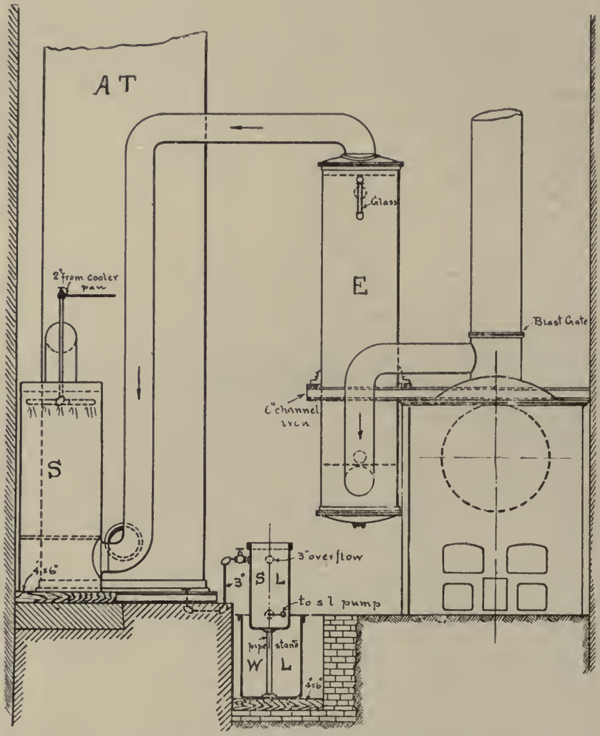

FIG. 62.—DIAGRAM COKE SYSTEM PLANT, CRESCENT CITY CARBONATE CO., NEW ORLEANS, LA.

Fig. 63 shows the manner in which the lye circulates through the heating and cooling apparatus.

CYLINDERS AND VALVES.

The steel cylinder in which the carbonic acid gas is shipped in its most condensed form, *i. e.*, in a liquid, must necessarily be made strong, owing to the high internal pressure it is subjected to. Yet they must be light in weight so as to avoid heavy shipping expenses as much as possible.

The invention of the Mannesmann process made possible the production of tubes of a light weight, at the same time possessing great strength. The pressure at which these cylinders are charged with liquid carbonic acid varies between 1,000 and 1,400 pounds, and as they are tested with a hydraulic pressure of 3,700 pounds, there is a factor of safety of about 3 to 1.

The question is frequently asked as to the liability of these tubes to burst. Ordinarily this liability does not exist. Burstings or ruptures may occur, however, in a case where a cylinder filled with liquid carbonic acid is subjected to heat. Even in that case, there is very slight danger, as the bursting takes place in the form of a rupture, no pieces of metal being detached.

The recent improvements made in the methods of manufacturing steel structural material and seamless tubes has made it possible to handle great pressures with practically absolute safety.

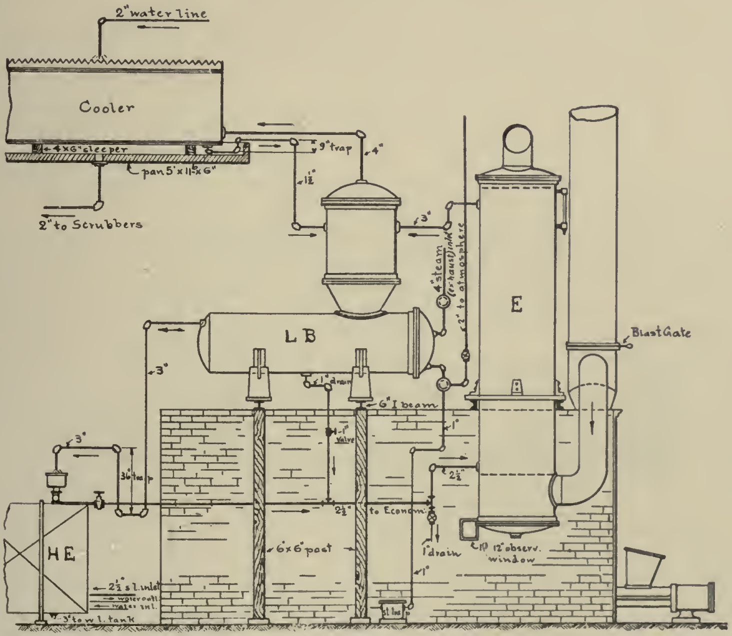

FIG. 63.—DIAGRAM SHOWING DETAILS OF CRESCENT CITY CARBONATE COMPANY'S PLANT, NEW ORLEANS.

As there has been some misapprehension in regard to the strength of these tubes, the following test will be of interest. It was made by the Watson-Stillman Co., of New York, about the year 1895, before many witnesses: A Mannesmann steel tube 8 inches in diameter by 5 feet long and ¼ inch thick, which had been in use for high pressure air motors for about two years, carrying air pressure at 2,000 pounds per square inch, was used for the experiment.

The tube (Fig. 64) was first submitted to a hydraulic pressure of 2,150 pounds, when it was struck several blows with a fourteen-pound sledge having a 3-foot handle, the sledge being swung from the end of the handle. These blows made no impression whatever. At 4,000 pounds the expansion was found to be three thirty-seconds of an inch. When the pressure was removed, the bottle returned to its original measurement, this pressure being near its limit of elasticity. A second application of pressure was then made up to 5,000 pounds per square inch, at which the tube began to stretch, and between 5,000 and 6,000 pounds the tube increased one-eighth of an inch in circumference. At 6,100 pounds the cylinder began to stretch over a small area at a point near its center, and continued to do so until it was ruptured, at about 6,150 pounds pressure.

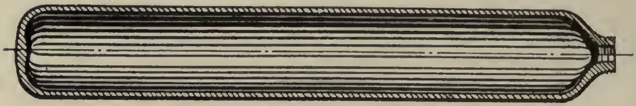

FIG. 64.—MANNESMANN STEEL TUBE.

The character of the rupture was a mere split in the steel, 18 inches long. No pieces were detached and the fracture was quite regular in its form, showing high ductility in the material and freedom from any liability to project detached pieces in case of a rupture. As the tube tested had been in use in one of the Hardie motors for a period of two years under a pressure of 2,000 pounds, this indicates that there had been no perceptible deterioration in use, and supported the assertion that the duration of the reservoirs may be considered indefinite, and that no allowance in estimates of cost of operation need be made for their renewals or repairs. Fig. 65 represents the style of cylinders made by the Mannesmann process.

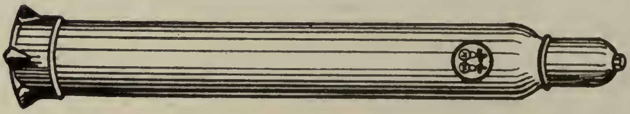

FIG. 65.—TUBE MADE BY MANNESMANN PROCESS.

Other tests have been made of these cylinders, one of which, 9 inches in diameter, expanded fifteen-sixteenths of an inch before fracture, showing extraordinary ductility. In all tests made in Germany upon these tubes no fragments were ever detached and the fracture was always of the same character, a simple longitudinal rent usually near the middle of the tube.

In Germany the cylinders used for liquid carbonic acid must be tested by an authorized inspector to at least double the pressure to which they are subjected at temperatures of 80° F., *i. e.,* about 200 atmospheres or nearly 3,000 pounds. It is customary in this country to test these tubes in the factory in which they are made, before delivery, to a hydraulic pressure of 3,700 pounds, and a certificate of such test is stamped in the metal near the neck of the tube.

Owing to the expansion of the liquid carbonic acid with increasing temperature, which is considerably greater than the expansion of water, these cylinders are to be filled with liquid carbonic acid, at the ordinary liquefying temperature of 70° F., only three-quarters full, to allow sufficient room for expansion. In Germany it is a rule to charge not more than fifty pounds of liquid carbonic acid into a cylinder having a volume of about sixty-six pounds of water. The specific volume of liquid carbonic acid at 70° F. is 29.37 cubic inches (water, 28 cubic inches); at 88° F. its volume increases to 32.8 cubic inches; above 88° it strives to change into the gaseous form which further increases its volume.

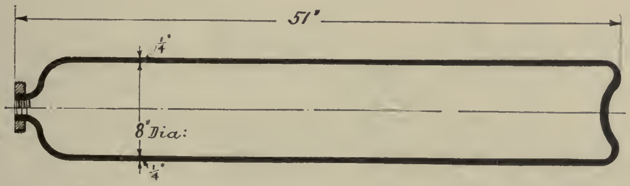

FIG. 66—SEAMLESS DRAWN TUBE MADE BY HARRISBURG PIPE AND PIPE BENDING COMPANY, HARRISBURG, PA.

The volume usually allowed in the United States is 40 cubic inches per pound of liquid. It is of course possible to crowd more than one pound of liquid into this space at low condenser temperature. This is no doubt a risky proceeding and should not be permitted.

Two styles of cylinders are manufactured by the Harrisburg Pipe and Pipe Bending Company, Harrisburg, Pa., one of which is shown in Fig. 66. This is a seamless drawn cylinder made from a solid piece of steel without welding, having a capacity of fifty pounds liquid carbonic acid. Its inside diameter is 8 inches, the walls consist of ¼-inch material and its length over all is 51 inches. It has a volume of about 2,325 cubic inches and can be charged with liquid carbonic acid up to fifty-five pounds. The other is a welded cylinder 5 inches inside diameter, walls being of strong ¼-inch material, same length as the seamless; capacity, twenty-five pounds.

Some of the cylinders made in Germany have a special foot welded to their lower end, so as to make them stand firmly. This foot is round in cylinders used for city delivery; in those used for shipment by rail it is made square, so as to prevent the cylinders from rolling in the car, which may lead to ruptures and other damages.

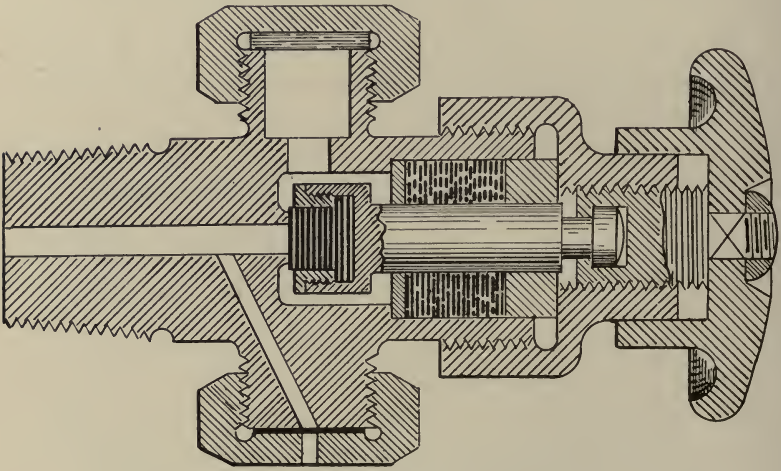

FIG. 67.—VALVE FOR CO_2 CYLINDER.

The tare weight of the cylinders, including valve and protecting cap, averages forty-six, sixty and one hundred pounds for cylinders designed to contain twenty, twenty-five and fifty pounds of liquid carbonic acid.

The caps are required for the protection of the valve. They should be made of forged iron or of soft forgeable cast iron and should be provided with perforations to allow the escape of gas that may leak out of the valve. Their weight varies between five and ten pounds.

The valves are of varied construction. The tapered shank, by means of which it is screwed into the neck of the bottle, is threaded with a ¾-inch pipe thread. The nipple, which establishes connection with the gas line, is closed by means of a cap to prevent escape of gas in the case of a leaky seat. This nipple is threaded with a ½-inch standard pipe thread. The seat is flat and usually consists of hard rubber or of a metal of special composition.

The stuffing box is packed by means of packing rings, which consist of a special Garlock and rubber back packing or of rubber rings, which are not influenced by temperature changes and which do not stick to the metal. A rubber packed valve of special construction is shown in Fig. 67. The stuffing box packing can be so adjusted that it is absolutely tight, hence preventing leakage of gas, even if the seat is defective. Upon opening the valve the rubber packing is compressed mechanically as well as by the pressure of the gas, so that no gas can leak through the stuffing box. Stem and seat can be exchanged easily. A special safety diaphragm is provided, made of copper plate which is proportioned to break at a pressure of 2,000 pounds. The stem is protected by means of a solid hand wheel, and the valve can be closed and opened by hand without effort. Keys are not required with this construction.

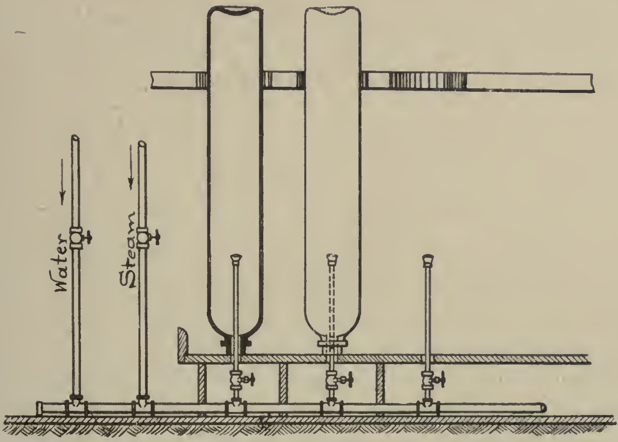

FIG. 68.—STEAM RACK FOR CLEANING CYLINDERS.

When a cylinder is filled and the valve shows signs of a leak, it must be set aside and the defect must be remedied. Should the valve need special repair, the gas may be blown back into the gasometer. The weight of each filled cylinder should be checked by weighing again before shipment. The filled cylinders are placed in the shipping room, where they are kept in an upright position until time for shipment.

Each new cylinder must be carefuly cleaned before it is put into commission. This is done by means of a caustic soda solution, which dissolves any oily substance contained therein. It is then placed over a steam nipple in a rack, as shown in Fig. 68. The steaming process should last about ten to fifteen minutes, after which the cylinder is thoroughly rinsed with sweet water. It is then set aside in the same position until dry.

The cylinders which are constantly in use should also be cleaned from time to time.

CHAPTER VI.

SUERTH SYSTEM FOR PRODUCING CO_2.

A PRODUCER GAS PLANT.

A new system which has created quite a stir among manufacturers of liquid carbonic acid has recently been introduced by the Suerth Machine Works in Suerth, Germany. In this system the exhaust gas, which has served for power purposes in a producer gas engine, is the source from which the carbon dioxide is obtained. The advantages claimed for this process are economy in the cost of production of CO_2 and that it needs neither a steam boiler nor a brick smoke stack. As a further advantage it is claimed as a fact that a concession to operate a factory of this kind is more easily obtained, and that no coal-heated lye boiler is required. The last-named advantage no longer has any weight, however, as no modern plant is now constructed which includes a coal-heated lye boiler. The difficulty of obtaining a concession does not exist in this country and it is not customary in America to build an expensive brick stack for every little steam plant. In its stead a sheet iron smoke stack is used, the cost of which is so small that it does not enter into consideration as a rule. Regarding the increased economy of gas production, it is of so little consequence that it does not offset the disadvantages arising from the absence of a boiler. In addition it has other disadvantages which make it undesirable for large plants and useful only in small plants occasionally.

The gas for the operation of the gas engine is produced by means of a special producer. Gas engines using producer gas made from anthracite coal or coke have been developed by Koerting in Germany, and by Wilson, Duff and Mond in England. The Koerting engines have recently been introduced into this country by the De La Vergne Machine Company, of New York, and many large power engines of the Koerting type have been constructed by this company and are now in operation.

There are three systems of producing gas for power purposes in use, namely, the "Pressure Producer Gas Plants," the "Bituminous Gas Plants" and the "Suction Producer Gas Plant."

This last named is the most economical for power units up to 100 brake horse-power. It uses either anthracite coal or coke, the latter material being preferable in the production of CO_2.

It is called a suction producer plant for the reason that when the gas engine is working it produces a suction effect upon the gas and the air, drawing the mixture into the cylinder. This has been made use of in the suction plant and the principle of the plant is that the gas engine, by drawing air and water vapor through an anthracite or coke fire, makes its own gas as it needs it.

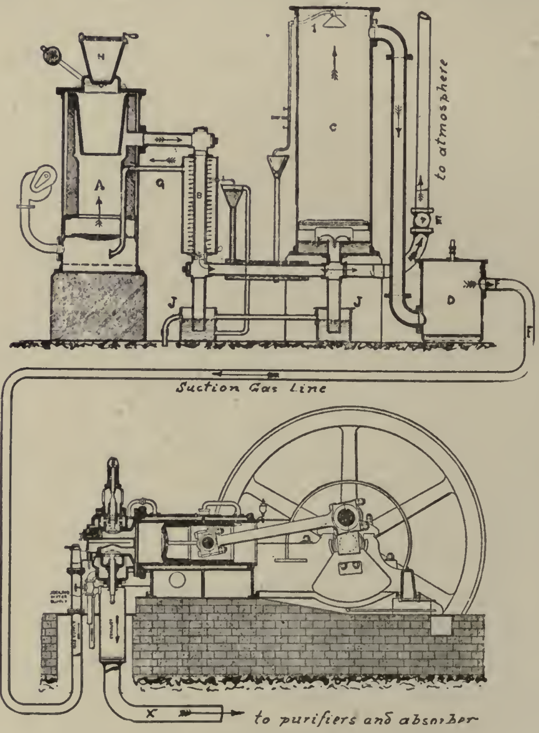

FIG. 69.—SUCTION GAS PRODUCER AND ENGINE.

The different parts of the apparatus consist of a generator, a vaporizer, and one or two scrubbers. A hand fan is provided for starting purposes, but is not otherwise necessary.

Diagram Fig. 69 represents a section through a suction plant. *A* is the generator, which is a cylinder of wrought or cast iron, with a firebrick lining. A small hand fan is used for starting purposes. *B* is the vaporizer, consisting of a grilled pipe passing through a water jacket as shown. Its function is to vaporize the small quantity of water required in the generator. *C* is a coke-scrubber for cleaning the gas, and *D* is a gas-box fixed close to the engine. The fire is lighted in the fire-box under the generator by means of oil waste and ordinary kindling. Coke has previously been introduced into the generator through hopper *H,* the fire-box is then closed, and the valve *E,* leading into the atmosphere, is opened. The fan is then started either by hand or by means of a small electric motor. If a motor is used, it is possible to brighten the fire from time to time.

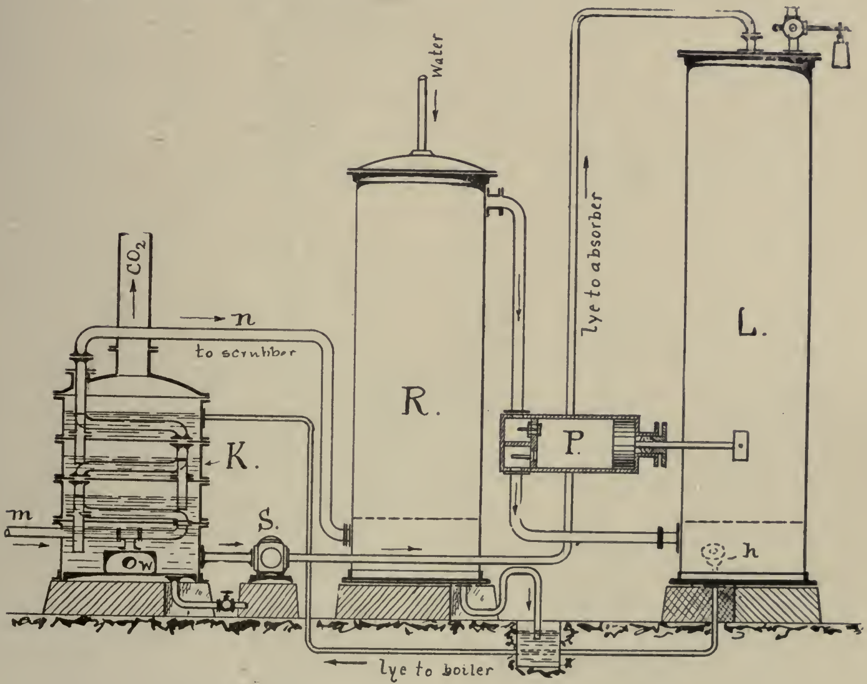

FIG. 70.—PURIFIER, ABSORBER AND BOILER—SUERTH SYSTEM.

While the fire is being blown up, the smoke and hot gases—which resemble those from a blacksmith's forge—pass through the

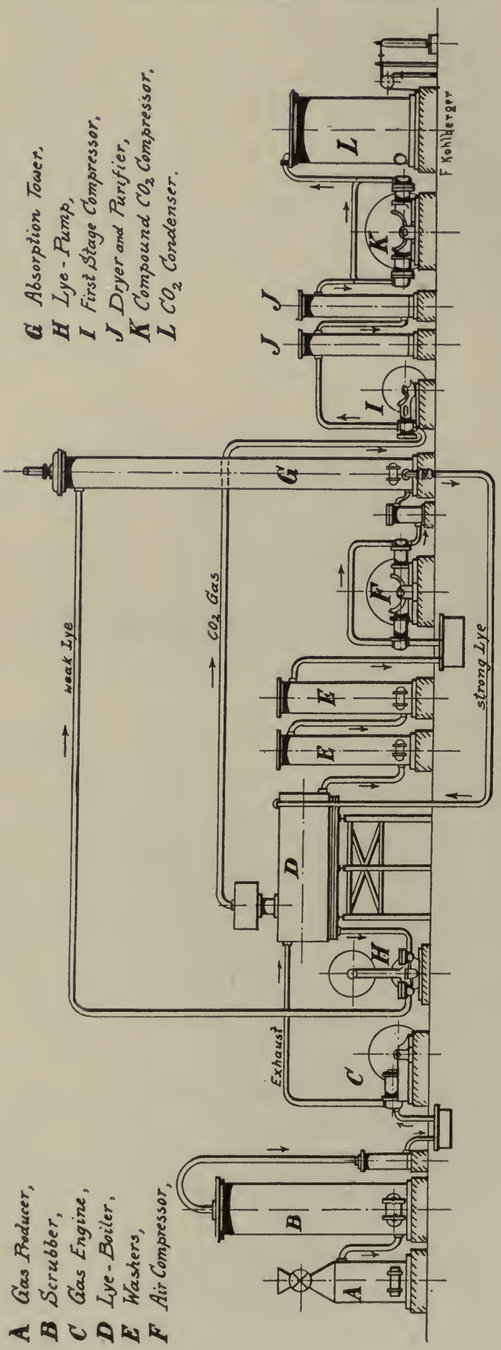

FIG. 70a.—COMPLETE DIAGRAM OF THE SUERTH SYSTEM FOR MANUFACTURING LIQUID CARBONIC ACID.

vaporizer *B* and escape into the atmosphere through valve *E* and its atmospheric connection. The passage of these gases heats the vaporizer and forms water vapor, which is drawn into the bottom of the generator. After about six minutes the gas is tested and as it improves in quality, the valve *E* is gradually closed, and the gas is driven through the scrubber *C,* where it meets a stream of water from the spray-pipe *1*. The purified gas passes out of *C* into the gas-box *D*. As soon as the gas is sufficiently rich, valve *E* is closed entirely and the engine is started. The vessels *JJ* are water seals for collecting the surplus of water from the scrubber.

The oxygen of the air is used to produce carbon monoxide in the generator, and the water-vapor dissociates into hydrogen and carbon monoxide. This gas, after having been purified in the scrubber is ignited in the cylinder of the gas engine and consumed to carbon dioxide and steam. After having performed its work in the engine cylinder it is discharged into the exhaust line *X,* forming a mixture of carbon dioxide, nitrogen, steam and traces of oxygen. As its temperature is very high, it is used for the purpose of heating the lye in a special heater *K* (see Fig. 70), passing through a pipe coil *n,* into scrubber *R* for further purification. This scrubber is constructed upon the same principle as those employed in a coke CO_2 plant and is used for the same purpose, *i. e.,* the removal of solid impurities, elimination of sulphuric acid and the condensation of steam contained in the mixture.

The purified product of combustion is then taken up by a pump *P* and forced into absorber *L* at a pressure of from three to five atmospheres. The absorber is of a similar construction to that usually employed, except that it must be built sufficiently strong to withstand a working pressure up to 100 pounds. The absorbing fluid consists of potash lye of not less than 20 per cent concentration. A pump, *S*, circulates the lye continually between the lye heater *K* and absorber *L* and the saturated lye returns to the heater because of the pressure existing in *L*. A float valve*, h,* controls the return of the lye to *K*.

Should the heat of the exhaust gas passing through the pipe line *m-n* not sufficiently heat the lye to effect the liberation of CO_2, it is possible to burn an extra volume of producer gas in fire-box *w,* adding the products of such consumed gas to the exhaust from the engine at *o*. No heat exchangers nor cooling coils to reduce the temperature of the lye after boiling are used. The temperature of the lye is maintained near the boiling point continually. Ordinarily this temperature of absorption is kept at 110° to 120° F.; with increased pressure, a correspondingly higher temperature of the lye is feasible.

When the lye returns to the lye boiler, it is released from the pressure prevailing in the absorber and the CO_2 contained in the bicarbonate of potassium is readily liberated both through the reduction in pressure and the addition of heat from the exhaust gas.

The unabsorbed nitrogen, as well as the unused air is discharged through a vent valve located at the top of absorber *L*.

It is claimed that about one-half to three-fourths pounds of coke will furnish one pound of liquid carbonic acid. The power required to operate compressor and pumps is furnished by the gas engine.

This system has one striking feature, which is in its novelty. In economy of operation it does not materially surpass a good coke plant, operating with steam and an economical power equipment. It is true that a gas engine using producer gas furnishes power considerably cheaper than a steam engine. On the other hand a steam engine is more reliable in its work, requires less attention and can be handled by any ordinary engineer.

If the power consumed in the average liquid carbonic acid factory reached several hundred horse-power, the difference in the cost of power production would probably justify the change from steam to producer gas.

The absence of steam in a CO_2 gas factory is certainly no advantage, as it is required for purposes other than furnishing power. For instance, cleaning and sterilizing the steel cylinders, for heating, etc.

The steam boiler, which is absent in this plant, is replaced by the producer equipment, which requires just as much attention as the steam boiler.

Absorption of CO_2 under pressure—as used in the Suerth system, although an ordinary absorption equipment can be used as well—has its advantages and its disadvantages. The advantages in this case are absence of heat exchangers and lye coolers, the saving of one pump, and in having less water requirements.

These are fully counter-balanced by the necessity for constructing every apparatus for high pressure, the danger that not all of the undesirable products mixed with the CO_2 are expelled in the absorber, more power required for the lye pump, and an extra compressor for handling the gas between the scrubber *R* and the absorber *L*. The complete diagram is shown on the opposite page.

To sum up, it appears that a new and novel system has been placed upon the market and has been received with interest, which does not, however, possess features which enable it to materially reduce the present cost price of liquid carbonic acid, nor has it advantages of simplicity which would make it preferable in any way over a coke steam plant.

CHAPTER VII.

QUALITY TESTS OF CARBONIC ACID.

TESTING FOR MOISTURE.

Among the most frequent deleterious substances to be found in carbonic acid gas is water. The principal trouble caused by its presence is its liability to freeze in the small block-tin conductors, stopping them up and sometimes bursting them.

Moisture when contained to that extent in the gas can be detected in the following manner: Saturate a sheet of white filtering paper with a concentrated solution of copper sulphate and dry, without burning, in a hot place. After drying, the paper appears of a slightly greenish color.

When testing, blow the gas against the sheet by opening the cylinder valve slightly. If it discolors rapidly, changing into a decided blue, it is ample proof of the presence of too much moisture.

TESTING FOR LUBRICATING MATERIAL.

Sometimes the gas contains small traces of lubricating material, which is an impurity difficult to entirely avoid. Its presence may be suspected when complaints are received of defective frothing power of the carbonic acid, this power being destroyed by oils and fats. To test for this impurity a tall glass cylinder is cleaned with soda and water, then filled with clean water, and the gas allowed to bubble through slowly for some time. A little ether is next poured into the glass, which is then closed and shaken up for a while, and after the ether and water have separated, a strip of writing paper is dipped into the ether without touching the water and withdrawn. As soon as the ether has evaporated a grease mark will show on the paper if any oil or fat is present.

In order to avoid this trouble it is well to interpose in the pipe line a small separator, consisting of a simple expansion receptacle.

The latter will retain the greasy substance by adhesion and should be cleaned from time to time.

TESTING FOR ATMOSPHERIC AIR AND CO.

The presence of air is a great disadvantage, as its presence retards a proper carbonating, prevents an effective binding of the beverage with the gas and escapes with the CO_2 in large bubbles as soon as it is relieved of pressure.

An accurate test that will disclose the presence of air in connection with CO is made in the following manner:

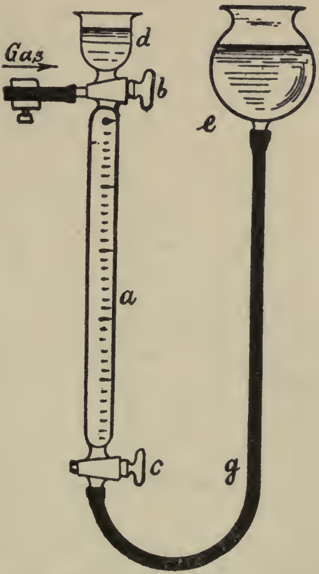

FIG. 71.—SIMPLE BURETTE FOR TESTING.

Fig. 71 illustrates a simple burette required for the purpose. A glass tube, *a,* graduated into 50 or 100 equal parts, is provided with a funnel, *d,* on top and connected to a pear-shaped bulb, *e,* at the bottom. A three-way cock, *b,* allows communication between the funnel and the tube and also between gas inlet *f* and the tube. Cock *c* is of the straight-way type. Before starting the test, *e* must be filled with warm water. Then open cock *c* and expel all atmospheric air from the tube through connection *f* by placing *b* in the proper position. A simple snapper is used to close rubber connection *f* after the tube has been filled with water. Now establish a connection between the gas to be tested and the tube, and allow the gas pressure to force the water out of the tube back into *e*. The contents of the tube do not consist of anything but the gas to be tested. Close communication *f-a* and fill funnel *d* with a concentrated solution of caustic potash lye. Allow this lye to enter the tube through cock *b*. The lye will absorb the CO_2 very rapidly and sufficient lye must be filled into cup *d* to prevent the entrance of air into the vacuum which exists in the tube after the absorption of the CO_2 and before more lye has been admitted. If the CO_2 is pure the space in the tube will be entirely filled with lye. If a gas space remains in the top of the tube that resists the absorption by the lye it is evident that this space is taken up by the percentage of air contained in the CO_2. The amount can be determined by reading, provided the tube is properly graduated, or by comparative measuring.

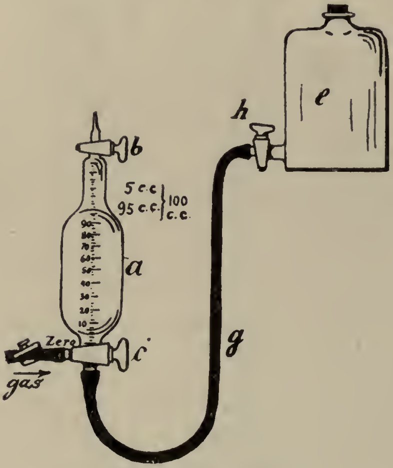

FIG. 72.—TESTING APPARATUS.

The unabsorbed gas must not be combustible. If it burns it is a proof of the presence of carbon monoxide.

The instrument represented in Fig. 71, while giving good results, requires very careful manipulation, and as such tests should be made frequently they must not consume too much time and care. A very handy little apparatus which was recently constructed by a well-known manufacturer of pure CO_2 is illustrated in Fig. 72. Its manipulation requires little time and the results obtained are accurate.

The lower part of the test tube, *a,* is graduated into 95 cubic centimeters, while the narrow upper part contains 5 cubic centimeters, marked in 10 half cubic centimeters. Stop cock *b* is of the ordinary single-way construction, cock *c* has three-ways, connecting with *a*, in one position, with the gas container in the second and with bottle *e* in the third position. Bottle *e* contains a concentrated solution of caustic potash, an ordinary cork stopper closing its mouth, while cock *h* confines the lye in the bottle when out of commission. Rubber tube *g* establishes connection between *e* and *a,* when desired. The operation is as follows:

Remove the cork stopper from the mouth of *e,* open cock *h,* and fill rubber tube *g* with lye, so that the latter's level corresponds with the zero point of the test tube. Then set the three-way cock *c,* open cock *b,* and blow gas from the gas-container through the tube until all the atmospheric air is expelled. Now close *b* and open the communication between *a* and *e.* The lye will then enter the test tube and absorb the CO_2 very rapidly. As receptacle *e* contains a sufficient quantity of lye to fill the test tube, communication *g* may be left open until the process of absorption is completed. An occasional shaking of the tube will hasten absorption.

The balance of the gas resisting absorption will be crowded into the neck of the test tube, where it can be read in half cubic centermeters or half per cents.

TESTING FOR HYDROCARBONS.

Bituminous hydrocarbons are detected by their strong and disagreeable odors; also by means of a potassium permanganate (MnO_4K) lye, to which a few drops of sulphuric acid have been added.

The gas to be tested is discharged through this solution and if a discoloration takes place it establishes the presence of these impurities.

TESTING FOR SULPHURETTED HYDROGEN.

This disagreeable gas can be traced by the use of a piece of filter paper saturated in a lead acetate solution $(C_2H_3O_2)_2P_3 + 3H_2O$. In blowing the gas against the paper the latter must not change its color. If it darkens it is a sign that the gas contains sufficient sulphuretted hydrogen to make it unfit for carbonating purposes.

CHAPTER VIII.

COOLING TOWERS FOR WATER.

THE VARIOUS TYPES.

The necessary apparatus for the handling of water used in carbonic acid factories is considerable. A factory of 250 pounds capacity per hour will consume about forty gallons per minute. About 50 per cent of the water so used is unfit for further employment owing to the impurities which it has absorbed in the scrubbers. The remaining 50 per cent which has been used for cooling only is available for other purposes.

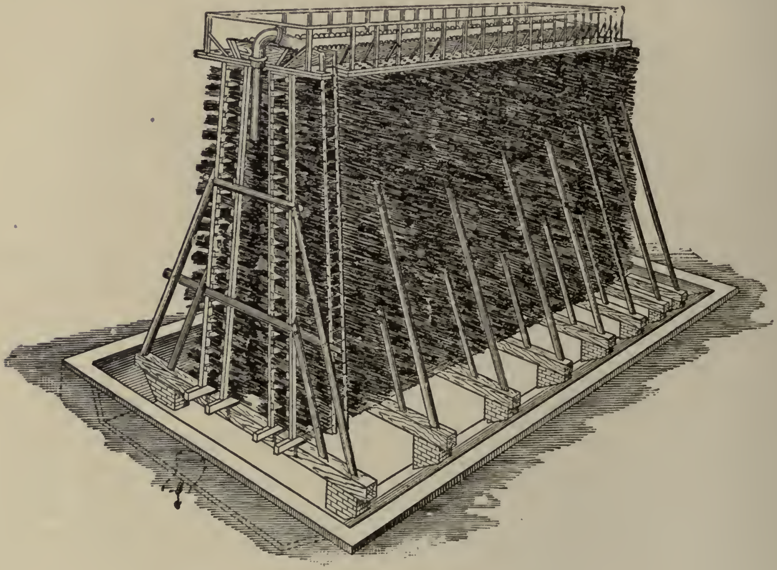

FIG. 73.—SIMPLE FORM OF COOLING TOWER.

Water of low temperature greatly assists in the liquefaction of the CO_2 and if the water supply is of a high temperature it is advisable to install a deep well, which ordinarily furnishes water of between 54° and 58° F. Should the capacity of the well be limited it is possible to save 50 per cent of the total quantity required by the use of a cooling tower. This apparatus is for the purpose of restoring the original temperature of the water which has become heated while passing over coolers and condensers. The cooling tower is also useful in cases where the original temperature of the water is high for the purpose of reducing that temperature as much as possible. In many of the southern cities of the United States, located on rivers, the water of the latter furnishes the needed supply, and is not only of a high temperature in summer but is very often also extremely muddy. In such cases the cooling tower is constructed to serve the

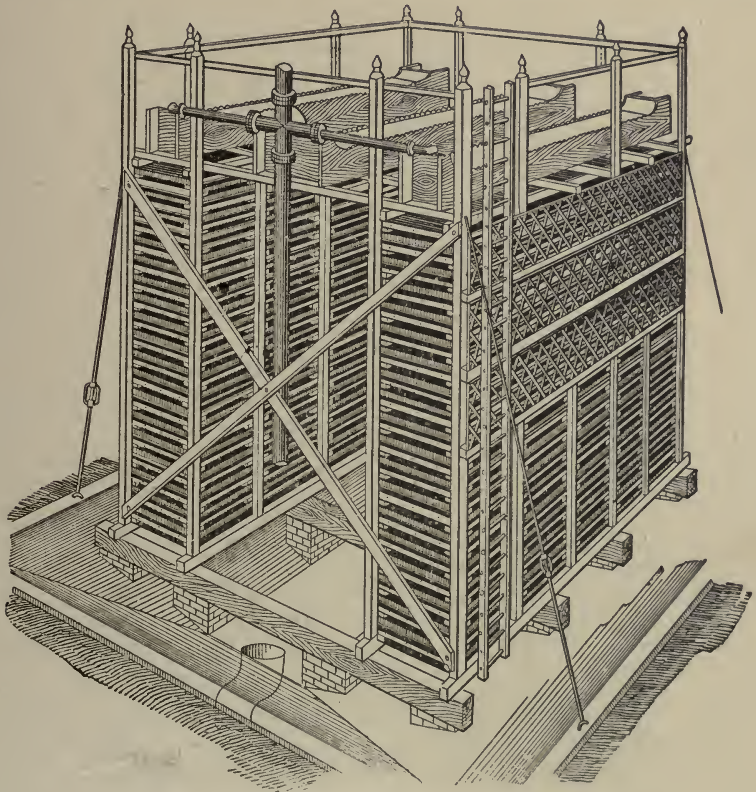

FIG. 74.—COOLING TOWER CONSTRUCTED ENTIRELY OF WOOD.

purpose of reducing the temperature as well as for the removal of at least a part of the mud and other impurities.

The principle of the construction of the cooling tower is based upon the fact that during the evaporation of a part of the water running over it a very considerable amount of heat is absorbed from that which is left.

FIG. 75.—COOLING TOWER MADE OF STEEL AND GALVANIZED IRON.

Effective cooling and a rapid evaporation of a part of the water is accomplished because of the large surfaces over which the water is spread in a fine layer and to which the atmospheric or forced air currents is allowed free access in passing through the tower.

The quantity of water evaporated is indicative of the effectiveness of the cooling work. If as much as 10 per cent of water is evaporated it will be found that the temperature of the remaining 90 per cent has been materially reduced. A dry atmosphere has a greater capacity for absorption than one which is already highly saturated. In the former case the evaporating surface over which the water is spread does not need to be as large as in the latter. The surfaces of a cooling tower using atmospheric air currents—no forced air circulation—should be not less than 12 square feet for every five gallons of water. This surface will be ample to evaporate about two to three pounds of water per hour; in so doing about 2,200 B. T. U. will be removed and the water will be very materially reduced in temperature. With a large evaporating surface and satisfactory exposure to the air currents it is possible to reduce the temperature of the water considerably below that of the surrounding atmosphere.

FIG. 76.—ANOTHER TYPE OF COOLING TOWER CONSTRUCTED ENTIRELY OF WOOD.

The simplest way of providing a large surface is obtained by means of bundles of shrubs placed within and held together by a structure as shown in Fig 73.

Another construction consisting entirely of wood is shown in Fig. 74. It consists of saw-toothed slats which are hung in vertical rows, one below the other, thereby providing a large area.

A tower which is much used is shown in Fig. 75. It is built of steel and galvanized iron throughout and is accessible from all sides. A wire screen surrounds it and prevents splashing and waste of water carried away by air currents. The water to be cooled is pumped to the top of the tower. It runs down by gravity and is collected in a suitable receptacle at the base, from where it is taken to the object to be cooled.

Fig. 76 is an illustration of another type of cooling tower constructed entirely of wood which is in general use in the United States.

CHAPTER IX.

CARBONIC ACID IN THE REFRIGERATING INDUSTRY.

CO_2 AS A REFRIGERANT.

Carbonic acid is extensively used for refrigerating purposes owing to its many favorable characteristics as a refrigerating medium. The majority of the great perishable goods carrying steamers are equipped with CO_2 refrigerating apparatus and its popularity on land for use in the varied industries requiring low temperatures is increasing rapidly.

Mechanical refrigeration consists principally in the work of extracting heat from a refrigerating medium during liquefaction and absorbing heat during evaporation at low temperature. The choice of the medium is governed by its boiling-point at ordinary pressures, the latent heat of vaporization per pound, the number of cubic feet of vapor that must be compressed to produce a certain refrigerating effect, or, in other words, the size of the compressor necessary, the pressure required to produce liquefaction of the gas at certain temperatures, and the specific heat of the liquid.

In order that the above characteristics of a refrigerating medium may be fully understood it is necessary to be familiar with the changes which take place within the same during its practical application, the first of which is that of temperature. The object of refrigeration is the reduction in the temperature of a solid, liquid or gaseous body below that of its surroundings, and the maintenance of such lower temperature against the natural influences tending to restore the original equal condition, or, in other words, the tendency of a colder body to absorb heat from its surroundings until equal temperatures are established.

The words "hot" and "cold" are relative terms, and merely represent the sensation experienced by the nerves when any part of the body is exposed to a temperature varying from that of its own normal condition. Cold is simply the absence of heat—science does not recognize that expression. The temperature of a body that feels cold is raised by absorbing heat, and the temperature of a cold room rises not because cold escapes, but because of the entrance of heat.

THERMOMETERS.

Variations in temperatures are registered by an instrument called a thermometer, which consists of a glass tube sealed at the top, having a bore of constant area to which a bulb containing mercury or spirits of wine is attached. The fine thread of mercury enclosed in the tube lengthens when the bulb is exposed to temperatures of a higher level and contracts when that temperature drops to a lower level.

In order to start with a fixed volume of the enclosed mercury, its bulb is exposed to the temperature of melting ice, the length of the thread of mercury within is then marked on the tube. The next fixed point is obtained by placing the bulb in boiling water. The mercury expands until it has reached its fixed volume at that temperature, which is again indicated as above. Thus two fixed volumes and temperatures, that of ice and of boiling water, have been established. The intervening length is divided into equal spaces called degrees. These points are designated by figures 32 and 212 on the Fahrenheit, 0 and 100 on the Celsius and 0 and 80 on the Reaumur scale.

The Fahrenheit thermometer is commonly used in the United States. Men of science prefer the Celsius scale on account of its conformity to the metric system. It will thus be seen that the graduation of the thermometer scale is rather arbitrarily fixed; it assumes, however, considerable significance as soon as the action of certain gases, for instance, atmospheric air, is compared with it.

These gases increase and decrease in volume with a corresponding increase and decrease in temperature, and it has been found that there is a fixed relation between temperature and volume to the extent that, for instance, atmospheric air of 32° F. increases and decreases $\frac{1}{492}$ of its volume for each degree of increase or decrease of temperature F. (law of Gay Lussac); hence the volume of air will be reduced to practically nothing at a temperature of 490° below zero Fahrenheit. This is called the absolute zero point of temperature, that is, at this point there is supposed to be an entire absence of heat and motion.

UNIT OF HEAT.

In fixing the standard of heat measurement known as the heat unit, the capacity of water to absorb heat was taken as a basis. The heat unit which is adopted in the United States is known as the British thermal unit and represents the quantity of heat required to raise the temperature of one pound of water one degree, Fahrenheit.

SPECIFIC HEAT.

When two bodies of water of even weight, but of different temperatures are mixed, an average temperature will be established, which will be exactly one-half the difference between the two. If, however, one body of water is replaced by a metallic body of the same weight, the resulting average temperature will not correspond with that obtained in the first experiment. This proves that the capacity of heat absorption differs with different bodies. In adopting water as the basis of measurement, the heat absorbed by various bodies has been found by comparison, and is known as specific heat of a body. It varies slightly with the change of temperature, but these variations are so slight that they are of no importance in the practical work of refrigeration.

LATENT HEAT.

All gases contract in volume with a decrease in temperature, so much so that many gases will condense and change into a liquid as soon as they have acquired a correspondingly low temperature at the pressure of the atmosphere. Water exists in three forms, viz., in the solid known as ice, in the liquid and as a steam or vapor. If a known quantity of ice of a temperature of 20° F. is placed in a vessel to which a flame is applied, its temperature will gradually rise to 32°; at this point the ice begins to dissolve and it melts without a further rise in temperature, although the flame continues to supply considerable heat. Not until all the ice has been converted into water will a further increase in temperature be noticeable. As soon as that is accomplished the temperature rises until it has reached the 212° mark of the Fahrenheit thermometer. At this point the water changes into steam and it will again be seen that no further rise in temperature occurs in spite of the continuous application of heat. When the process is reversed and the steam is cooled, its volume decreases, it enters a saturated condition and finally condenses into water. If the process of removing heat is continued it reaches its freezing point at 32° F., its temperature stops falling until many additional heat units have been removed. When water of 32° F. is converted into ice of 32° it has been necessary to remove 142 heat units from every pound of water; when steam of 212° has been condensed into water of 212°, 966 heat units have been removed to accomplish that change. This heat which is taken up by the water when it passes from the solid into the liquid state, or from liquid to vapor, and vice versa, without causing a sensible change of temperature, is termed the latent heat of fusion, of liquefaction or of vaporization. It is used during the fusion while doing the work of disintegrating the molecular structure, doing internal work.

VAPOR AND GASES.

The changes in the condition in which water exists—ice, liquid and vapor—takes place under atmospheric pressure, because its boiling point is considerably above the temperature of the atmosphere. Steam, or water vapor, is one of the few gases that condense sufficiently at atmospheric temperature to change into a liquid. The majority of the gases require the application of pressure for the purpose of reducing their volume before they can be liquefied. If the pressure applied is sufficiently high, it is only necessary to reduce the temperature in order to produce liquefaction.

Gaseous bodies are generally called vapors when they are near the point of their maximum density, and a distinction is made between saturated vapor, superheated vapor and wet vapor. It is saturated when it is still in contact with some of its liquid, superheated when it does not hold particles of liquid in suspension, and wet or moist when liquid particles are held in suspension. Ordinary gases are those which will not liquefy at atmospheric pressure and temperature, and a permanent gas is an elastic substance that can not be liquefied. According to the best scientific understanding, the existence of a so-called permanent gas is extremely doubtful; it is generally believed that all gases can be liquefied provided a sufficient pressure is applied and the temperature is sufficiently lowered.

Generally speaking, saturation of a gas takes place with a higher pressure when its temperature is higher and with less pressure at a lower temperature. Each gas, having its own peculiar characteristics, requires different treatment as to pressure and temperature during liquefaction. All gases have weight, some—for instance, carbonic acid—being much heavier than air, others, such as hydrogen, being much lighter. Each gas has a point on the temperature scale above which it can not be liquefied, below, it liquefies if enough pressure is applied.

This pressure, temperature and volume of a gas, measured at the freezing point under atmospheric pressure, are frequently referred to as critical data; that is, when a gas is subjected to pressure at temperatures within which it can be liquefied, its volume decreases from that of its gaseous form into an intermediate volume, until, upon continually increasing the pressure, it reaches its volume as a liquid; at this critical point, pressure, volume and temperature converge and the substance passes from the gaseous into the liquid state. The critical data of various gases, together with their boiling and freezing temperatures, are given in the following table:

CRITICAL DATA.

SUBSTANCE	Boiling Point at atmospheric pressure in degrees F.	Freezing Point at atmospheric pressure in degrees F.	Critical Temp. in degrees Fahrenheit	Critical Pressure in atmospheres 1 atmos.=14.7 lbs.	Critical Volume in cu. ft. of 1 lb.
Water.............. H_2O	+212	+ 32	+657	205	0 037
Alcohol........... C_2H_6O	+172	—148	+423	67	0.114
Sulphuric acid....... SO_2	— 14	—105	+313	81	.....
Ammonia........... NH_3	— 27.4	—106.6	+266	115	0.048
Carbonic acid...... CO_2	—110	—110	+ 88	75	0.035
Oxygen........ ......O	—296	—269	—180	52	.....
Atmospheric air.	—312	.....	—220	39	.....
Nitrogen..............N	—317	—353	—231	36	.....
Hydrogen............H	—400	.....	—382	21	0.037

The temperatures given in the column "critical temperatures in degrees Fahrenheit," are those above which no liquefaction will take place at any pressure, and after the significance of that temperature had been fully understood it became possible to liquefy the most refractory gases by pressure when cooled down below their critical temperature. It also explains the great difficulty of liquefying air, its critical temperature being so low that it requires a special intensifying apparatus, as devised by Professor Linde, to cool it sufficiently before it can be liquefied.

HEAT AND WORK.

Heat as it appears ordinarily is regarded as a natural phenomenon. Another form of heat is produced by chemical combinations, and the third is produced as a result of mechanical energy expended during the operations of friction, percussion and pressure.

The relation between heat and work was established in 1842 by Mayer and Joule which led to the recognition of the first law of thermodynamics, viz., that heat and work are mutually convertible at the rate of 778 foot-pounds for every unit of heat. When this law is practically applied to one cubic foot of air inclosed in a cylinder having a movable piston, it will be found that for each degree increase in its temperature there will be an increase of $\frac{1}{493}$ of its volume and the piston will be moved a corresponding distance. The law holds good as far as the conversion of work into heat is concerned; it must be modified, however, when the condition is reversed, as in this case only a certain portion of the heat can be converted into work; the balance remains unconverted as heat of a lower temperature, and can not be transferred without the expenditure of some external energy—second law of thermodynamics.

The steam engine is one of the most economical means of turning heat into work; in doing its work steam of a high temperature expands in the steam cylinder; after performing its work it enters a condenser where the temperature is much lower; the heat carried over into the condenser represents the unconverted balance of the whole. In the refrigerating machine the process is exactly opposite. Gas of a low temperature enters the compressor and mechanical energy is converted into heat, changing the volume as well as the pressure of the gas. When the heat so imparted to the gas is removed, liquefaction takes place during which the latent as well as the specific heat of the gas is absorbed. This liquid can then be made to evaporate by removing the pressure which keeps its volume concentrated, and it immediately boils at a low temperature, turning again into a gas. Before it can boil, however, it must absorb heat, and as the temperature of the substance surrounding it is much higher than its boiling point, it abstracts the heat from its surroundings.

The refrigerating industry requires the service of gases—refrigerating media or agents—that have the capacity of absorbing large quantities of heat at low temperatures, which heat can subsequently be removed from the gas at high temperatures. Water is used to remove the heat from the gas after its volume, pressure and temperature have been changed by work. It follows that the critical temperature of a gas, at which it liquefies, must be higher than that of ordinary water. In addition, it is of importance that the pressure required to liquefy the gas does not exceed practical limits. Among the gases suitable as refrigerating agents carbonic acid, ammonia and sulphurous acid have been found to conform best to the requirements as set forth. The qualities of these three refrigerants which, according to Professors Lorenz and Stetefeld are comparatively equal in practical efficiency, are enumerated in the following table:

QUALITIES OF GASES.

SUBSTANCE	Absolute pressure in lbs. per sq. inch at 0° F.	Heat of vaporization per pound at 0° F. (old data)	Heat of vaporization per pound at 0° F. (Lorenz)	Volume in cubic feet per pound at 0° F. (old data)	Volume in cu. ft. per lb. at 0° F. (Lorenz, Stetefeld)	Specific heat of the liquid (old data)	Specific heat of the liquid (Mollier, Lorenz, Stetefeld)	Heat of vaporization per cu. ft. (old data)	Heat of vaporization per cu. ft. at 14° F. (Stetefeld)	Loss in % due to cooling the liquid (Lorenz, Stetefeld)	Useful heat of vaporiz. per cu. ft. compr. volume (Lorenz, Stetefeld)	Volume in cu. ft. per lb. at 14° F. (Stetefeld)	Loss in % due to clearance, friction and leakage (Stet.)
Carb. acid..CO_2	310	123.2	115	0.27	0.3	1.00	0.79	444.7	483.5	17	400	0.44	19
Sulph. acid..SO_2	10	171.2	161	7.35	7.4	.41	0.277	23.3	32	5	28	5.3	43
Ammonia..NH_3	30	555.5	588	9.10	9.5	1.02	1.153	61.7	83.7	4.5	80	7.0	42

Any one of the substances named in the table has a boiling point which is much below normal temperatures. Carbonic acid, for instance, boils at 110° below zero at atmospheric pressure. Before it can be changed from a gas into a liquid it must be relieved of its latent heat; it follows that if its latent heat is restored to it, it will begin to boil and again become a gas. In boiling, it will absorb heat from any substance that may be near it, and on being compressed, the gas gives up the heat so absorbed to the cooling water and again becomes a liquid. The compression system of refrigeration using the latent heat of vaporization of the substance named, consists of three parts:

1. A compressor which reduces the volume of the gas and increases its temperature by changing work into heat.

2. A condenser, in which the heat imparted to the gas is given up to cooling water, thereby liquefying the gas.

3. An evaporator in which the liquid is made to boil, absorbing heat from the surrounding media and changing into the gaseous condition.

These three parts are illustrated in the diagram Fig. 77. *A* is the compressor in which work is converted into heat, changing temperature, pressure and volume of the gas entering it. *B* is the condenser into which the compressed and heated gas is discharged, cold water being used to remove the heat contained in the gas, carrying it away. The gas, concentrated in volume and robbed of its heat, liquefies. *C* is the evaporator, which in this case consists of iron pipe coils located in an insulated room. The liquid carbonic acid passes from the evaporator through the regulating valve, *R,* which reduces its pressure. It then expands or evaporates and absorbs heat from the surrounding air, reduces the temperature of the latter and returns to the compressor to again start the same cycle of operations. This cycle applies to all the vapor compression machines, with the only difference that volumes, pressures and temperatures vary as shown in the foregoing table.

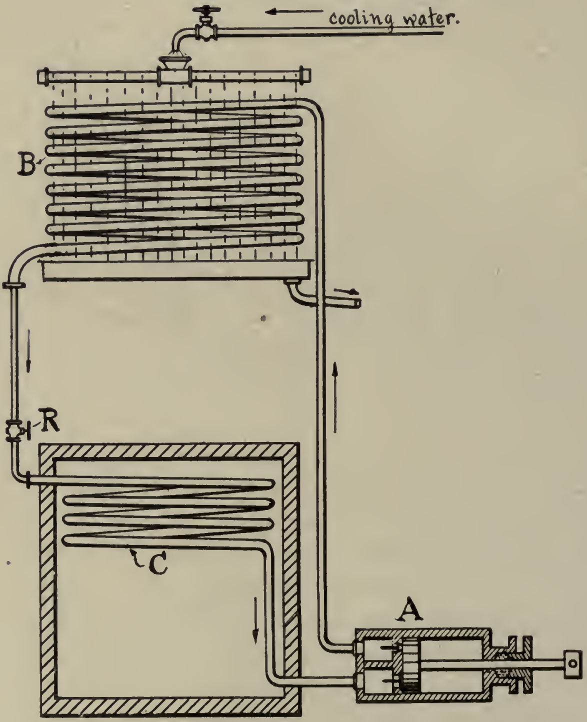

FIG. 77.—DIAGRAM OF CYCLE OF COMPRESSION SYSTEM.

It has been explained that each of these three refrigerants requires power to compress it before liquefaction, so that the question of the amount of power required in the operation of one or the other system needs to be carefully considered. Manufacturers of the various types of compression machines have made the claim that there is considerable disparity among the three systems concerning this point, each claiming that the advantage is with the particular machine and system made in his establishment.

COMPARATIVE EFFICIENCY OF COMPRESSION REFRIGERATING MACHINES

Investigations with plants in operation conducted by eminent authorities during a number of years, have shown that under ordinary conditions the above named refrigerating agents are practically equal in their efficiency, so that a preference of one system over the other on that account is not justified. There are, however, features in each system which may be called advantageous or disadvantageous. For instance, the latent heat of vaporization of ammonia per pound is greater than that of any of the other agents; this is an advantage inasmuch as it reduces the losses that occur in cooling the liquid ammonia to the temperature of the evaporating gas; the liquid ammonia being at or near the temperature of the water used on the condenser, carries this heat with it into the evaporator, where it is absorbed by the evaporating gas constituting a loss which is equal to the specific heat of the liquid refrigerant multiplied by the fall of temperature between that of the condenser and the evaporator. These losses are shown in the table and it will be seen that from this point of view carbonic acid is on the unprofitable side.

The same table shows that there are 400 units of heat available after deducting the heat of the liquid per cubic foot of gas in carbonic acid, as against twenty-eight in sulphurous acid and eighty in ammonia. As compressors are built to handle volumes and not weights, it follows that the advantage is largely in favor of carbonic acid, as it requires a cylinder volume which is only one-sixth of the volume necessary for the ammonia system, while the volume required for the sulphurous acid machine of even capacities is over fifteen times as large.

For a given capacity the CO_2 compressor is the smallest; it has the advantage of a small cylinder bore, small piston and valves, reduced frictional losses and less liability of mishap. The ammonia system is regarded as having the advantage in regard to the heat of evaporation per pound, while the carbonic acid system has the advantage with relation to the heat of vaporization per cubic foot. Sulphurous acid machines requiring large volumes operate with the least pressure, which is claimed as an advantage from the standpoint of the advocate of that system, while the much higher pressure—900 to 950 pounds—necessary in the liquefaction of CO_2 has often been alluded to as a disadvantage.

As a matter of fact pressures are nowadays of very little importance; all engineers agree that with the present excellence of material used and tools employed, all pressures may be readily overcome with a good margin of safety. Besides, it must be remembered that a small cylinder with high internal pressure can be made just as safe as a large cylinder with low internal pressure. All carbonic acid machines are provided with safety valves, which remove the danger of bursting, and even of accidents caused through carelessness on the part of the operator; and it is a fact that with thousands of these machines in operation, no explosion or bursting—aside from the breaking of safety plates—has ever occurred. In view of these facts, the carbonic acid machine is today considered the safest refrigerating machine under all conditions, the feature of the high pressure referred to being of no importance to the user, as he can in nowise be affected by it.

Theoretically, the efficiency of the CO_2 system is about 12 per cent less than that of the NH_3 and SO_2 machines; there are, however, many practical compensating features which enable it to more than make up that loss. Stetefeld has found by tests and corresponding calculations of the indicator diagram that the losses sustained because of radiation in the refrigerator, clearance, the resistance of the gases on their way from the refrigerator to the compressor and when passing the suction valves, and, lastly, piston and valve leakage, average 48 and 49 per cent in the ammonia and sulphurous acid system and not more than 25 per cent when carbonic acid is used as the refrigerating agent.

The piston leakage alone averages about 25 per cent in NH_3 and SO_2 machines and only 9 per cent in CO_2 machines. This leakage is so small in the CO_2 machine because the piston and rod packing consists, with normal cooling water, of leather cups, and these cups fit so tightly to the cylinder and the piston rod that but very little CO_2 leaks by the piston and out through the outer end of the stuffing box. The frictional losses in the suction line are so small because in CO_2 machines the velocity of the gas is less on account of the ample dimensions of pipes and valves—although these dimensions do not nearly reach those required in either of the other two systems—and also on acocunt of the great density of the gas. It will, therefore, be seen that the practical over the theoretical volume must be enlarged 48 and 49 per cent in ammonia and sulphurous acid machines and only 25 per cent in carbonic acid compressors. These figures are based on water temperatures for condensation of 65° F.

The following table explains the comparative value of the three refrigerants in practical operation. In computing this table, Mollier's data regarding the properties of CO_2 and the Lorenz and Stetefeld data of the useful heat of vaporization have been adopted;

COMPARATIVE REFRIGERATING VALUES.

SUBSTANCE	Theoretical compr. vol. required at 14°F. per ton per min. in cu. ft.	Loss due to radiation in the refrigerator (brine system)	Loss due to clearance in %	Loss due to friction in the suction pipe and valves in %	Loss due to leakage of piston and valves in %	Total loss in %	Actual required compr. vol. at 14° F. per ton per min. in cu. ft.	Compressor vol. usually allowed in practice per. ton per min. in cu. ft.	Theoretical efficiency per I. H. P. in B. T. U.	Practical efficiency per I. H. P. in B. T. U.
Carb. Acid....CO	0.49	6	5	4	9	24	0.60	0.61	14,855	13,370
Sulph. Acid. SO	7.04	6	6	14	23	49	10.556	10 6	16,673	13,300
Ammonia ....NH_3	2.4	6	6	11	25	48	3.56	4.00	16,673	13,300

The feature of cooling water, temperature as well as quantity, is of importance in each of the three systems, especially in the carbonic acid machine, owing to the fact that its critical temperature is not much higher than the summer temperature of ordinary river water. When the initial temperature of the condenser water rises above 70° F., it is advisable to use a greater quantity of cooling water, in order to maintain an average condenser temperature of about 75° F.; if this rule is carried out, the maximum efficiency of the machine will be maintained.

With temperatures above 75° F. the efficiency of the CO_2 machine diminishes more rapidly than with the other two systems. The decrease in the efficiency, however, has generally been overestimated, as machines using condenser water of 88° and 90° F. still perform refrigerating work averaging 70 per cent of the work which it is possible to accomplish with condenser water of normal temperature. A number of these machines installed on shipboard have come under the author's close observation and the falling off in the efficiency when leaving water of 72° F. at Cape Hatteras and entering the gulf stream with temperatures of between 86° and 89° F. did not exceed 25 to 30 per cent.

Notwithstanding the fact that the efficiency of the CO_2 machine diminishes when using sea-water of high temperature for condensation, it is estimated that 90 per cent of the refrigerating machines installed on board ship use carbonic acid as the refrigerating agent, which indicates that the consideration of safety is of greater importance than the question of maximum efficiency. This is also borne out by the fact that the only place which the cold-air machine ever had in the refrigerating industry was its use on vessels, simply on account of its safety and in spite of the fact that its refrigerating duty per horse-power is only one-sixth of the refrigerating work per horse-power of any of the three vapor-compression machines.

COMPARATIVE CHARACTERISTICS OF NH_3, SO_2 AND CO_2.

In comparing the characteristics of the three gases it will be found that while ammonia and sulphurous acid have a sharp, penetrating odor, carbonic acid is odorless. The two former are decidedly corrosive in their action upon metals, while the latter's action is entirely neutral. Ammonia dissociates into its constitutent parts at higher temperatures; carbonic acid does not decompose under any condition. Accidents such as burstings and explosions, caused by lack of condenser water, or carelessness on the part of the operator, do occur with ammonia machines; in the case of carbonic acid such liabilities to mishap are practically eliminated. Ammonia as it exists in the refrigerating system, *i. e.*, mixed with lubricating material and other impurities, is combustible, while carbonic acid is a positive fire extinguisher. In the construction of ammonia and sulphurous acid machines only iron and steel can be used, while any suitable metal can be employed in the construction of the carbonic acid apparatus. A fraction of 1 per cent of ammonia in the atmosphere can not be endured for any length of time, while 8 per cent of carbonic acid in the air may be inhaled without danger. Carbonic acid does not have any deleterious effect upon the blood; it deprives the respiratory organs of the necessary oxygen and this constitutes the only danger in inhaling a large amount of it. In the case of a leak, it does not endanger the life of the attendant, nor does it spoil the food products with which it may come in contact; on the other hand, a leak may be detected by its odor when the charge has been made odoriferous by alcohol impregnated with camphor. In case of a leak it is almost always possible to stop it without interrupting the operation of the machinery. Impurities, such as air or water in the system, do not influence it to any extent. Lubricating material and water absorb very little carbonic acid; the system remains clean and maintains its full efficiency. Large interceptors and rectifying apparatus are not required, which adds to its simplicity.

The cheapness of liquid carbonic acid has greatly stimulated the use of CO_2 refrigerating machines. This gas is required in a number of extensive industries, and can be bought anywhere at the low price of a few cents per pound. In the brewing industry the carbonic acid required in the refrigerating apparatus may be obtained from the fermenters; in that case it costs practically nothing to replenish the charge from time to time, especially in an establishment that is equipped with a gas collector and carbonating outfit.

PROPERTIES OF CARBONIC ACID.

Carbonic acid gas is much heavier than air, its specific gravity at atmospheric pressure is 1.529 (air = 1). According to Regnault, Schroeter, Mollier and Luhmann, its boiling point at atmospheric pressure lies at —78.2° C. or 109° below zero F. According to Mitchell it lies at 124° below zero F., but —109° F. is considered correct. It solidifies at about the same temperature, viz., —110° F. The specific heat of carbonic acid gas by weight at constant pressure is 0.2167 (air = 0.2375); at constant volume it is 0.1714; of the liquid it is 0.79 and not 1 as is variously stated. Mitchell found the specific weight of the liquid at 32° F. = 0.93, at 42° F. = 0.8825, at 57.3° F. = 0.853, at 65.3° F. = 0.7385, and at 86° F. = 0.6. This is considered too low. According to Luhmann, it is at 14° F. = 0.9951, at 32° F. = 0.947, and at 68° F. = 0.8266, which in comparison with more recent data seems to be slightly high. The following table giving the densities of liquid carbonic acid at temperatures reaching upward nearly to the critical temperature was recently published by U. Behn:

DENSITIES OF LIQUID CO_2

Temp. in °C.	Temp. in. °F.	Density	Difference per 1°C.
+30	+86	0.598	0.0470
+20	+68	0.772	0.0108
+10	+50	0.860	0.00735
0	+32	0.925	0.00602
—10	+14	0.981	0.00525
—20	— 4	1.031	0.00422
—40	—40	1.116	0.00392
—50	—58	1.154	0.00374
—60	—78	1.191	0.00367

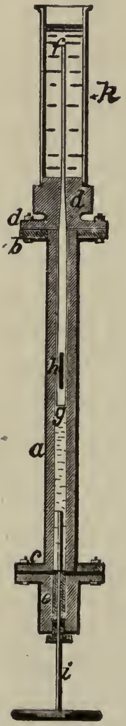

FIG. 78.—DEVICE FOR DEMONSTRATING LIQUEFACTION AND CRITICAL TEMPERATURE OF CO_2.

The latent heat of vaporization per pound at 32° F. is also variously given as 108, 100, 98 and 92 B. T. U. Mollier's figure of 100 B. T. U. per pound of CO_2 at 32° F. has generally been accepted. Andrews established the critical temperature of CO_2 above which no liquefaction occurred under any pressure at 30.92° C. or 88° F. The instrument which he used to demonstrate this fact is illustrated in Fig. 78. It consists of a strong copper tube provided with flanges *b* and *c* on its ends. A special top piece, *d,* contains a glass tube, *f-g*; this tube is sealed at the bottom with mercury, *h,* after it has been filled with the gas. The remaining space in the copper tube is then filled with water and the pressure screw, *i,* operated to compress the gas within the glass tube by means of the mercury seal. The instrument was constructed to sustain a pressure of 400 atmospheres. Funnel *k* contains water of a given temperature, so that by compressing the gas, liquefaction could be observed at any temperature below 88° F., from the fact that upon reduction in pressure, visible boiling set in and a line separating liquid and vapor appeared.

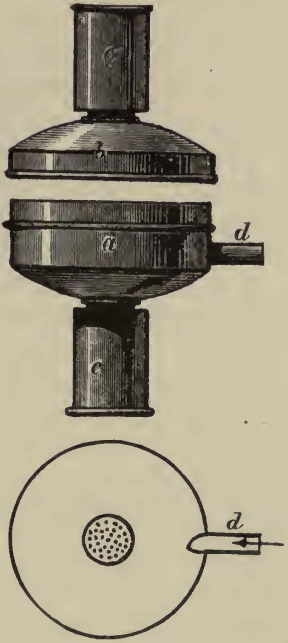

FIG. 79.—CRYSTALLIZING APPARATUS FOR CO_2.

Thilorier and Natterer produced quantities of crystallized carbonic acid through rapid evaporation; if these crystals are compressed, they have the appearance of chalk, evaporate slowly and have a specific weight of 1.2. The instrument used for the purpose consisted of two hollow dished brass cylinders as indicated by *a* and *b* in Fig. 79. The dished heads contained a number of small holes as shown in the plan view; *c* and c_1 are the handles by means of which the crystallized carbonic acid was compressed. The gas evaporated into the apparatus through connection *d,* producing a very intense cold, which crystallized a part of it, while the balance of the vapor escaped through the small holes in the heads. The crystals appeared like snow and could be compressed into the resemblance of a snowball by the two halves of the apparatus. When exposed to the air this crystallized mass evaporated very slowly, as the great quantities of heat necessary for its evaporation could not be absorbed from the air immediately surrounding it.

Schroeter and Mollier, as a result of experiments, have recently published a table giving the exact properties of CO_2. Mollier's values differ slightly from those given by Schroeter; they are believed to be more nearly correct, however, and have been generally accepted. The table is given below, its values having been directly altered into B. T. U.:

PROPERTIES OF SATURATED CO_2 VAPOR.

(Changed to B. T. U. from Mollier's table.)

Pressure in lbs. per sq. in. gauge	Temperature in deg. F.	Specific volume of liquid in cu. ft. per lb.	Specific vol. of saturated vapor in cu. ft. per lb.	Expansion on vaporization	Latent heat per lb. in B. T. U.	Heat equivalent of external work in B. T. U. per lb.	Internal latent heat in B. T. U. per lb.
P		v′	v″	v″—v′=u	r	APu	P
284	— 5	.0161	.3182	.3021	119.86	15.98	103.88
355	+ 9	.0165	.2497	.2332	113.26	15.41	97.85
427	+20.7	.0170	.2028	.1858	106.94	14.76	92.18
498	+31.2	.0176	.1698	.1522	100.44	14.06	86.38
569	40.5	.0181	.1435	.1254	93.76	13.26	80.50
640	49.0	.0188	.1232	.1044	86.90	12.42	74.48
711	56.7	.0194	.1059	.0865	79.65	11.45	68.10
782	63.8	.0204	.0919	.0715	71.73	10.39	61.34
853	70.3	.0213	.0795	.0582	63.22	9 22	54.00
924	76.7	.0226	.0676	.0450	52.87	7.74	45.13
995	82.6	.0249	.0563	.0314	39.29	5.79	33.50
1066	88.2	.0307	.0385	.0078	10.51	1.56	8.95

THEORY OF THE CARBONIC ACID REFRIGERATING MACHINE.

During the various stages of the cycle, the carbonic acid gas enters the compressor in a saturated condition; when compressed, it is partially saturated and partially superheated, or entirely superheated. The latter case takes place when the gases enter the compressor in a dry condition. The period of condensation lies partly within the saturation and partly in the superheated zone, provided the condenser temperature permits pressure below the critical, viz., 75 atmospheres; when higher pressures are required the condensation takes places entirely within the superheated zone. Figs. 80 and 81 illustrate compression below and above the critical pressure. In the latter case the work of the condenser consists in the removal of the heat from the superheated gas and the cooling of the CO_2 to nearly the initial temperature of the condenser water; when pressures below 75 atmospheres are permissible, the work of the condenser consists in the removal of the sensible heat from the gas, the latent heat of liquefaction and the cooling of the liquid to nearly the initial condenser water temperature.

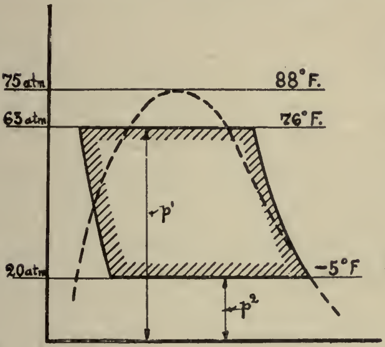

FIG. 80.—COMPRESSION BELOW CRITICAL POINT.

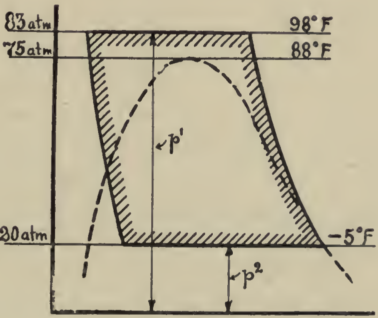

FIG. 81.—COMPRESSION ABOVE CRITICAL POINT.

The sum total of the heat abstracted is, therefore, the heat contained in the gas when it enters the condenser minus the heat still remaining in the liquid after it leaves the condenser. This heat so abstracted is re-absorbed in the refrigerator during the evaporation of the liquid and the sum total of the latent plus the sensible heat is the same on both sides of the expansion valve, minus the small frictional loss occasioned by passing through the latter. The difference in the amount of the heat abstracted in the condenser and the heat absorbed in the evaporator is the equivalent of compressor work.

With carbonic acid machines, it will be found that when working with dry gas they are capable of performing a refrigerating duty which exceeds that of the wet system by about 10 per cent. When manufacturers, nevertheless, adhere to the wet system, it is because of certain practical considerations peculiar to their particular case. The packing of the piston consists of leather cups; this material does not withstand temperatures above 200° F. and in order to keep them pliable, it is necessary to remove the heat of compression by means of wet gases from the evaporator. Metallic packing with its consequent greater piston leakage and dry gas compression, offers no gain in comparison with the wet system and its slight loss of evaporation, which is offset by the advantage of using a piston tightly packed with cupped leathers.

The fact that during compression the gas is in a superheated state, occasioning considerable changes in its entropy with temperatures and pressures above the critical, explains the peculiarity that the refrigerating work of this system does not cease with high condenser temperatures. These superheated temperatures of CO_2 entering the compressor in a dry-saturated condition with adiabatic compression are given in the following table:

TEMPERATURES AND PRESSURES.

(Mollier, changed to B. T. U. by J. C. Goosmann.)

Suction pressure in pounds per sq. in.		284.4= 19.3 atm.	355.5= 24.16 atm.	426.6= 29 atm.	497.7— 33.84 atm.	568.8= 38.7 atm.
Suction temperature in degrees F.		—4.9	+11.8	+21.7	+31.1	+41
Discharge pressure		Superheated temperature in degrees F.				
In pounds per sq. in.	In atmospheres					
426.6	29.	+42.8	+30.2	—	—	—
568.8	38.7	+82.4	+69.8	59	50	—
711.0	48.36	114.8	100.4	89.6	80.6	71.6
853.2	58.0	141.8	127.4	116.6	107.6	98.6
995.4	67.88	167.0	152.6	140.0	131.0	120.2
1137.6	77.54	188.6	174.2	161.6	150.8	140.0
1279.8	87.2	210.2	194.0	181.4	170.6	159.8
1422.0	96.86	228.2	212.0	199.4	188.6	176.0
1564.2	106.52	244.4	226.1	215.6	204.8	192.2
1706.4	116.18	260.6	244.4	231.8	219.2	206.6
1848.6	125.8	276.8	258.8	246.2	233.6	221.0

It is also apparent that partial liquefaction does occur in the expansion valve; the investigations on this point, however, have not yet been closed.

DETAILS OF CONSTRUCTION OF CO_2 REFRIGERATING MACHINES.

Owing to the practical impossibility of obtaining castings that will withstand the high internal pressures without a large percentage of them having to be discarded as defective or porous after they are half finished, English and American manufacturers have adopted soft forged steel for the cylinders. This material requires considerable lathe and drill work for the bore, canals and other openings. When finished, however, it is hardly necessary to subject them to tests. In Germany the cylinders consist of high grade close-grain castings, and complaints regarding inferior, porous or excessively hard castings are rarely met with. The bore of the cylinder of the carbonic acid machine should be about one-fourth of the stroke; for instance, a machine of twenty tons capacity having a bore of 4 inches should have a stroke not shorter than 16 inches. It will also be found that a machine of 5-inch bore by 20-inch stroke will conform very accurately to all the corresponding details of construction. This latter machine will easily develop a capacity of forty tons, which shows the effect of a slight increase in the bore and stroke upon the capacity.

A long piston is of great advantage. The relation of diameter and length of piston is about 1:2.5. The suction canal should be so placed as to allow the gas to cool the whole cylinder effectively before reaching the suction valves. (See Fig. 82.) These valves are usually placed in the horizontal position, but as they are comparatively small and of light weight it does not require a very heavy spring to close them. A long stem guide keeps them centered and of even wear. The discharge valves are of the usual poppet valve design; they are placed vertically and are therefore always in a perfectly centered position. The area of the discharge and of the suction valves is one-seventh of the piston area for the former and one-half for the latter. There is no difficulty in allowing this area for the suction valve located in the cylinder head, but on the piston rod end two valves are frequently used, as there is hardly sufficient room for one valve having the required area. The width of the seat should not exceed 0.1 to 0.12 of the valve-disc diameter, and an angle of seventy to ninety degrees for the discharge valve seat and sixty to seventy-five degrees for the suction valve are considered good practice. A valve

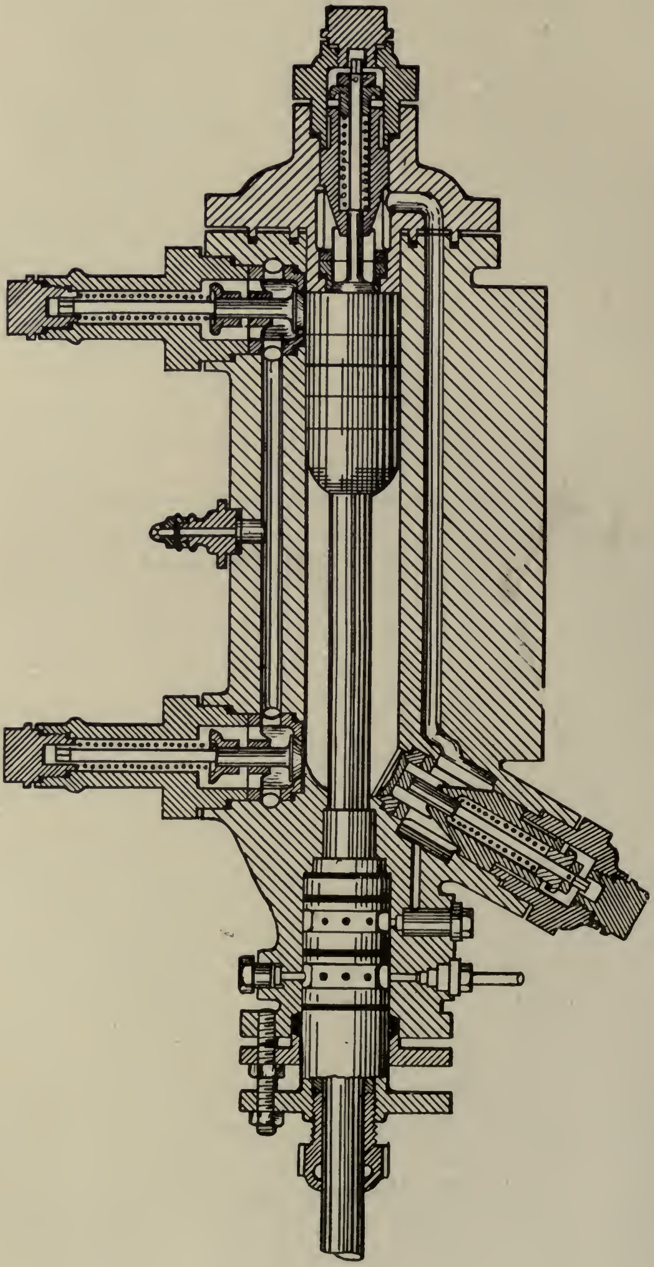

FIG. 82.—LONGITUDINAL SECTION THROUGH COMPRESSION CYLINDER.

lift of 0.33 of its own diameter for the suction valve and 0.28 for the discharge valve, are figures which will prove satisfactory. Strict attention should be paid to the valve spring, which is often too stiff. A spring tension of eight to nine pounds for the suction valve and ten to eleven pounds for the discharge valve will be found ample.

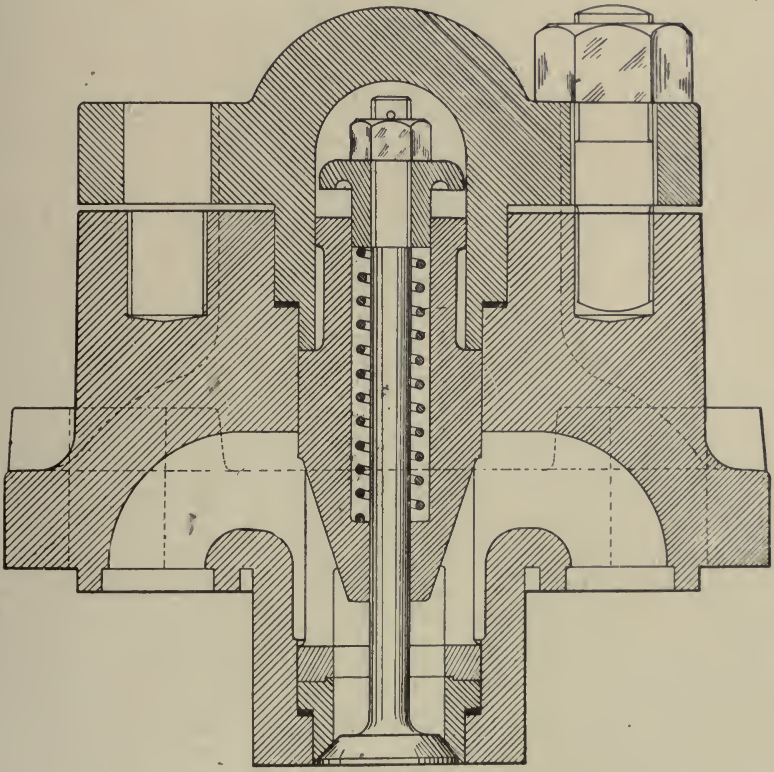

FIG. 83.—SUCTION VALVE CO_2 REFRIGERATING MACHINE.

A well proportioned valve, properly balanced, is of much more importance than is usually accorded; the operation of such a valve can hardly be heard in the carbonic acid machine, owing to the great masses of metal in the cylinder, which muffles the sound, and also to its own lightness.

Properly constructed suction and discharge valves are shown in Figs. 83 and 84.

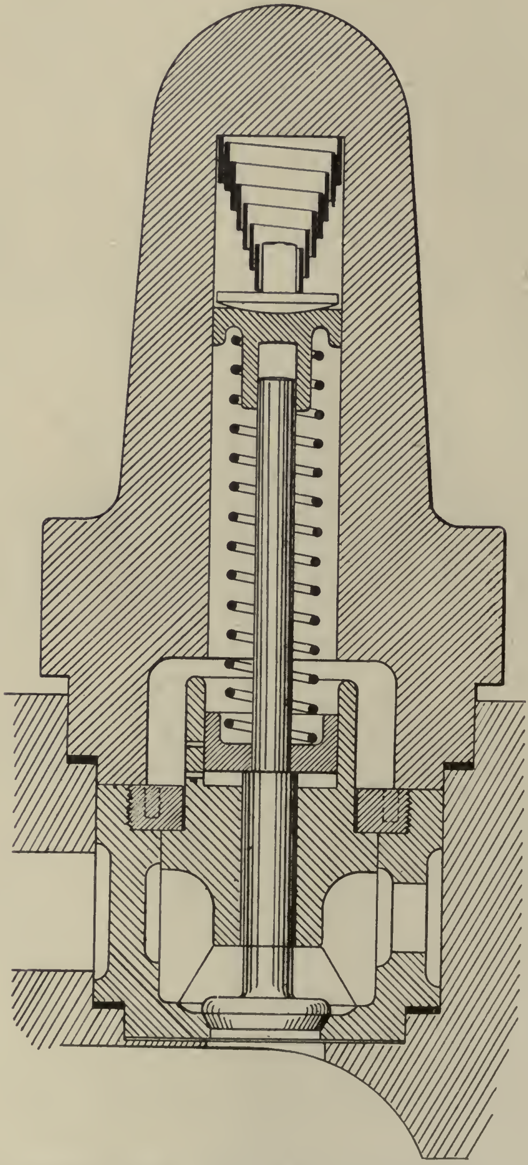

FIG. 84.—DISCHARGE VALVE CO_2 REFRIGERATING MACHINE.

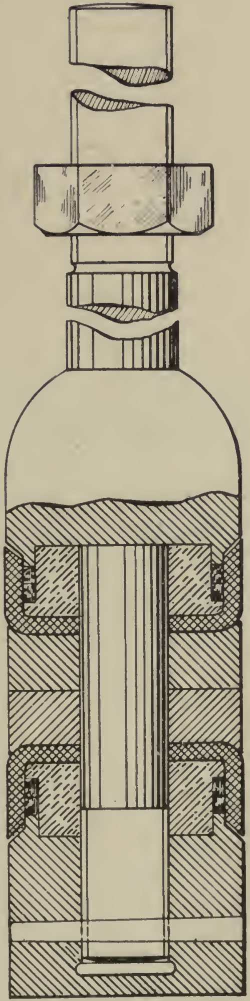

FIG. 85.—PISTON CO_2 REFRIGERATING MACHINE, SHOWING LEATHER CUPS.

The piston is provided with leather cups as shown in Fig. 85, and its rod is usually case-hardened and carefully ground in the lathe. The middle parts of the piston are made of composition and should be of the same diameter as the bore, while the steel parts should be turned down one sixty-fourth inch less than the bore, so that only the composition rings come in contact with the cylinder wall. The leather cups are made of three-sixteenths inch oak-tanned center-stock leather and have an average life-time of six months.

The most essential point is the stuffing box. Owing to the high internal pressure, as well as to the comparatively large piston rod, it is necessary to divide the stuffing box into several chambers, consisting of removable lanterns, which are so arranged that the pressure is reduced by steps. The chamber next to the cylinder bore takes care of the leakage; a controlling device is usually connected to this chamber by means of which the gas is returned to the suction side at a pressure higher than that of the evaporation and lower than the condenser pressure. The next chamber is kept under oil by a force pump, which forces the oil into it at a pressure slightly above that of the suction. An oil outlet, controlled by a ball valve, leads from this chamber to the suction canal of the compressor, so that a small amount of oil together with an occasional bubble of gas enters

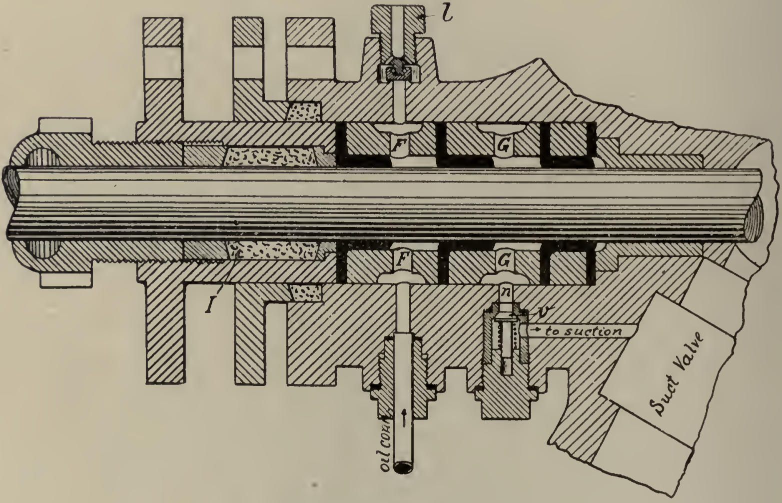

FIG. 86.—SEDLACEK STUFFING BOX.

the compressor at this point. "Garlock" or any other soft packing is used at the outer end merely as a wiper of the lubricating material, preventing oil leakage at that point.

The first successful stuffing box which was constructed on this principle was invented by J. Sedlacek, an Austrian engineer, and is illustrated in Fig. 86. In this stuffing box, chamber *G* is used to collect the leak gas passing from the cylinder into it until a pressure about 20 per cent lower than that produced during compression is reached. Canal *n* connects chamber *G* with the suction side of the compressor. Interposed in this canal is a V-shaped valve, *v*, which is so proportioned that a suction pressure of 22 atmospheres on the larger area corresponds with a pressure of 45 atmospheres on the small area. Oil chamber *F* is supplied with lubrication by means of a force pump, and the pressure maintained in same should always be above the evaporating pressure. The outer packing, *I*, consists of "Garlock" rings, which prevent the leakage of lubricating material at the outer end.

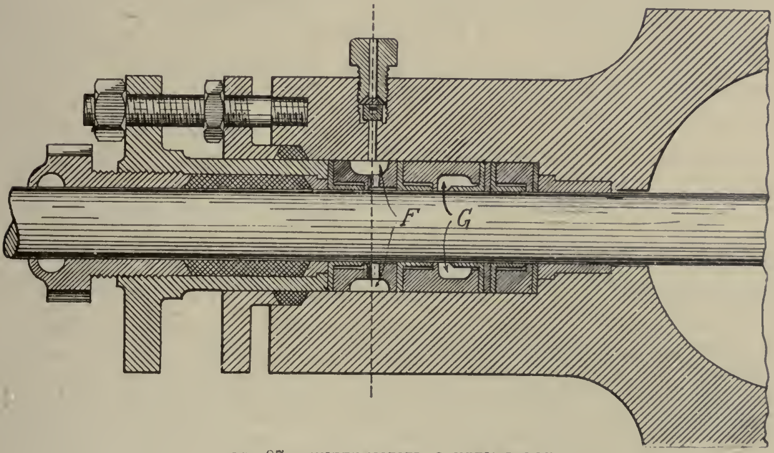

FIG. 87.—WITTENMEIER STUFFING BOX.

As soon as the pressure in *G* exceeds 45 atmospheres it opens valve *n*, and the leak gas escapes into the suction side.

This stuffing box has been modified by F. Wittenmeier, who changed the location of release valve *n*, by placing it in a duct leading from the oil chamber *F* to the suction side. In this stuffing box, *G* is simply used as a gas pressure chamber which counteracts by its elasticity the strain to which the packing is subjected during the compression stroke. Fig. 87 shows the details of construction.

The Sedlacek construction has this fault—that as the valve area of release valve *n* is fixed, it can not be adjusted to conform to the changing summer and winter pressure of liquefaction. Owing to its location its operation can not readily be observed, and the engineer is unable to ascertain whether it works properly or not.

To overcome these disadvantages and to afford ready means of observation covering every set of packing within the stuffing box, a device has been designed by the author, which is illustrated in Fig. 88.

Gas chamber *G* and oil chamber *F* are separate lanterns. Lubricating material is fed by *F* by means of an automatically operating oil pump. Pipe connection *P*, with ball valve *V*, leads to the oil separator of the suction line, so that the oil pressure in oil chamber *F* is constantly slightly greater than that of the suction pressure. Auxiliary cylinder *A* is connected to gas chamber *G* by means of a small copper pipe. Piston *B*, with hollow trunk valve B_1, controls the gas exhaust port leading to the suction valve chamber. Adjacent to cylinder *A* is a small cylinder, A_1, in which a piston, *T*, is movable. Both cylinders are connected by means of passage *U*, which, together with the lower end of cylinder *A*, is filled with a heavy liquid. The rod of piston *T* is weighted down by means of a lever carrying an adjustable weight on its free end. In place of this weight a spring may be used. The leak gas collects in chamber *G*, and as soon as a pressure about 15 atmospheres lower than the high pressure is reached, it forces piston *B* to recede until trunk valve B_1 uncovers the gas exhaust port and the leak gas escapes into the suction port. It is clear that by adjusting the weight, or the tension of the spring, any fixed release pressure may be maintained.

It is essential to maintain a relatively higher pressure in *G*, for the reason that it serves in itself to prevent gas leakage; it also prevents the excessive flow of oil which might otherwise find its way into the cylinder, so that the oil in one chamber and the leak gas in another serve as checks on each other, the oil seal preventing escape of gas and the gas seal checking the admission of oil into the cylinder.

A very small quantity of gas is carried by the piston rod into oil chamber *F*, from which it escapes with an occasional drop of oil into the oil separator, so that in reality the gas is released twice; first, from chamber *G* to the suction port at a pressure of 15 atmospheres lower than the high pressure, and next, from oil chamber *F*, at a pressure slightly above that which prevails in the suction line oil trap.

So long as the packing remains intact it is impossible to detect even the slightest gas leakage. As soon as the packing is worn the operator will immediately be notified by the action of the controlling device. The glands must then be taken up, and if that does not remedy the defect, the packing must be renewed. If the packing between chambers *G* and *F* becomes defective, it will be shown by

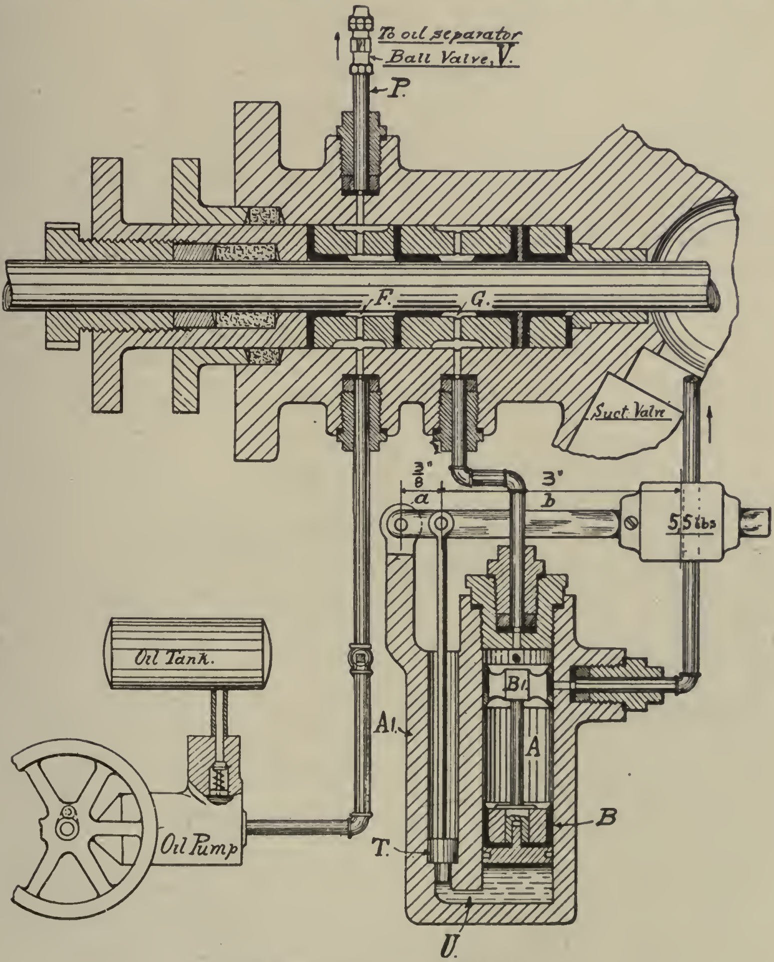

FIG. 88.—GOOSMANN STUFFING BOX.

increased temperature of the pipe connection between *F* and the oil trap.

The stuffing box employed by the J. & E. Hall Company of London, England, is shown in Fig. 89. A small auxiliary cylinder, *a*, is provided with a piston, *b*. The piston rod extends through a suitable cover. Piston rod chamber *C* contains the lubricant, and a pipe connection with valve, *d*, provides communication between chamber *C* and the lantern in the stuffing box. Space *E* is connected with the condenser by means of connection and valve *f*. A hand pump forces oil into chamber *C* at *h*, and the piston rod indicates whether it is filled or empty. Valve *d* is then slightly opened and the condenser pressure acting upon the full area of piston *b*, forces oil into the stuffing box lantern. It is clear that the pressure by means of which oil is forced into the stuffing box is greater than that existing in the compressor owing to the reduced area of that end of the piston to which the rod is attached. It follows that the stuffing box is sealed continually with oil at a pressure greater than the highest pressure of compression.

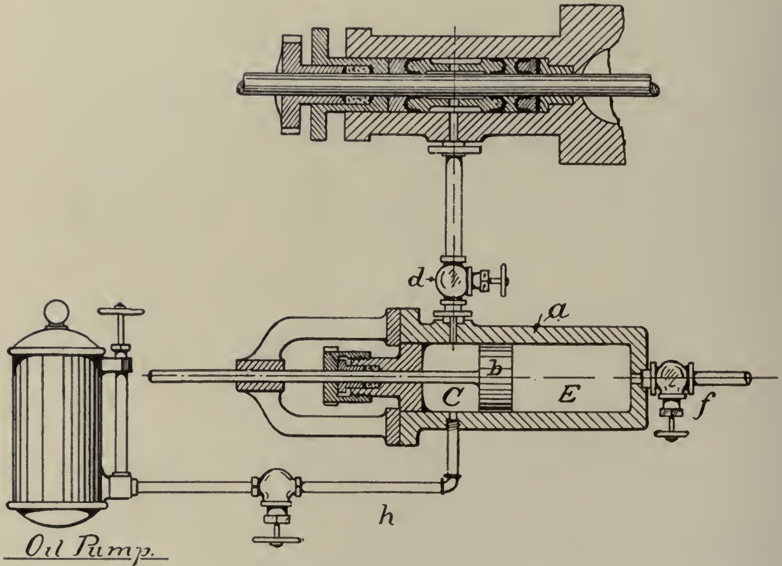

FIG. 89.—HALL STUFFING BOX.

Leather cups are used almost exclusively as the packing material, they having given much better satisfaction than any other known method of packing. In packing the stuffing box with this material, the glands must be drawn up tight, as no provision for expansion of the material need be made in this case; only the outer nut which holds the "Garlock" packing in place, is left comparatively loose. The life time of this packing is a season or more with ordinary care. A simple trap is used to separate the oil from the gas; it is usually connected in the direct line of the discharge pipe between compressor and condenser, as it is of small dimensions and can easily be supported.

Safety valves are always used. They are employed without the necessity of arranging for the discharge of the gas into the atmosphere.

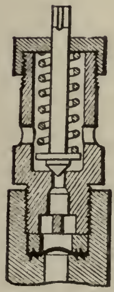

FIG. 90.—SAFETY VALVE, WITH COPPER DISC.

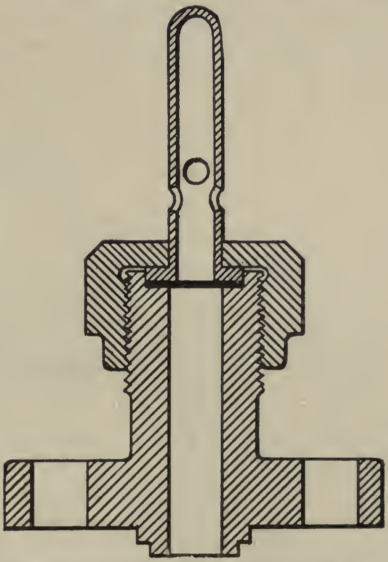

FIG. 91.—SAFETY VALVE, WITH CAST-IRON DIAPHRAGM.

The location of this valve on the compressor is in the discharge canal between the discharge valves and the delivery stop valves, so that they also serve the purpose of protecting the compressor in the case of careless starting, without opening the delivery stop valve. This valve is usually provided with a cast iron diaphragm, proportioned to break at a pressure of about 150 atmospheres. (Fig. 90.)

A safety valve having a copper disc, designed to break at a point considerably below that to which the machine is tested, located at the base and above that an ordinary spring safety valve, to prevent excessive loss of gas, is shown in Fig. 91. The disc is made perfectly gas-tight and the spring valve comes into play whenever it becomes ruptured.

When condenser water of a temperature above 74° F. is used it is advisable to provide a special liquid cooler, for the purpose of reducing the temperature of the liquid before it passes the expansion valve. Submerged, atmospheric and double-pipe condensers as illustrated by Figs. 55, 56 and 57, are used. The customary rules prevail regarding the surface of the evaporator pipe, with this difference, that the evaporating temperature may readily be dropped much below zero F. without a great difference being caused in the pressure between that of the evaporator and the condenser, or, in other words, without changing materially the ratio of compression, which ordinarily is 1:3.

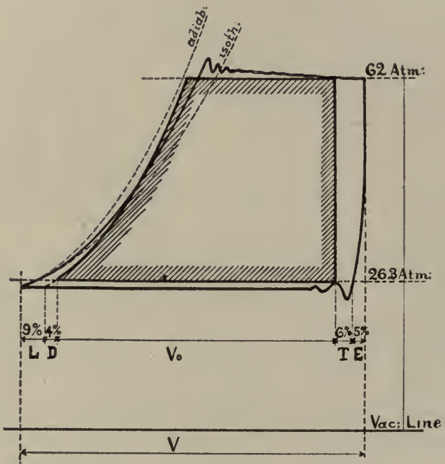

FIG. 92.—THEORETICAL DIAGRAM COMPARED WITH INDICATOR DIAGRAM.

While it is true that the theoretical efficiency of the carbonic acid system is not equal to that of the ammonia machine, owing to the greater percentage which the specific heat of the liquid carbonic acid bears to the latent heat of evaporation, yet the practical efficiency of the machine, owing to compensating features, make up for the above loss. These consist in less piston leakage, a smaller depression of the suction line, and slightly smaller loses through clearance. A comparison of the theoretical diagram*, Fig. 92, with that obtained

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* The diagram is calculated in accordance with the recommendation advanced by Mr. Stetefeld, according to whose theory E represents the volume of expansion, T = the losses through radiation in the refrigerator, D = the depression caused by the resistance in the suction pipe and L = the piston leakage.

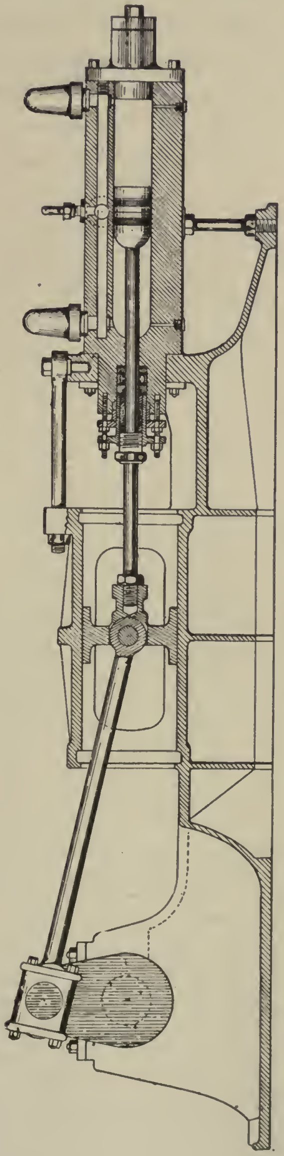


FIG. 93.—BEST TYPE OF CO_2 REFRIGERATING MACHINE, SHOWING LONGITUDINAL SECTION THROUGH THE CYLINDER.

by the indicator, will be of considerable assistance in explaining this point, and it will then be seen that in practice the three most prominent refrigerating agents—ammonia, sulphurous acid and carbonic acid—are practically equal in efficiency and economy of operation.

Fig. 93 illustrates one of the best types of CO_2 machines, showing longitudinal section through the cylinder.

INDUSTRIES FOR WHICH THE CO_2 REFRIGERATING MACHINE IS ESPECIALLY ADAPTED.

The carbonic acid machine is especially adapted for buildings where the engine room is located in the basement, such as hotels, department stores, apartment houses, hospitals, etc., because of its safety and noiseless operation. In cold storage houses requiring very low temperature the carbonic acid system is especially desirable, as it produces temperatures of ten degrees below zero economically. It is possible to operate rooms in which widely differing temperatures are maintained—from zero to 34° F., with one suction pressure, without perceptible loss of capacity. The suction pressure maintained when temperatures near the freezing point are desired averages 22 atmospheres, and in order to reach temperatures of zero in another part of the system it is only necessary to reduce the suction pressure gradually to 19 atmospheres, which does not materially change the ratio of compression nor the density of the gas.

Carbonic acid machines have found great favor for use on board ship and it is said that 90 per cent of the refrigerating plants installed for marine purposes operate on this system. This preference is due to the fact that the carbonic acid machine may be installed in the main engine room without the necessity of providing for an especially ventilated room; the condenser coils may be made of copper, which successfully withstands the action of sea water; and lastly, for reasons of safety, as the presence of ammonia in such large quantities as are required in an extensive refrigerating system are regarded as a constant danger in case of an accident to ship or machinery. The fact that a vessel runs into warm water occasionally does not seem to interfere with the efficiency of the plant operating on the brine system when summing up the results of the complete trip. At least this point is maintained by the managers of steamship lines plying between Europe, Australia and India. Many of these cargo carriers require very low temperatures in the holds, and in such cases the carbonic acid system is used almost exclusively.

For use in the brewing industry the carbonic acid system is particularly valuable, especially when a gas collecting and carbonating equipment is used on the premises; in this case the fermentation gas serves as the refrigerating medium without expense in that particular and offers the additional advantage that it is always available. In an air circulating equipment the direct expansion pipes can be placed in the air chamber without danger, as a leak of gas into the air would do no harm whatsoever.

OPERATING PRACTICES.

It is of very little consequence, in operating this system, whether the evaporator coils are fed from the top or from the bottom, as the liquid carbonic acid evaporates so rapidly, even at very low temperatures, that a bottom-feed would cause no inconvenience. For the sake of uniformity it is well to adhere to the top-feed which is the rule with ammonia evaporation. Before starting the machine, the discharge delivery valve must be open; if this is neglected the safety diaphragm will be broken, which occurs with a very loud report, directing the attention of the operator startlingly to the fact. The suction stop valve must then be closed to avoid unnecessary loss of gas. The average speed of the carbonic acid machine varies from eighty revolutions for machines of small unit—two to five tons—to sixty revolutions for machines of above fifty tons refrigerating capacity, which corresponds with an average piston speed of 2 to 3 feet per second. All connections are made by means of flanges and the packing ring consists of vulcanized fiber, which has the necessary power of resistance combined with sufficient elasticity to make a tight joint. It is not affected by the gas.

As a majority of these machines have no water-jacket and are operated on the wet gas system it is well to maintain a sufficiently high suction pressure until the gas returns to the machine at a low temperature; the evaporating pressure may then be reduced gradually until the pressure required for effective work is reached.

The gauge is usually provided with two dials, one with red, the other with black figures. The red represents the temperature at which the liquid carbonic acid evaporates at the corresponding pressure and the general rule pertaining to the relation of the temperature of the evaporating gas within the cooling pipes to the desired temperature in the refrigerator is that the former should be 10° to

15° F. lower than the latter. With a properly distributed pipe-surface this rule will yield satisfactory results. For cooling water and beer to temperatures of 40° F. the evaporating pressure should be not less than 32 atmospheres, which corresponds with a temperature of evaporation of 28° F. With a suction pressure of 35 atmospheres, the "frost" returning to the compressor will disappear, because the evaporating temperature is slightly above the freezing point, which does not diminish the cooling effect, so long as the medium to be cooled has a temperature above 40° F.

For general cold storage and ice making purposes a pressure of 22 atmospheres has given very good results. When temperatures of zero and below are required the evaporating pressure must be gradually reduced to 18 or 19 atmospheres by reducing the valve opening in the expansion valve. Care must be exercised that the gas returns to the machine at a sufficiently low temperature to maintain a cylinder temperature not above 130° to 140° F.; in that case the average temperature of the gas discharge will register 150° to 160° F. In no case should the temperature of the cylinder be allowed to rise to 200° F., as this will injure the piston and stuffing box packing in a short time.

The condenser pressure is governed by the temperature of the condenser water. When water at 60° F. is available, it may leave the condenser at 70° to 75° F. The average condenser temperature of the CO_2 will then be above 74° F., which fixes the condenser pressure at 62 to 64 atmospheres. With an initial temperature of the condenser water at 70° F., the overflow should be kept at about 75° F. and corresponding condenser pressure of 65 to 68 atmospheres should then be maintained. When the initial water temperature exceeds 70° F., inlet to and overflow temperatures from condenser should be kept close together with a condenser pressure not below 70 atmospheres. The amount of the condenser water used should be governed by the temperature of the liquid carbonic acid, and the operator should endeavor to reduce this temperature to as near the initial temperature of the cooling water as possible. In extreme cases a liquid cooler, consisting of a spiral coil through which the liquid passes, submerged in the coldest available water, should be employed.

When the condenser pressure drops below its lower limit, which will be shown by the gauge, the charge must be replenished. The system is charged through a valve which is usually placed directly in the suction canal of the compressor. The connection between this valve and a filled CO_2 cylinder is to be established and the gas is discharged into the suction side by its own pressure. When the pressure in the cylinder is reduced to that in the suction of the system the cylinder should be heated by steam or a gas jet to force as much as possible of the gas against the comparatively high pressure of 300 pounds into the refrigerating system. The cylinder should be heated until it has reached a temperature of 110° F. at the neck when all the CO_2, except a very small remnant—usually about one to one-and-a-half pounds—has left it. The charging valve, as well as cylinder valve must then be closed. If the pressure is not yet high enough another filled cylinder must be connected in place of the one just emptied. Careful engineers will have no trouble in obtaining all the gas from the cylinder, without reducing the suction pressure, which would mean an interruption in the refrigerating work. When heating the cylinder during charging, it should be made an absolute rule never to heat it before at least a part of the liquid carbonic acid has been charged into the refrigerating system.

CHAPTER X.

CARBONATED MINERAL WATER AND OTHER BEVERAGES.

VARIETIES OF MINERAL WATERS.

The term "mineral water" is usually applied to all spring waters containing an unusually large amount of mineral matter of variable character in solution, and it becomes a mineral water of medicinal or therapeutical value when it contains salts, minerals and gases which have recognized curative or dietetic merit. The quantity of the matter in solution is of little importance; it is the general characteristics of its ingredients only which determine the value of a mineral water.

Another factor of importance is the temperature of the water upon reaching the surface of the earth. Some mineral waters gush forth from the earth at a high temperature with gas and steam pressure and are called thermal waters, others are cold and are called non-thermal waters.

These waters accumulate at various depths below the surface of the earth, having acquired their peculiar qualities by dissolving certain formations of the alkali earth on their way from the surface to these greater depths. Many small veins are united at the lower stratas, from whence they are forced upward back to the surface by means of hydraulic or gas pressure.

Carbonic acid is the principal agent in accomplishing this process of decomposition and absorption, as it changes the carbonates of the metals and of the alkali earth into bicarbonates, thereby rendering them soluble in water.

Many of the mineral waters contain large volumes of carbonic acid. The process of impregnation has taken place in the interior of the earth, sometimes at considerable depths and frequently under high pressures. These springs are particularly numerous in localities where volcanic conditions have prevailed at some time, or in places where organic matter is changing its composition unceasingly. The volume of carbonic acid absorbed by these waters varies from one to five times that of the water. It is most agreeable when contained in the water in a free condition, that is, when simply absorbed by the water and not bound with metallic ingredients.

Many of the alkaline-saline waters are sulphated, containing considerable sodium sulphate in addition to sodium carbonate and sodium chloride. These waters are commonly known as "Bitter-water." Carbonic acid gas is usually present in the non-thermal waters of this class. When saturated with considerable quantities of carbonic acid they have a marked diuretic effect. In large doses such waters are purgative, increasing peristalsis and liquefying the intestinal contents.

Of the saline muriated or chlorinated waters the most important are those whose chief element is sodium chloride or common salt. In addition to this salt, the salts of magnesium, potassium, calcium and lithium are often found, as well as combinations of iron, iodine and bromine.

Their medicinal value depends entirely upon their composition, many of them are highly regarded by most capable analysts, while others are almost worthless. The best known European waters of this class are found in Kissingen, Homburg, Arnstadt, Kronthal, Mergentheim, Niederbronn, Pyrmont, Rehme, Schmalkaldren, Droitwich, Harrowgate and Nantwich. Similar waters are found in America at Canon City, Mineral Springs, in Colorado; Blue Lick Springs, Kentucky; Akesion Springs, in Missouri; Ballston Spa and Saratoga Springs, in New York; Sheboygan Mineral Well, Wisconsin.

These are all non-thermal waters, most of them containing free carbonic acid gas, but frequently they are charged with additional CO_2, which increases their stimulating properties and imparts to them an agreeable pungent taste.

Lithia waters have met with great favor in cases of gout and renal calculi, as they prevent gouty attacks and aid in the expulsion of the urinary concretions. The great majority of the natural lithia waters contain salt of lithium only in slight traces. In order to be effective they must contain not less than twenty grains of lithium salt in every gallon of water. Lithium is usually found in a chloride or a sulphate, but sometimes it is found in the form of a carbonate. The first two salts occur in saline or alkaline waters and the last in alkaline waters alone. The milder lithium waters, when charged with an excess of carbonic acid, are an excellent table water, as they have a slight diuretic action upon the gastro-intestinal, as well as upon the urinary functions.

In order that patients living at points distant from the locality of the springs, the water of which is considered good for their particular ailment, may experience its curative effect, most all of the natural mineral waters are bottled and sent to all parts of the civilized world. It is, however, a fact that during bottling, storing and transportation nearly all of these waters are undergoing changes which make them much less desirable for medicinal purposes than the water obtained directly at the spring. This undesirable result can not be obviated for the reason that during its formative period while in the earth ingredients from various vegetable, mineral and metallic substances have been absorbed, and when said water is exposed to the air, particularly in the case of water containing iron, the oxygen of the air acts upon the iron and precipitation, clouding and other undesirable changes take place.

NATURAL VS. ARTIFICIAL MINERAL WATERS.

Modern chemistry has made it possible to prepare mineral waters artificially, and the best waters so prepared are today considered vastly superior to the natural product, since it is possible to incorporate in the water only such ingredients as are required to produce the desired result, leaving out any substances which would cause undesirable changes and which are unavoidable in the use of the natural water.

Dr. W. Jaworski has recently called attention to the fact that the natural mineral waters must be pronounced "curative waters containing impurities" (*medicamenta cruda*), since it is impossible to avoid certain impurities contained therein, while the artificial mineral water when prepared with reference to certain specific cases of organic disorders, and containing only such ingredients in proper concentration as are required to act as the curative agent, are neither natural nor copied mineral waters, and that they must be termed a specific medicinal mineral water, especially prepared for a certain defined case.

The effect of such waters upon the secretive as well as the regenerative functions of the human organism can therefore be controlled much better with a mineral water prepared in accordance with the requirements of the organism and the pathological condition of the patient, than with a natural mineral water which is more or less impure and does not contain the curative agents in the necessary concentrated form. For this reason Jaworski designates the natural mineral water, of which the composition is entirely irrational and which is compounded as chance in the laboratory of nature decreed it, *medicamenta cruda,* while those compounded for a certain specific case, containing the curative salts and gases in proper concentration, have a right to be termed *medicamenta pura.*

A comparison between natural and artificial mineral waters is permissible only in considering those artificial waters which are made to conform precisely to the analyses of the corresponding natural water and which are shipped under similar conditions. The comparison is usually made directly at the spring, and while they may be nearly identical in their composition during the first day, they will become more dissimilar from day to day owing to the changes which are continually taking place in the natural water. This disadvantage does not occur in the case of the artificial product, the latter remains constant in its composition for years. It is evident, therefore, that the artificial product is preferable to the natural, at least at any point distant from the location of the spring.

To offset this plausible argument in favor of the artificial product it has been claimed that the natural water contains certain wholesome properties which can not be found in the former by the most painstaking chemical analysis. Modern chemistry, on the other hand, insists that the properties which must be considered the curative agents are contained in the water in considerable quantities, and as only these need be considered it is clear that the artificial water containing these in the same concentration as the natural, must necessarily have the same wholesome effect.

The results of many investigations made from a chemico-physiological view-point coincide fully with those of a geological nature, as well as with experiments having a purely chemical character.

Dr. Max Roloff, professor of physio-chemistry in Halle, Germany, has made the study of the comparative properties of natural and artificial mineral waters a specialty for many years; he may, therefore, be considered an authority on the subject. He asserts that modern analytical chemistry is sufficiently developed to disseminate the therapeutical value of any water thoroughly. He shows that the properties of the water from the same spring varies considerably and that its composition is greatly influenced by temperature, season and rainfall, and he finally emphasizes the fact that variations, even to the extent of 10 per cent, have very little effect upon the patient who is taking the water.

Therefore, it may safely be assumed that the chemical analysis of the natural mineral waters is sufficiently accurate in designating the curative properties and their concentration in the water, and knowing these, it is a comparatively simple matter to produce an artificial water that equals the former in its curative powers and excels it in purity and keeping qualities.

Every grain of salt dissolves in water into its smallest possible molecule, the molecules having the capacity to be charged electrically, and are called ions. The dissolution into these parts is governed by established rules which are the same for the salts used in the manufacture of artificial as well as those contained in the natural water. For instance, the chemical analysis of a natural water establishes as its ingredients potassium, sodium, sulphuric acid and chloride. It makes no difference whether the chloride is present in the form of sodium chloride or potassium chloride, the result in the manufactured water will be the same so long as the correct number of ions is used. It has also been shown that the action of the artificial water is the same as that of the natural in every particular. One of the experiments to establish this point was the degree of electrical conductivity of the water, both waters showing the same instrument readings.

There are only two factors which are likely to produce a slight difference in quality, temperature and pressure of solution, and in order that the resemblance may be perfect, the temperature, and particularly the pressure, should be the same in the artificial as that found in the natural product. The pressure especially is of the greatest importance. The majority of the natural non-thermal waters are under a pressure of carbonic acid gas, and as they have been under that pressure for a long time, the gas is thoroughly absorbed by the water; hence it is advisable to carbonate the artificial water at a pressure somewhat higher than that of the natural in order to allow for losses of gas through a slightly less effective absorption. It follows that the artificial water, in order to be of the same quality as the natural, must be made under conditions which closely resemble those under which the natural product was created, plus an additional carbonating pressure, in order to impart the greater volume of carbonic acid gas to the water necessary on account of the shorter period of carbonating and its less efficient absorption.

It will be seen from the above that it is well within the power of the mineral water manufacturer to produce a product which has the same beneficial and curative powers as the natural water, and since it is possible to reproduce the famous medicinal mineral waters of all countries in the most obscure village, it is possible to offer the benefits derived therefrom to the poorest sufferer who is not in a position to seek the restoration of health directly at the location of the natural spring.

INGREDIENTS OF MINERAL WATERS.

The principal ingredients of mineral waters are certain chemicals, varying according to the specific purpose for which the water is required. In some cases fruit juices, syrups, wine, cordials and sugar are added in order to make the beverage more palatable.

The presence of carbonic acid imparts to these drinks their peculiarly refreshing and stimulating character. It has a pleasing, cooling and pungent effect upon the palate and produces an exhilarating effect upon the system generally. It stimulates the gustatory nerves, the flow of saliva, the secretion of gastric juice, and is readily assimilated by people upon whom common water induces heaviness in the stomach and dyspepsia.

Carbonic acid in water checks acid fermentation in the stomach, cures nausea, and is the most natural and effective anaesthetic known to overcome a chronic disposition to vomit. It promotes the peristaltic motions of the stomach and intestines. It is a much esteemed remedy in acute febrile diseases, and is ardently desired by patients on account of its thirst-allaying and cooling power which is perceptible at once in the mouth and stomach.

In cases of chronic catarrhs of the stomach, intestines, kidneys and bladder, as well as of the air passages, carbonated waters are a chief remedy. They are a welcome vehicle in the administration of medicines, as they eliminate the nauseous taste of the latter.

The action of carbonic acid upon the bacteria in water is of particular interest. Professor Koch, Berlin; Professor Babes, Bucharest, Professor Leone, Munich, and other scientists have found that it effectively retards the propagation of germ life in water, and that it exterminates the great majority of microbes, very few having sufficient vitality to withstand its action. This is particularly true with reference to the cholera and typhoid fever bacillus, as the former is positively exterminated in three hours, while the typhoid fever germ shows signs of life for about five hours only.

Professor Leone experimented with the hydrant water furnished by the city of Munich, which has a reputation for exceptional purity. Tests of water obtained fresh from the main reservoir contained only five microbes in one cubic centimeter; after twenty-four hours the number had increased to 100; in forty-eight hours this number had grown to 10,500; in three days to 67,000; in four days to 315,000 and in five days to over half a million. This tremendous propagation took place alike in standing as well as in moving water, and Professor Leone concluded that it was due principally to the loss of carbonic acid from the water. To prove this theory he experimented with carbonated water taken from the same source and found that samples of water containing 176 microbes in one cubic centimeter on the first day showed the diminished number of 87 after a period of five days; in ten days the number was reduced to thirty and after a period of fifteen days to only twenty. During the same time the number of microbes in ordinary water would have reached many millions in every cubic centimeter.

WATER AND ITS PURIFICATION.

The method of purifying water before it can be used for the purpose designed depends altogether upon its composition. Sometimes it is necessary to employ elaborate and expensive means while at other times a simple process of purification is entirely satisfactory. In this connection it should be borne in mind that the term "pure" has only a relative meaning. Absolute purity is unattainable. Modern chemistry has led to the realization of that fact. At the same time it has pointed out the ways and means whereby the desirable state of purity can be attained, and it has familiarized us with the various sources of contamination and how to avoid same.

That water is a medium for breeding and spreading disease germs has been recognized since the very earliest stages of civilization and long before anything in regard to its composition and its action in the system was known. Yet the dangers of impure waters were fully understood and such old and ancient communities as Jerusalem and Rome adopted measures to guard against same. These measures were necessarily crude as compared with those of the present generation, yet in spite of their crudeness they demonstrated that it was possible to avoid, or at least, curb epidemics which were due to the impurities in drinking water.

All water, no matter where originated, is impure and the method employed to make it suitable for drinking purposes depends entirely upon the kind of impurities. The natural sources of water admit of certain classifications and the means of purification are usually indicated by same. Of the various classifications the following may be mentioned as the most common: 1, rain, snow and hail; 2, surface and running water; 3, subsoil, well and spring water; 4, deep well water; 5, mineral water. Of these the first is usually the purest. It is often free from foreign matter, but it may have absorbed large volumes of gaseous matter during its flight through space, particularly in densely populated sections of the country, which may make it unfit for drinking purposes.

The running waters of brooks, rivers and streams are comparatively pure, and contain only slight quantities of foreign matter. On the other hand, if a brook or streamlet originates from subterranean reservoirs and issues from the ground after having traversed considerable distances below, it is most always charged with mineral matter of various composition. Above ground it pursues its way over the earth's surface carrying in suspension the material of which that surface is composed, such as clay, sand, decayed vegetation, etc., and must be purified accordingly. Subsoil water is never entirely safe for drinking purposes. It is comparatively free from germ life and foreign matter in areas which are very sparsely populated. In the neighborhood of densely populated sections it should never be used unless thoroughly purified.

Deep well water is usually germ free and often rich in mineral matters owing to the long distance through which the water percolated before it reached the lower strata. In most cases it contains iron in solution and sometimes ammonia and sulphuretted hydrogen, so that its use for domestic purposes can be determined only by a careful analysis. Regarding the last class, mineral water, its use is limited and its worth or worthlessness remains to be demonstrated in the chemical laboratory.

When the origin and composition of the water is known, the purpose for which it is to be used must be considered before the proper means as well as the extent of the purification to which it is to be subjected can be determined. When the water is to be used in the manufacture of ordinary carbonated beverages, intended for a palatable, refreshing and thirst-allaying liquid only, it does not need to undergo the same process of purification which must be applied to water used in the manufacture of high-class mineral waters. Ordinary clear hydrant water which is fit for drinking purposes is usable for carbonated beverages unless its use is particularly prohibited or restricted by the local department of health.

The rules which apply to the purity of hydrant water to be used in the manufacture of carbonated beverages are: 1. It must be perfectly clear and without color. 2. The microscopical examination must show no signs of organic life at a magnification of one hundred times. 3. It must be entirely odorless. 4. It must have no peculiar taste of any kind. Aside from these general rules, the locality from which the water is obtained should be inspected; if the inspection shows healthy surrounding conditions which preclude the possibility of infection, it may be assumed that the water is pure and that it can be used without further purification. However, the fact that a water is clear, colorless and tasteless is not always a proof of its purity. In the majority of cases a mechanical purification by means of filtering will at least be found necessary, and in all cases it is advisable to have the water regularly examined by a chemist, because the impurities which may be in the water are so numerous and their detection is so difficult that they frequently can be found by a chemical analysis only.

One of the best tests for organic impurity in water is one-fourth of a grain of permanganate of potash to a gallon of water, allowing it to stand for a time. The permanganate will impart a faint purple tinge to the water which will gradually disappear if organic matter be present. The more impure the water the sooner the purple color will disappear, and if very impure a dirty straw color will take its place. Many of the ingredients entering into carbonated beverages are of such a character that in combination with impure water a cloudiness or precipitate in the bottles will result, thus rendering the goods unsalable. The presence of lime in water is frequently the cause of cloudiness, or milkiness in lemon soda and other beverages. This evil may be remedied by boiling, which is not always practicable. Another remedy is to turn the water into a large tank and then add lime until the water is alkaline. Stir it thoroughly and allow it to settle, then draw from a faucet, which should be placed at least three inches from the bottom. In obstinate cases, the services of a chemist may be required.

The business of manufacturing carbonated beverages depends for its success very largely upon the availability of large quantities of pure and wholesome water. The latter is the principal ingredient in the beverages and its quality is therefore a question of the utmost importance, as it concerns the public health. Yet the great importance of the purity of water used in many of those establishments which should exercise the greatest care regarding it is very often entirely disregarded. In many instances even the most elementary rules for the selection and use of the water are neglected, which can be due only to a lack of knowledge concerning its complex composition. Quite frequently the water may have the appearance of purity itself, and yet it may contain some of the most deadly germs, or it may carry suspended and dissolved soluble matter, which makes it unusable for the purpose for which it seems, according to all apperances, entirely suitable. All water used in the manufacture of beverages must be—first of all—entirely free from disease germs of any kind. But these germs thrive in the clear and odorless fluid as well as in water which clearly shows its impurity. Among the most deadly germs which thrive in clear and cold water are the cholera and typhoid fever bacillus. Low temperature has very little effect upon these as well as upon many other microbes. Exhaustive experiments show that even the congelation of water does not destroy all its microbe organisms, and that in fact ice may become a veritable vehicle of disease germs. The only process known to exterminate germ life in water positively is the high temperature of boiling and evaporation and for that reason ice manufactured from distilled water is positively free of it, unless it is afterwards contaminated by exposure to impure air or other polluted surroundings.

Many of the salts contained in water prevent the manufacture of a first-class beverage. Unfortunately the influence of the salts, which may be found in solution in the water upon manufactured beverages has not been sufficiently studied, but that their presence has a great deal to do with the character of the same is shown by the differing quality of the latter, when made of the same ingredients, by the same method and under the same conditions, but with a different water.

It will thus be seen that the source, constituent parts and color of the water should be carefully considered before it is used indiscriminately in the preparation of beverages intended for the use of the public.

In order that the influence of the water upon beverages, which is due to its varying composition, may be fully appreciated, its origin as well as the process of its formation should be understood.

Water is the chemical combination of two parts of hydrogen with one part of oxygen. In this combination it forms a transparent liquid, which is the most abundant and most necessary for living beings of any in nature, except air. It is essential to all vegetable and animal life and constitutes nearly seven-eighths of the human body.

But if water actually were what its chemical formula represents it to be, simply a compound of hydrogen and oxygen, the difficulties and troubles which arise because of its use could not appear. In reality the composition of water is much more complex. It is charged with gaseous matter and contains minerals and metals in solution, owing to which it obtains characteristics that makes its use oftentimes disastrous in its results. Water is a solvent, that is, it will absorb solids, gases and other liquids. It will actually absorb its own bulk of some other chemical agents and absorbs atmospheric air to the amount of twenty times its own volume. Thus it acquires almost endless impurities in the atmosphere as well as during its filtration through the ground. It is familiar to us in three forms; that is, the solid—as ice; the liquid—as water; and the gaseous—as steam.

In the form of ice it exists in immense masses around the poles, and 99 per cent of the earth's supply is contained in the oceans. The atmosphere is constantly charged with water, either as an invisible vapor that has evaporated from the oceans, lakes, rivers, etc., or concentrated in the form of clouds. Cool air currents condense the invisible vapors and it falls again to the earth as rain, snow or hail. During its formation it seizes hold of the various constituents of the air with which it comes in contact, and charges itself with them.

In this way carbonic acid, nitrogen and oxygen, ammonia and nitrites enter into its composition.

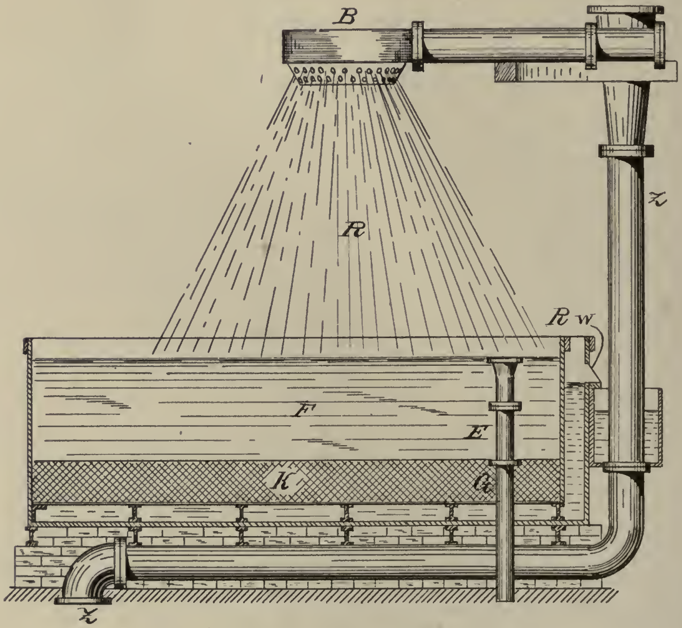
When it is thus charged with these constituents of the atmosphere, it falls to the ground and as it reaches the humus crust of the earth's surface it absorbs more carbonic acid. Owing to this highly charged condition it is enabled to penetrate the rocks and exercise its power of destruction and decomposition on even the hardest of them. It converts anhydrous bodies into hydrates, dissolves mineral matter, produces carbonates, and separates the metals from the substances combined with them. When the carbonates of the metals and of the alkali earth have been changed into bicarbonates, they have become soluble in water. In this condition they are carried to and deposited in other localities, where they are deposited in the form of carbonate of lime, so that new formations are created which, sometimes, reach gigantic proportions.

As nearly all the salts are soluble, water obtains in its filtration through the ground calcium sulphate, calcium carbonate and magnesium carbonate. These are readily changed into soluble bicarbonates if sufficient carbonic acid is present, in which case they will be deposited in another locality before the water again emerges from the ground. The chlorides, particularly sodium chloride, are readily dissolved when water passes over beds of rock salt. Sodium chloride is readily diffused through the rocks upon which its action is frequently assisted by silica. In this way the different elements of the rocks become impregnated with chloride, and the water which has been in contact with same will contain chlorides of sodium, of potassium, of magnesium, of calcium and others.

When river or lake water is used, it frequently contains endless varieties of vegetable and animal matter. Thus it will be seen that almost every water, no matter where it originates, is impure and that in almost all cases it is necessary to use the proper methods of purification before it can be used for domestic purposes.

The analyzation of water is a rather intricate matter, owing to the complexity of the impurities in the water. The substances most frequently found are sulphuric, carbonic, hydrochloric, sulphurous, silicic, nitric, and nitrous acids, potash, soda, lime, magnesia, ammonia, organic matters and divers matters in suspension. The acids are usually combined with the bases, forming salts which are clear and palatable water. Mechanical filtration removes the solid impurities from the liquid, and if the filtering medium is sufficiently fine it will also arrest nearly all of the animal and vegetable matter which is held in solution and causes coloration. One class of filters even removes the most minute organism, such as bacteria, from the water.

A filter is an apparatus in which liquids are passed through porous bodies capable of arresting and retaining all matter in suspension, thus clarifying the liquid. As filtering material, mineral, animal or vegetable substances may be used. Gravel, granite, quartz, coke and sand are the principal mineral substances used in filters, and to these may be added pumice stone, unglazed porcelain or cloth. Among the animal substances used for the same purpose may be mentioned felt, sponges, cloth and bone black. The principal vegetable substances for the same purpose are wood fiber, charcoal and raw cotton.



FLG. 94.—SPRAYING AND FILTERING DEVICE.

Chemical clarification of the water has been used for ages past by such people as the Chinese and even the Indians. The matter used for that purpose is known as alum. It is a compound and is used for the purpose of coagulating the matter held in suspension in the water, upon which same can readily be removed. This method is still in use and many of the large filters, which are constructed for the purpose of removing organic matter from the water, are equipped with a coagulating device.

Among the metals which are frequently found in well water, iron is the most prominent. This water is usually germ free and if found to be palatable in other respects, the iron can be oxidized and transferred into the insoluble condition by means of aerating. A subsequent filtration removes the insoluble iron and other impurities held in suspension.

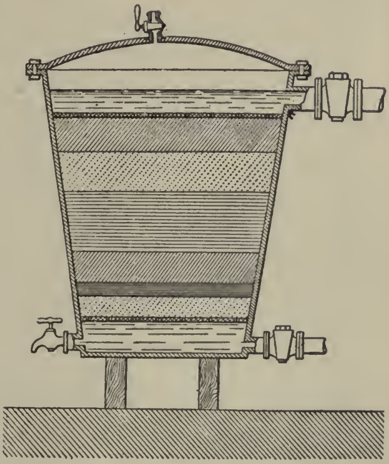


FIG. 95.—DAVID'S FILTER.

The apparatus used is illustrated in Fig 94. The main pipe has two or more branch pipes at its vertical end; the latter are provided with a spraying apparatus and the water falls in the form of rain through the air into the filter basin. The filter bed consists of fine gravel, the water passing through same and entering chamber, *B*. The overflow connection is for cleaning and draining.

Another simple filter is shown in Fig. 95. It is essentially a cast iron vessel with two taps, one at the top to admit water and the other at the bottom to run it off when filtered. The filter is closed with an iron cover, bolted on, and is filled with layers of various filtering materials, each inclosed between perforated iron plates. Commencing at the top the first layer is a bed of sponge, then a layer of gravel, next shreds of woolen cloth, after this a bed of bone black or charcoal powder and finally sand or fine gravel.

To clean the filter the direction of the current of water is simply reversed.

If the available water is very muddy, as is the case in nearly all cities located on the banks of rivers in the United States, it is advisable to use a quartz filter for the elimination of the mud and other principal impurities and a stone, porous porcelain or compressed cotton fibre disk filter for the final purification.

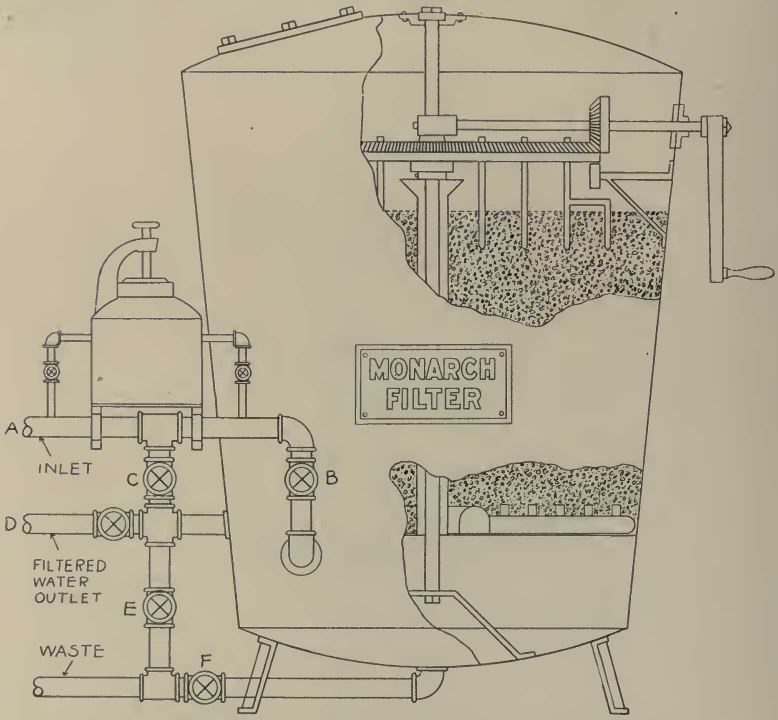


FIG. 96.—QUARTZ FILTER MADE BY INTERNATIONAL FILTER COMPANY, CHICAGO.

The quartz filter used for muddy water is provided with a coagulant chamber in which lumps of alum are deposited for coagulating purposes. This filter is shown in Fig. 96. It is provided with an agitating device for cleaning and its operation is readily apparent from the illustration.

When the greater part of the impurities has been removed in the quartz filter, it is necessary to employ a second filter having a different medium for the final purification. For this purpose a sand, pumice stone, or unglazed porcelain filter has given excellent satisfaction. It will be readily understood that the pores in the unglazed porcelain are so small that impurities of the most minute form will

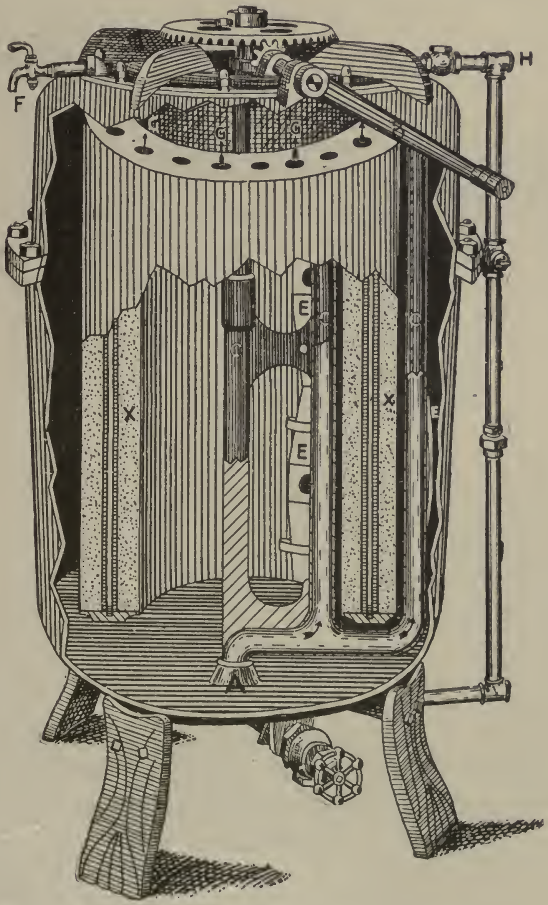


FIG. 97.—LYNN PORCELAIN TUBE FILTER.

be prevented from passing through the same, and the water which percolates through this medium will be positively free from all suspended matter. In order to facilitate filtration, the filtering medium has been so constructed that it presents a very large filtering surface to the water which passes through it. This is accomplished by adopting a cylindrical form for the filtering medium, this cylindrical form having numerous core holes running horizontally through the center of its wall. In operation the water is brought to bear on the inner and outer surfaces simultaneously and as the water is admitted into the filter under pressure it is forced through the filtering medium into the core holes. It can be readily seen that this

FIG. 98.—INTERNATIONAL DISK FILTER.

results in an enormous filtering area which far surpasses the area of any flat stone filters. The construction of the filter is shown in Fig. 97 and the core holes in the walls of the cylindrical filtering medium are designated with the letter *G*. As it is necessary to remove the impurities which gather on both sides of the filtering surfaces, the filter is equipped with a scraping device, which is moved by a geared crank. The collection of impurities adhering to the surfaces of the stone is removed by turning the crank and allowing the scraper to detach same from the stone, whereupon they are flushed out through the flush valve located at the bottom.

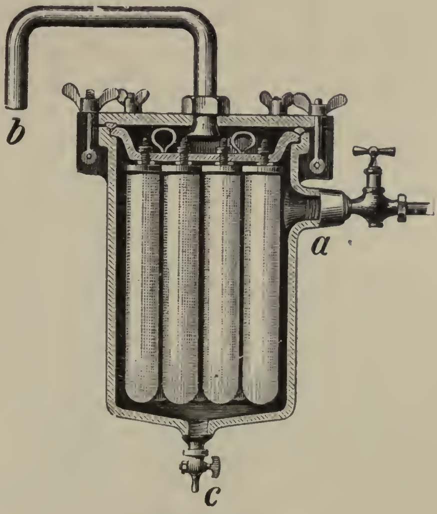


FIG. 99.—BERKEFELD FILTER.

Fig. 98 illustrates the disk filter manufactured by the International Filter Company, Chicago. The filter medium consists of compressed cotton fibre disks, which are successfully used for a thorough after purification of water. The special feature of this filter is that the filter medium is discarded when clogged and replaced with fresh, so that the filter is always like new and the results may, therefore, be depended upon for uniform efficiency. The advantage of having the filter always new is that the bacteria removed from the water can not go through the filter medium. This filter has also proved of value in the final purification of distilled water after the same leaves the still and passes into the cooling apparatus.

A filter which has found considerable favor in carbonated water factories is shown in Fig. 99. It contains a number of hollow cylinders made of infusorial earth. The peculiar properties and microscopical construction of this earth—composed as it is of the silicious skeletons of diatomaceæ—render it peculiarly suitable for the purpose of water purification.

The water passes through these earthenware cylinders, the surface of which retains the impurities. Cleaning of the filters is effected by air pressure. It is claimed that the pores of this filtering material are sufficiently small to prevent the passage of the most minute suspended organic or inorganic matter. The receptacle is enameled on the inside and tested to a pressure of 120 pounds, so that filtration under considerable pressure may be employed.

The filters illustrated and described above represent the various types which are most suitable for the purpose of mechanically purifying water which is to be used in the manufacture of carbonated beverages. It should be borne in mind that all of these filters must be frequently cleaned as otherwise the micro-organisms will accumulate in the pores where they will form veritable colonies of microbes. The only thorough method to prevent the propagation of microbes in the filtering material is the application of heat in any form. A number of apparatuses have been invented for sterilizing the filtering material and thereby exterminate the germ life absolutely, but as the application of such apparatuses is not always feasible in the bottling establishment, recourse should be taken to clean live steam, and the filtering material when subjected to its purifying influences for a sufficient length of time can then safely be employed again for its purpose because the danger of contamination by microbes no longer exists.

In many localities water cannot be purified mechanically to a sufficient degree to make it fit for drinking purposes. In such case, as well as in the case where water is to be used in the manufacture of high class mineral waters, the mechanical purification process must be supplemented by distillation. During distillation all of the foreign matter held in solution in water may be eliminated by means of evaporation and condensation of the vapor.

During distillation the pure water is separated from the impurities dissolved therein by evaporation, and any pathogenic bacteria which it may contain will be destroyed. A subsequent condensation converts it back into the liquid form. Owing to the high latent heat of water—960 B. T. U. per pound—it requires a large amount of heat for its evaporation. This heat is supplied either by a direct fire under a boiler or by live steam.

The simplest process of distillation is carried out by the aid of an apparatus shown in Fig. 100, which is composed of a retort, *A,* fitted with a head, *C,* communicating through a beak with a spiral coil, *S,* which is immersed in a tank through which flows a stream of cold water. To proceed, the water is introduced into the retort, the fire is lighted and the spiral coil is kept cool by allowing cold water to circulate through the tank. As soon as the water has been sufficiently heated the vapors rise from it into the head where any foreign matter that may have been carried along by the mechanical force of ebullition is deposited. It then passes into the spiral coil, where, as the result of the cooling action of the water, it is condensed and converted back into the liquid form. When leaving the spiral coil it should be collected in a perfectly clean vessel.

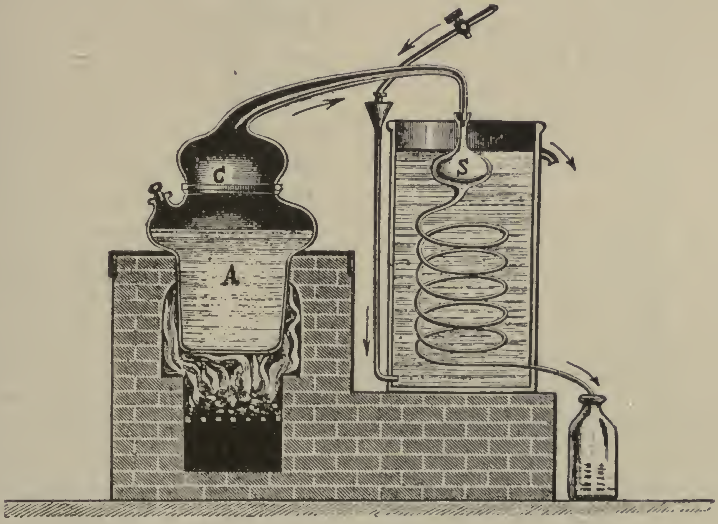


FIG. 100.—WATER STILL.

In order to avoid the carrying over of impurities into the distillate, only three-fourths of a given quantity of water should be evaporated in the still and the rest should be thrown away. This precautionary means is used principally to prevent the entrance of ammonia and hydrochloric acid into the distillate. The same means also prevents the carrying over of all organic matter during distillation, so that the resulting distillate remains entirely pure. When water is to be distilled in considerable quantities, it becomes necessary to construct a distilling apparatus with the view of utilizing the heat applied for this purpose as thoroughly as possible.

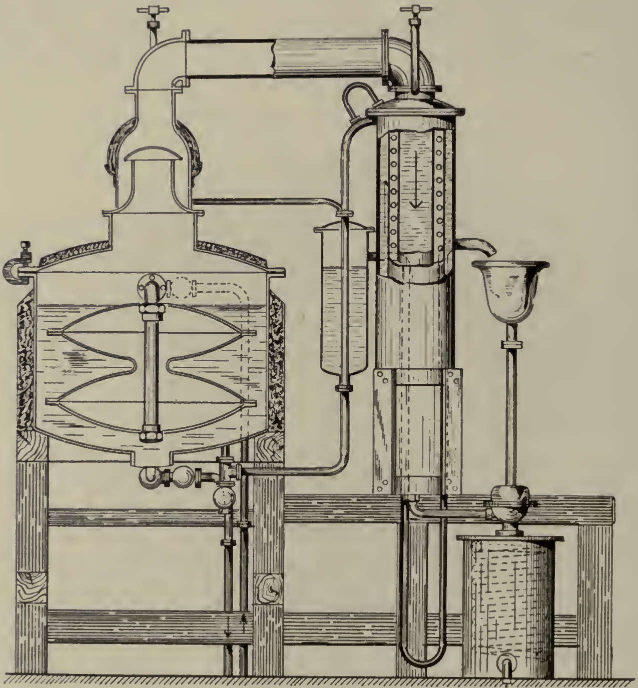


FIG. 101.—DISTILLING APPARATUS.

A number of distilling apparatuses have been constructed to allow the greatest possible economy in the expenditure of heat during evaporation and the partial reabsorption of the heat in the condenser, transferring a large bulk of it from the condensing steam vapors to the cooling water, which is subsequently evaporated.

The apparatus embodying this principle is shown in Fig. 101. Its principal body contains the evaporators, into which live steam is admitted. The evaporator does not consist of spiral coils, which are frequently used for boiling, but of several hollow, lens-shaped vessels, having a large surface. This shape is selected in preference to coils, as its surface, which will be covered with the precipitation of minerals from the water, can be cleaned much more readily. Steam from the boiler passes through this evaporator, thereby heating and evaporating the water surrounding it, and as it is enclosed within same, it can not come in contact with the water to be distilled, so that a contamination by the boiler steam is avoided. The vapor from the still is then condensed in the attached steam condenser, the inside of which is heavily tinned. Cooling water passes through the condenser in tubes, also heavily tinned; it picks up the heat from the vapor, thereby condensing the latter. This heated cooling water is then admitted to the still to be evaporated in its turn. Previous to entering the still it is advisable to boil it by means of exhaust steam, or any other available waste heat, during which the volatile matter, air and gas, are expelled. Solid impurities are forced to the surface during boiling and are carried away by skimmers.

If, in spite of the greatest care and cleanliness, a slight odor appertains to the distillate, it is necessary to deodorize it by filtering through charcoal contained in a receptacle made of infusorial earth or porcelain.

When water of considerable impurity has to be used in lieu of a more desirable product, it is well to subject it to a double distillation after the mechanical purification by means of filters. Diagram, Fig 102, illustrates a system of double distillation which is used in many mineral water factories. Steam from the boiler enters the still and travels through a nest of copper coils, thereby evaporating the water surrounding the latter; the steam then passes to the boiling pan located above the still. In this boiling pan the steam is condensed when it reaches the outlet of the block-tin pipe coil through which it passes; the condensation runs back through a spiral sheet-copper partition, within which the block-tin pipe coil is placed, so that the condensation is again boiled by the steam in the coil, while the lower temperature of the condensation is used to remove the latent heat of the steam, thereby condensing it. The balance of the heat which, if left, would effectually prevent the condensation of the steam is expelled by radiation, or by cooling in a separate submerged condenser attached to the boiling pan. The gases, air and odors, are discharged through the exhaust vapor pipe. The boiled condensation runs into the still, where it is evaporated by the live steam from the boiler. The vapors pass into the submerged condenser to be condensed and cooled and the double-distilled product is drawn off into sterilized receptacles. This apparatus produces 1,000 gallons of cold, pure, tasteless and odorless, double-distilled water with a 1-inch steam supply at seventy-five pounds boiler pressure and a 1¼-inch cooling water supply; and the estimated cost of water production is one-quarter to one-half cent per gallon.

A distillate that is being produced from live steam furnished by the boiler is often found unsatisfactory for the reason that it contains an odor which makes its use highly objectionable. This odor is evidently created by the high temperature in the boiler which scorches the vegetable matter in the water and creates a peculiar odor which is then absorbed by the water.

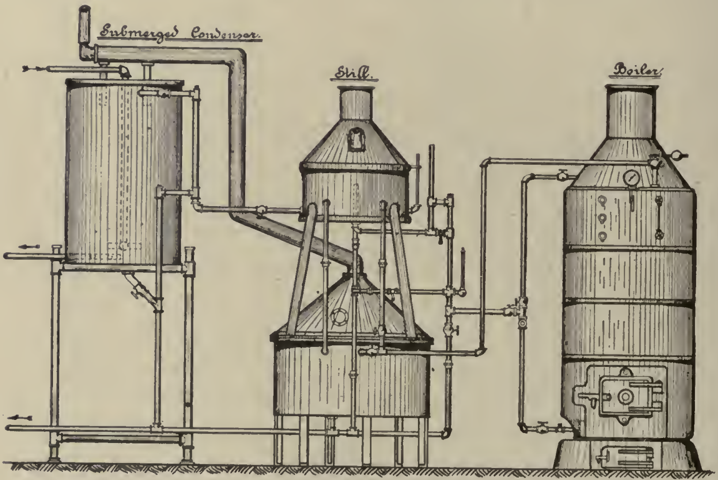


FIG. 102.—WITTEMANN DISTILLING EQUIPMENT.

A distillate possessing an odor of any kind is liable to spoil the product to which the very best extracts or fruit flavors have been added, because the odor absorbed by the water from the scorched matter is so pungent in its disagreeable nature that it overshadows the flavors of the fruits and extracts.

During the distillation process all the air and other gaseous matter is thoroughly expelled from the distillate in the ordinary distilling apparatus. There are, however, occasions where the oxygen of the air ought to be re-incorporated with the distillate in order to make the water palatable.

These objects are thoroughly accomplished in the Jewell still shown in the accompanying illustrations. Fig. 103 shows a vertical cross section of the apparatus illustrating its interior arrangement. The body of the still consists of a cast-iron cylinder *a*. This cast-iron cylinder is provided at the top with an end-plate *b* and at the bottom with another end-plate *c*, both of which are flanged to cylinder *a*. In the end-plate *b* are placed a number of vertical tubes

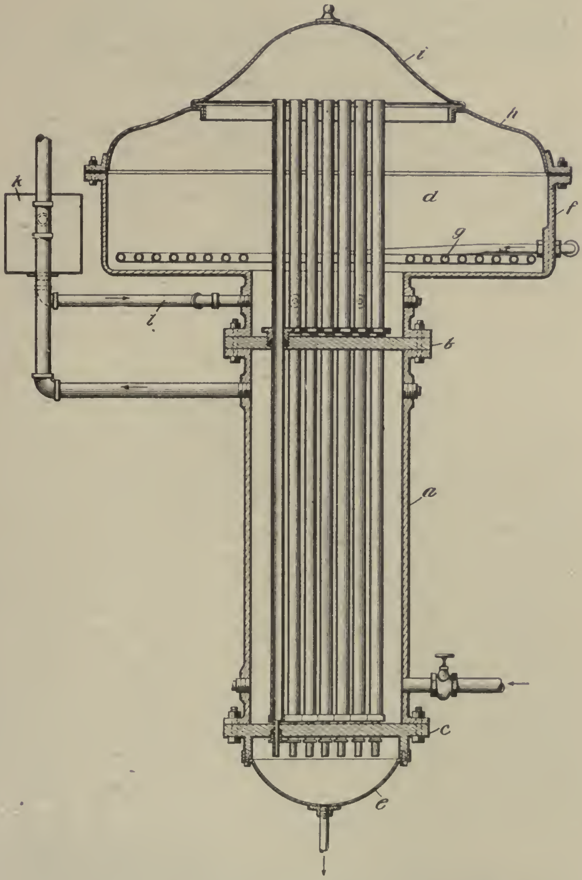


FIG. 103.—VERTICAL CROSS SECTION JEWELL STILL.

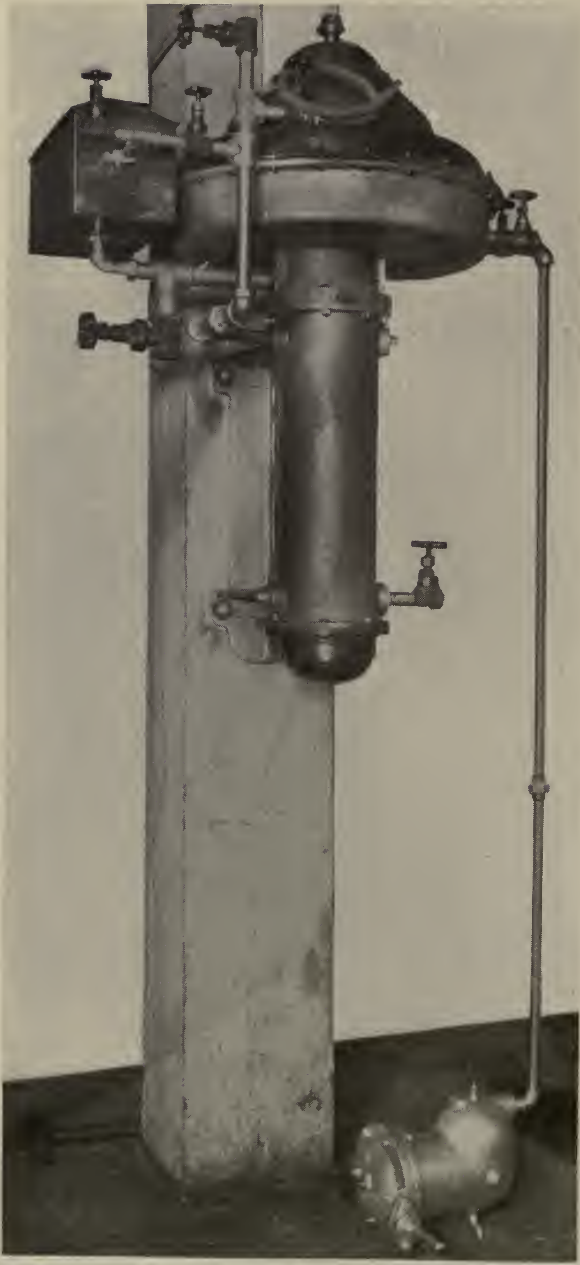


FIG. 104.—COMPLETE JEWELL STILL ATTACHED TO POST AND SHOWING TRAP CONNECTION.

which pass through the same and extend into the dome *d* of the still. The tubes are secured in the end-plate *b* in a suitable stuffing box, so as to allow expansion and contraction of the tubes. On their lower ends the tubes are capped and reduced to a small diameter, which passes through the lower end-plate *c*, being secured therein by similar stuffing boxes as those in *b*. Below the end-plate *c* and secured to the latter is a half-round bowl *e*, which is provided with an outlet flange through which the distillate is drained. The dome *d* consists of a solid cast-iron pan *f*, having at its lower end a flange by means of which it is bolted together with the flange of cylinder *a* and the cast-iron end-plate *b*.

In this pan, which we will term the evaporating pan, is placed a spiral evaporating coil *g* consisting of copper pipe. The evaporating pan is closed at the top by means of hood *h* and a removable cover *i*. This hood or dome forms the vapor space of the water evaporated in the evaporating pan. The water to be evaporated is contained in a float box *k*. A float in the latter controls the admission of water through pipe *l* into the evaporating pan, so that a uniform level of water is maintained in the latter. Steam of between 50 and 75 pounds pressure enters the evaporating coil and during its passage through spiral coil *g* it boils the water and finally evaporates same. In order that all the latent heat of the steam may be utilized, the steam outlet of coil *g* is controlled by a steam trap which discharges the condensed steam automatically.

The steam trap and its connection is shown in Fig. 104, which illustrates the exterior appearance of the apparatus. The cylindrical body *a* of the still is the condenser and cooler, in which the evaporated water is condensed and cooled. The inlet of the cooling water is shown at the bottom of cylinder *d* and the flow is connected with the float box *k* in a way that part of the water which has been heated to some extent in the condenser may afterwards be used in the evaporator. The condensation from the trap and the additional water passing through the condenser and cooler can be utilized for boiler feed purposes.

The operation of the still is as follows: Assuming that the evaporating pan *f* is filled to the proper level with water and that the steam is turned on into the evaporating coil *g*, it will be clear that the water will start to boil immediately and evaporate. This evaporation is greatly facilitated because of the fact that the body of water surrounding the evaporating coil is thin and that the surface of the water is large. The vapors pass upward into the hood *i* and are immediately drawn into the tubes because the rapid condensation which takes place in the condenser *a* produces a vacuum in the vapor space and in the upper ends of the tubes. The vacuum so created greatly enhances the rapid evaporation of the water. After the same has been condensed it cannot run out of the tube very freely, owing to the reduced outlet of the tubes. On account of this fact the condensation remains in the tube a sufficient length of time to permit of its thorough cooling before it runs into the half-round bowl *e*.

The apparatus is so proportioned that the distillate runs off freely enough so as to allow the rapid condensation of the steam continually generated in the evaporating pan. All the heat so created is simply transferred into the body of water used for cooling purposes. When this water is used for boiler feed purposes, together with the condensation of steam used for evaporating purposes, the losses occurring in this still are simply those of radiation. The condensation of the steam used in the evaporating coil *g* is of a temperature only slightly below the boiling point, and when this condensation is used for boiler feed purposes, it will be seen that the work in the boiler to re-evaporate this condensation is equivalent to the latent heat of steam only.

When this apparatus is used in conjunction with other machinery, it will be appreciated that it will form one of the most economical apparatus for the production of a pure distillate. In this connection it may be stated that the same still can be equipped for the use of exhaust steam in the evaporating coil.

Another modification of the apparatus would be its connection in multiple form. It must be stated, however, that for ordinary purposes and without making the equipment expensive and cumbersome in operation, the still as illustrated is thoroughly efficient and satisfactory. A peculiar feature of the same is that the atmospheric air and the oxygen contained therein is re-absorbed during the condensation of the vapor, so that the distillate does not lose its palatable characteristics. It will also be appreciated that owing to the moderate temperature of the live steam, scorching of any vegetable matter which may be in the water cannot take place and the distillate remains free from objectionable odors. In cases where the water contains objectionable gas from decomposed vegetable or animal matter, a gas chamber can be added to the hood *i* and such gases can then be blown off continually from the gas chamber. When the water is muddy and polluted with vegetable and animal matter, it is advisable to filter the water before admitting it into the float box *k*.

This is usually resorted to in localities using river water. But, throughout the territory of the great lakes it is hardly necessary to filter before distilling. Owing to its peculiar construction the evaporating chamber can be cleansed readily. It is also possible to remove precipitations without any difficulty in case the water contains considerable mineral matter.

A storage tank is ordinarily placed below the distilled water outlet in which the same is being collected. This tank is closed so as to prevent contamination of the water and is provided with a glass gauge showing the level of the water within.

In Fig 104 a complete view of still is shown fastened to a post. This still is of sufficient capacity to furnish from 35 to 40 gallons of distilled water per hour. It may also be fastened against the wall in a similar way, and if greater quantities of distillate are needed, a number of such stills can be connected in series and the accumulative distillate can then be very easily and readily drawn off into a storage tank of sufficient capacity.

The stills are manufactured by the Jewell Water Improvement Co., 120 West Jackson boulevard, Chicago, and are manufactured in a number of different sizes having a capacity of ten gallons per hour and upward.

In plants requiring large quantities of distilled water a more economical production is necessary. The means are readily at hand in the waste heat of flue gases from the boiler and exhaust steam from the engine, pumps, etc. If a subsequent aeration is required, which is advantageous in some cases, it can be readily done in a simple way. A complete plant, using the heat of flue-gases from the boiler, and, if that is not sufficient, additional heat from exhaust steam, is shown in diagram Fig. 105. It is a process of evaporating water at the lowest possible temperature in a partial vacuum, and it shows a great saving in its production, as the heat used would otherwise be lost in the atmosphere. The equipment and the manner in which it is operated can be readily understood by studying the diagram and comparing the description.

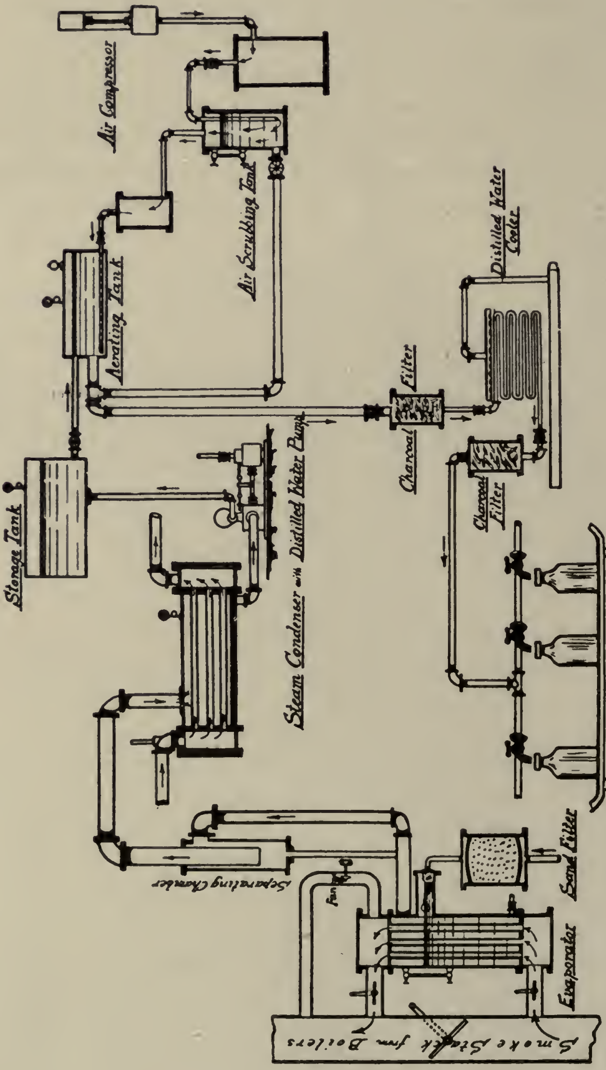


FIG. 105.—DIAGRAM OF WATER DISTILLING AND AERATING SYSTEM.

The water from the source of supply is first passed through a sand filter that can be readily cleaned. At the left of the diagram will be seen the main flue connection from the boiler, which contains the main damper. In starting up, the main flue damper is closed and two by-pass dampers on the connections from the main flue to the evaporator are opened. The evaporator tank is filled with filtered water and this supply is controlled by a "Utility" pump governor which automatically maintains a constant height of water in the evaporator tank. A strainer is placed between the pump governor valve and the tank to keep out any floating scale or dust. A vacuum is maintained in the evaporator by means of a vacuum pump, which also maintains a vacuum through the condenser and main vapor pipe line and the separating chamber. If any water is carried over by the vacuum pump it is precipitated in the separating chamber and is returned through the drip pipes to the evaporator. Air is kept out of the evaporator by means of a check valve that closes by its own weight when the water ceases to flow, as admission of the air would break the vacuum.

The vacuum pump maintains a partial vacuum in the evaporator so that the water is turned into steam below the atmospheric boiling point and consequently the temperature is not high enough to burn the organic matter in the water and produce foul gases. The object of the separating chamber is to secure only pure vapors in the condenser. The vacuum pump handles the distilled water after it has been condensed in the condenser and discharges it into the storage tank. If the water is used in the production of mineral waters, it has to be carbonated. In order to obtain simply pure drinking water, it must be aerated again. This latter process is shown in the second part of the diagram. The water flows from the storage tank by gravity to the aerating tank, where it is aerated by a supply of air passed through perforated pipes. This air is supplied by an air compressor which draws its supply from the outside of the building and discharges it through an air scrubbing tank. The air scrubbing tank is filled with distilled water and the air being discharged at the bottom is compelled to rise through the water. Consequently all the dust and foul matter is removed from the air. The water in this tank is kept pure by emptying and refilling it every twelve hours. Inasmuch as absolutely pure air is discharged into the aerating tank, the water acquires a natural and palatable taste. From the aerating tank the water comes down through a filter filled with bone-black charcoal. This acts as a deodorizer and helps to supply to the water those natural elements, such as magnesia and lime, which may have disappeared in the process. From this point the water flows to a cooler which is made up of coils of pipe and is cooled by passing over the outside of the cooler pipes, after which it enters another filter, which is supplied with pure willow charcoal. From there it goes to the header, where it is drawn off in bottles and five-gallon demijohns. There are many advantages claimed for carbonated beverages made from pure distilled water as compared with those that are not, of which the principal ones are that they are more wholesome and of better keeping qualities.

It is necessary to cool the water thoroughly, as lukewarm water has a great tendency to produce flakes and ropiness. If the water used as the cooling medium in the condenser and cooling coil is not sufficiently low, recourse must be had to some system of mechanical refrigeration.

The distillate must be used in the manufacture of mineral water as soon as produced. If kept in open receptacles it will soon become contaminated with bacteria, which will destroy its usefulness.

COMPOUNDING OF ARTIFICIAL MINERAL WATERS.

The most important chemicals used in the preparation of artificial mineral water are sodium, potassium, calcium and magnesium in combination with carbonic, sulphuric and hydrochloric acid; it nearly always contains phosphates; iron and mangan are present in small quantities; lithium, strontium, baryum and ammonium much less frequently, and bromide as well as iodide, but only in slight traces, if at all.

Nearly all the salts are soluble in water, other ingredients are made soluble through the action of carbonic acid, pressure and, sometimes, increased temperature.

Iron, mangan and sulphates are added to the mixture in a much diluted solution. Before iron and mangan can be added the mixture must be entirely free from atmospheric air in order to prevent oxidation and precipitation. The mixture is prepared in a special mixer, provided with an agitating device, and under constant carbonic acid gas pressure after all atmospheric air has been expelled from the same.

The air is discharged from the mixer by filling it full to overflowing, carbonic acid gas is then admitted at a pressure slightly above the atmosphere and is absorbed by the water under agitation. The solution containing the salts is then added, keeping the agitator moving at slow speed. Some of the heavy salts are liable to precipitate. This precipitation must be drawn off at the bottom of the mixer and must again be added to the solution until all have been dissolved.

Iron and mangan is introduced by drawing from the mixer a quart bottle full of the solution, to which the dissolved iron and mangan is added, which is mixed by turning and shaking the closed bottle gently and then emptying same into the mixer, carefully avoiding the entrance of atmospheric air. The mixture should be given plenty of time to thoroughly assimilate the various solutions, sometimes as much as twenty-four hours, and should then be drawn off into receptacles from which the air has been expelled by carbonic acid gas or distilled water.

WATER COOLING AND CARBONATING.

When the distillate leaves the cooler of the distilling apparatus, its temperature can at best be reduced to the temperature of the available water only which has been used for cooling purposes. The temperature of such water averages in summer 70° F. in the Middle States of the United States. In the South and along the rivers the temperature usually registers much higher and may be all the way up to 85° or 86° F. It will therefore be apparent that water of such high temperature does not cool the distillate so as to prepare it for the reception of carbonic acid gas. It is well known that liquids of high temperature do not absorb gas as readily as liquids of a correspondingly lower temperature. This is particularly the case with such gas as carbonic acid, which does not possess a great affinity for water, and which can therefore be incorporated with liquids only when the latter have been reduced in temperature. Even at low temperatures liquids do not absorb sufficient carbonic acid gas without resorting to mechanical force or pressure in order to make the beverage palatable and pungent in taste. But, as the presence of carbonic acid gas in water gives to it its peculiar life and stimulating character, it is absolutely necessary to force a volume of carbonic acid gas into the water, sufficient to make it a sparkling, refreshing and agreeable drink. Without carbonic acid the taste of water which forms the basis of any of the flavored carbonated beverages is flat, stale and disagreeable. In mineral waters which are used for medicinal purposes the presence of carbonic acid is all the more desirable, because it is in itself one of the ingredients which has a tendency to stimulate the whole system, thereby infusing a pleasant and agreeable effect and inducing renewed activity in the circulatory functions.

At atmospheric pressure water absorbs carbonic acid only to a limited extent. It is therefore necessary to resort to mechanical pressure in order to force the required volume of gas into the water. This pressure must then be maintained, as otherwise the volume of gas so incorporated with the water will immediately escape. The mechanical method of impregnating water with carbonic acid gas is greatly facilitated when the temperature of the water is sufficiently reduced. At low temperatures the gas is much more readily absorbed, and if such low temperatures are maintained subsequent to the carbonating process, the water is given a chance to more thoroughly absorb the gas, which in this way becomes more firmly bound with the water and does not as readily escape when the pressure is removed, as it will if the temperature of the water increases immediately after carbonating. A low temperature of the water increases its capacity for absorption, and an increase in the pressure with which the gas is charged into it does likewise. The proper relation of pressure and temperature for carbonating purposes must be fully understood, in order that uniformly satisfactory results may be obtained.

When distilled water is used as a base, the carbonating process is accomplished with less difficulty than is encountered if ordinary hydrant water is used. It must be borne in mind that ordinary hydrant water which has been exposed to the atmosphere contains a considerable volume of air. Ordinarily the volume of air so absorbed by the water represents twenty times the volume of the latter, and it will therefore be seen that if it is desired to incorporate from four to six additional volumes of gas with the water, the air contained therein will necessarily resist such impregnation. This difficulty does not exist in the case of distilled water, for the reason that all atmospheric air has been thoroughly expelled from the water during the distilling process. It may be stated in this connection that if the distillate should have had a chance to reabsorb atmospheric air after the distilling process, the air can be again expelled therefrom by forcing carbonic acid gas into the water under pressure. When this is done it will be found that at 60 pounds of gas pressure and a temperature of the distillate of 40° F. all atmospheric air can be expelled. This must be done during the saturation process by expelling the air from the saturator from time to time. Many of the saturators are provided with an air collecting chamber, where the latter collects and from whence it is discharged into the atmosphere.

In order that the necessity of employing pressure for carbonating purposes may be fully understood it should be borne in mind that water absorbs about its own volume of carbonic acid at atmospheric pressure and at a temperature of 50° F. But the water does not obtain its desired characteristics as a carbonated beverage with a volume of gas less than from four to five times the volume of water; the required additional gas must therefore be forced into the water by mechanical means, and this method is exemplified in the mechanical apparatus known as the carbonator.

When the temperature of the water has been reduced very low, it is possible to introduce into the liquid a volume of gas which will be in excess of what is needed. This volume will be partly liberated from the water during a rise in its temperature. The volume so liberated appears in the form of pressure in the receptacle in which it is enclosed, and may become so high as to cause considerable breakage of bottles. It will be seen that this also is detrimental, and should be avoided. For these reasons the relations of pressure and temperature during carbonating are very important factors in a carbonating plant. A volume of gas which is insufficient to produce the desired beverage is as deleterious as a volume of gas which produces over-saturation of the water. The former does not produce the desired sparkling and exhilarating effect and the later will result in breakage of bottles, causing loss and damage.

A reduction of the pressure at which a certain body of water is charged with gas liberates a part of the latter. Exchange of air and CO_2 gas takes place when a closed barrel contains a body of water saturated with CO_2 at a certain pressure and a volume of air above the water. The CO_2 diffuses into the air and the water absorbs a part of the air in place of the gas.

Water filled into an open glass loses its CO_2 nearly entirely, and with it most of its refreshing properties.

A large body of water saturated with CO_2 at a fixed pressure and temperature does not lose its gas when the pressure is slightly reduced. This condition is called over-saturation and is produced more readily with a large body of water than with a small quantity. A condition of rest favors over-saturation and a condition of motion prevents same.

For all practical purposes the pressure and temperature at which saturation takes place have been established.

Bunsen and Pauli made the first investigations in this direction and established the following rules:

1 cubic foot of water of 32° F. and atmospheric pressure absorbs 1.7967 cubic feet of CO_2 at atmospheric pressure.

1 cubic foot of water of 41° F. and atmospheric pressure absorbs 1.4496 cubic feet of CO_2 at atmospheric pressure.

1 cubic foot of water of 50° F. and atmospheric pressure absorbs 1.1847 cubic feet of CO_2 at atmospheric pressure.

1 cubic foot of water of 59° F. and atmospheric pressure absorbs 1.0020 cubic feet of CO_2 at atmospheric pressure.

1 cubic foot of water of 68° F. and atmospheric pressure absorbs 0.9014 cubic feet of CO_2 at atmospheric pressure.

Wroblewski was the next scientist to establish reliable data regarding the absorption of CO_2 by water at various pressures. He found that the coefficient of saturation is the quantity of CO_2 gas in cubic centimeters at atmospheric pressure and the temperature of 32° F. required to saturate one cubic centimeter of water at the temperature of 32° F. and the pressure P. Upon this basis he established the following table:

SATURATION OF WATER WITH CO_2.

P. Pressure in pounds	S. Coefficient of saturation		$\frac{S}{P}$	
	At 32° F.	At 54° F.	At 32° F.	At 54° F.
0	1.797	1.086	1.797	1.086
73.5	8.65	5.15	1.730	1.030
147	16.03	9.65	1.603	0.965
220.5	21.95	13.63	1.463	0.909
294	26.65	17.11	1.332	0.855
367.5	30.55	20.31	1.222	0.812
441	33.75	23.25	1.124	0.775

These figures demonstrated the following law regarding the solubility of carbonic acid in water:

First—If the temperature remains constant and the pressure increases, the coefficient of saturation increases at a much slower rate than the pressure.

Second—If the pressure remains constant and the temperature decreases, the coefficient of saturation increases much faster in comparison with the gradual reduction in temperature.

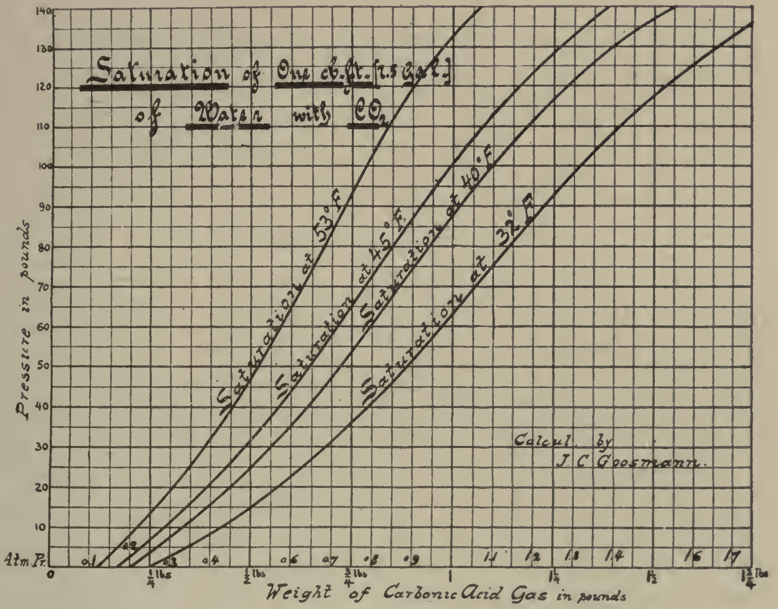


FIG. 106.—DIAGRAM SHOWING SATURATION OF WATER WITH CO_2.

Third—The solubility of liquid carbonic acid in water exceeds very little that of the gaseous CO_2 at pressures just below the point of liquefaction.

The accompanying chart (Fig. 106) illustrates the saturation curve at temperatures of 32°, 40°, 45° and 53° F., and the point of saturation or the point governing the highest possible solubility of carbonic acid in water is set forth in the following table. In this table P is the gauge pressure of the carbonating pump in pounds, and at that pressure one cubic foot (7.5 gallons) of water is capable of absorbing the quantity CO_2 gas in pounds as stated in the table at the temperature of the water 32°, 40°, 45° and 53° F.:

SATURATION OF ONE CUBIC FOOT OF WATER WITH CO_2.

P. Pressure in pounds. (Gauge)	One cubic foot (7.5 gall.) of water absorbs CO_2 in pounds.			
	At 32° F.	At 40° F.	At 45° F.	At 53° F.
0	0.25	0.20	0.17	0.12
5	0.35	0.27	0.23	0.17
10	0.43	0.34	0.29	0.22
15	0.50	0.40	0.34	0.26
20	0.57	0.45	0.39	0.31
25	0.64	0.50	0.44	0.35
30	0.69	0.55	0.49	0.39
35	0.74	0.60	0.53	0.42
40	0.79	0.64	0.57	0.45
45	0.84	0.69	0.61	0.49
50	0.89	0.72	0.65	0.52
55	0.93	0.76	0.66	0.55
60	0.97	0.80	0.72	0.58
65	1.02	0.84	0.75	0.60
70	1.05	0.87	0.78	0.63
75	1.10	0.90	0.82	0.66
80	1.14	0.94	0.85	0.68
85	1.18	0.98	0.89	0.71
90	1.24	1.02	0.92	0.74
95	1.27	1.05	0.95	0.76
100	1.31	1.10	1.00	0.78

P is the gauge pressure of the carbonating pump in pounds, and at that pressure one cubic foot (7.5 gall.) of water is capable of absorbing the quantity of CO_2 gas in pounds as stated in the table at the temperature of the water of 32°, 40°, 45° and 53° F.

Practice has since established the required relation of carbonic acid gas in water for certain specific beverages. It has been found that water which is to be highly flavored with fruit, etc., does not need to be impregnated with the same volume of gas that is required for soda and other mineral water, whereas in the case of seltzer siphons the volume of gas required is considerably larger than in any other beverages. It is ordinarily assumed that from three and one-half to four volumes of gas are sufficient for carbonating a volume of water when the latter is to be used for fruit beverages. For soda water this volume is increased to six and for seltzer siphons it is as high as eight volumes of gas to the volume of water.

In the chart shown herewith (Fig. 107) the relation of pressure and temperature is given to impregnate ordinary water, soda water and seltzer siphons with the necessary volume of carbonic acid gas. Three curves are shown representing, respectively, ordinary water, soda water and seltzer siphons. For ordinary water four volumes of gas have been taken as a basis, for soda water six volumes have been used; and for seltzer siphons the volume of carbonic acid gas has been increased to eight. At the foot of the chart in the horizontal line will be found the various temperatures of the water to be carbonated, and in the vertical line are given the respective pressures which are needed in order to incorporate the desired volume of gas with a volume of water. By following the horizontal and vertical lines, the point at which the carbonating curve converges with the same establishes the corresponding pressure and temperature. Or, if the temperature of the water is known and it is desired to establish the carbonating pressure in order to obtain the desired result, it is only necessary to follow the vertical line of the corresponding temperature until it meets the carbonating curve, then follow the horizontal line to the left and find the pressure required.

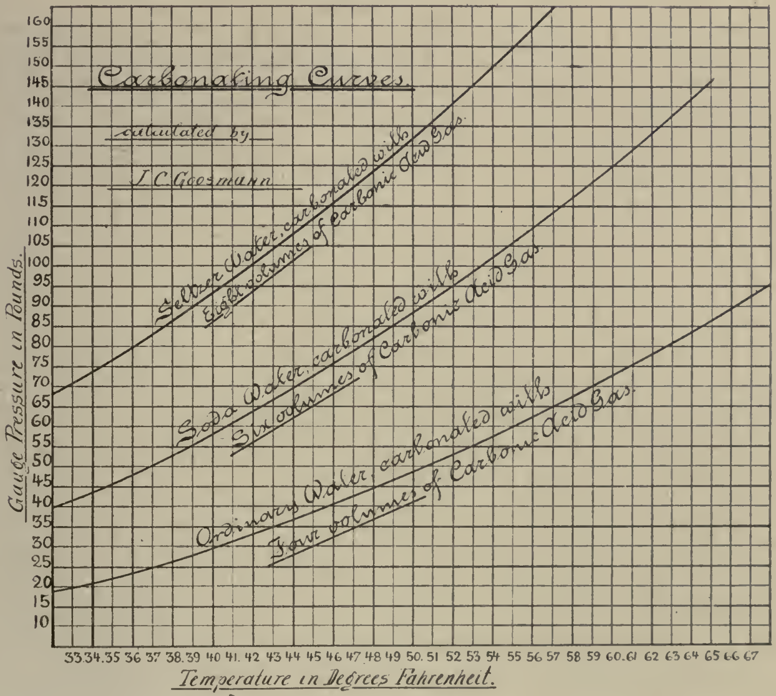


FIG. 107.—CHART SHOWING RELATION OF PRESSURES AND TEMPERATURES FOR IMPREGNATION OF LIQUIDS WITH CARBONIC ACID GAS.

In the chart are given three carbonating curves, of which the lower curve is used for ordinary water, the middle curve for soda water, and the highest curve for seltzer siphons. By using this chart, pressures and temperatures can be immediately established and uniform results will be the outcome. On the other hand, if the pressure is known at which the carbonator should operate, then by means of this pressure the temperature to which the water must be cooled can readily be found.

When this relation of pressure and temperature for carbonating purposes is understood, it will easily be seen how necessary it is to establish the temperatures of the water which correspond with normal pressures, in order that a sufficient volume of carbonic acid may be absorbed by the water so as to make it serve the purpose for which it is intended.

The means for cooling the water may be widely varied. The cooling of water is based upon a very simple physical law. This law relates to the removal or transfer of heat, and according to it the heat of a higher level in a certain body can be readily transferred to the heat of a lower level of another body. In order to make this clear, it may be permissible to point to the fact that when a body of water of a higher temperature is mixed with a body of water of a lower temperature, it will be found that an average temperature will be established, which is the arithmetical middle between the high and the low temperature. The heat in the water of the high temperature has simply been absorbed by the water of the low temperature, or, in other words, a transfer of the heat from a higher level to a lower level has taken place. The same result can be obtained by establishing a thermal contact between the water of a high temperature and the water of lower temperature. In this way the two bodies are kept separate and yet a transfer of heat from the high level to the low level can take place. This simple rule can be carried into practice very readily by passing a body of warm water to be cooled through a block-tin coil submerged in a tank containing a body of water of a lower temperature. During the passage of the water through the coil its heat will be absorbed by the water in the tank until it corresponds in temperature nearly with the water in the tank, provided the surface of the block-tin coil is sufficiently large to allow all of the heat of the water inclosed therein to be absorbed by the water in the tank. This establishes three factors with which we have to deal when cooling the water. The first factor is the high temperature of the water to be cooled, the second factor is the temperature of the cooling medium, and the third factor is the surface by means of which thermal contact is established between the water of high and the medium of lower temperature. When the temperature of these two mediums is very far apart, the transfer of heat from the higher level to the lower level will be very energetic. On the other hand, if the difference in temperature is not very great, then the transfer of heat from the higher to the lower level will be rather slow. When the difference in the temperature is not very great the surface of contact between the two mediums must be increased, and on the other hand, if there is a wide variation of temperature between the medium to be cooled and the cooling medium, then the surface of contact may be diminished. In order to illustrate this law, it will be readily seen that the heat of water at a temperature of 90° F. will be much more readily picked up by the cooling medium consisting of ice water of a temperature near 32° F. than it would be if ordinary hydrant water of a temperature of 65° F. was used. For practical purposes it has been found that when the temperature of the distillate is high, it is economical and advisable to use a cooler in which ordinary hydrant water is used as the cooling medium. But, as soon as the temperature of the distillate has been reduced to nearly the temperature of hydrant water, it is necessary to resort to other means in order to reduce the temperature of the distillate to the desired carbonating temperatures, which should be in the neighborhood of 45° F. The latter means, by which a more effective cooling and the final low temperature of the distillate is reached, consists of ice water, brine of a low temperature and mechanical refrigeration. The methods employed in order to obtain satisfactory and economical results will be fully explained and illustrated hereafter.

In the large majority of bottling establishments too little attention is devoted to the advantages of low temperature carbonating. In many of these places the idea seems to prevail that so long as water of an established purity is passed through the carbonator it is suitable for the purpose for which it is intended. Nothing could be more erroneous. Even if the liquid has passed through the complete procedure from one apparatus to the other, it may be as little suited for this purpose as though it had not been treated at all. When water has been purified suitable means must be employed in order, first, to absorb the required volume of carbonic acid gas; second, to prevent excessive breakage during carbonating and stoppering, and, third, to diminish wear and tear in the machinery.

The crudest method of cooling the water, or in other words, removing the heat therefrom is to circulate water through a block-tin coil as shown in Fig. 108. In this device the block-tin coil is enclosed in a circular iron tank. The coil is placed within the tank at a suitable distance from the bottom, so that its complete surface may be benefited by the cooling medium surrounding it. Above the coil is placed a perforated disc made preferably and substantially of wood. Upon this platform is placed crushed ice, which is salted down so that the temperature of the solution obtained therefrom will be below the freezing point of the Fahrenheit thermometer. The necessary water is then added so that the block-tin coil is completely submerged. When to this solution more ice, salt and water is being added from time to time, it is necessary to establish a drain line by means of which the overflow may be carried off. In this way the water which passes through the tin coil can be cooled to between 40° and 45° F.

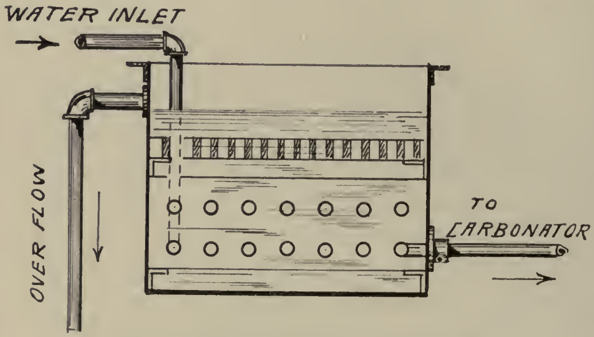


FIG. 108.—COOLING TANK WITH SUBMERGED COIL.

As has been pointed out it is necessary to consider the temperatures of the water to be cooled, as well as the cooling medium, in order to establish the necessary pipe surface through which a given amount of heat can be transferred in a given time from the water to the cooling medium. For example, if the temperature of the water from the filter is 80° and the temperature of the brine solution 30°, it is possible to transfer through each square foot of surface of the block-tin coil 6,000 units of heat every twenty-four hours.

Assuming that a quantity of fifty gallons of water is to be cooled per hour from 80° to 50° F., which is a difference of 35°, the required pipe surface is calculated as follows: As fifty gallons of water corresponds to a weight of 415 pounds, it becomes necessary to remove 14,515 heat units from this quantity of water per hour. One square foot of surface of block-tin pipe will transmit 6,000 heat units in twenty-four hours, or 250 per hour, hence it will be necessary to use a block-tin coil of about 60 square feet of surface. If the outside diameter of the block-tin pipe used for this purpose is one-half inch, it will be necessary to use a coil 270 feet long to remove the heat from fifty gallons of water per hour of an initial temperature of 80° when the water is being cooled to 45° F. For the same cooling work a quantity of ice of approximately 100 pounds per hour will be needed.

The above example shows that in calculating the transfer of heat from a warm body of water to that of a cooling medium of low temperature, it is necessary to obtain the temperatures of the water to be cooled as well as the cooling medium to be used, in order to correctly estimate the cooling surface to be employed. If instead of a brine solution obtained from ice, salt and water, deep-well water of a low temperature is being used, then the temperature of the deep-well water must be taken into consideration, together with that of the sweet water to be cooled.

Deep-well water of as low a temperature as 54° F. is frequently obtained and if such water is used for the purpose of cooling the sweet water to be carbonated, it is possible to reduce the temperature of the latter to about 60° F. When the difference in the temperature between the medium to be cooled and the cooling medium is only slightly more than 10°, the transmission of heat through one square foot of cooling surface is proportionately diminished. With a difference of 10° between the water to be cooled and the water used for cooling purposes, the heat transmission per square foot of block-tin pipe will not exceed 3,000 heat units in twenty-four hours. It follows that if the temperature of the water is to be reduced from 80° to 60°, which is a difference of only 20°, it will be necessary to employ just as much pipe surface to obtain this result with water of 54°, as is required to reduce water to 45° with a brine solution of 30°. In other words, the pipe surface is the same in the case of reducing water to 45° by means of a brine solution of 30°, as compared

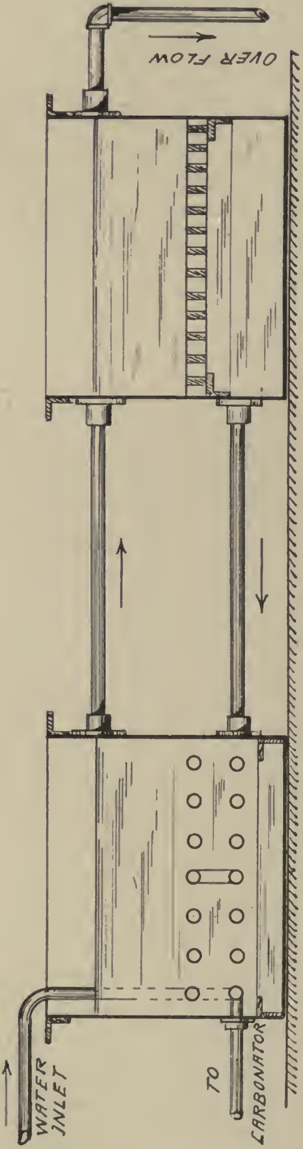


FIG. 109.—COOLING AND BRINE TANK WITH NATURAL BRINE CIRCULATION.

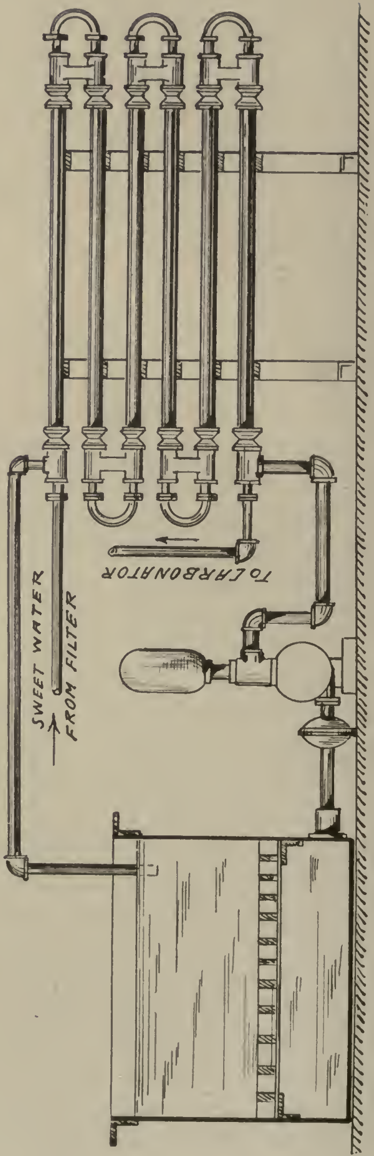


FIG. 110.—DOUBLE-PIPE WATER COOLER WITH BRINE TANK AND PUMP.

with reducing the same quantity of water to only 60° with the cooling medium (deep-well water) of 54° F.

In the apparatus shown in Fig. 109 two tanks are employed for the purpose of cooling the sweet water which enters the block-tin coil in the direction of the arrow. The tank shown on the right hand, in the illustration, is used for making the mixture of ice, salt and water. This solution passes through a perforated false bottom into the lower part of the tank and is conducted by means of a pipe connection to the adjoining tank, in which the block-tin coil is placed. As the cold solution enters the cooling tank, it picks up the heat from the water in the block-tin coil and as its temperature is raised thereby, it becomes lighter and flows through the top connection back into the tank in which the cooling medium is prepared. In this way a natural circulation is produced and the water will periodically return to the brine tank to be cooled again by additional ice, and on account of its own gravity it will flow into the bottom of the cooling tank to remove more heat from the water passing through the block-tin coil. The surplus of water produced through the melting of the ice can be drained off through a suitable overflow connection. It is understood, of course, that both tanks are placed on the same level, in which case a sufficiently active circulation of the brine solution will take place to insure efficient work in the cooling tank.

A more desirable means of cooling is obtained by employing a cooler of the double-pipe pattern. An equipment of this kind is shown in Fig. 110. The double-pipe cooler consists of one-inch copper tubing within a two-inch wrought-iron pipe. The copper tubing is heavily tinned and the sweet water to be cooled enters the top pipe of the cooler and leaves it at the lower pipe. The brine solution is forced into the two-inch pipe which surrounds the one-inch copper pipe, it fills the annular space between the inner and outer pipe, and travels upward within the same, leaving the condenser at the top fitting and returning to the brine tank. It will therefore be seen that the sweet water and brine solution pass through the double-pipe cooler in a counter current, and it has been found that this method of cooling is more efficient than any other, for the reason that the most intimate contact with the surface through which the heat is to be transmitted is established throughout the length of travel. It will also be clear that the water of a high initial temperature meets the brine when the latter leaves the condenser and when it has picked up a great deal of the heat from the sweet water, and again the cooled sweet water meets the brine of lowest temperature in the bottom part of the cooler, so that it can be still further reduced in its temperature, whereby a very efficient cooling is accomplished. It has been found that the cooling surface when so employed becomes from four to five times as effective as the cooling surface placed in a tank and submerged by the cooling medium, so that each square foot of surface in a cooler of this kind will remove up to 30,000 heat units per twenty-four hours, provided the difference in the temperature between the water to be cooled and the cooling medium is not less than 40° F.

In the foregoing the crudest form of cooling the water has been explained and illustrated. This method is not economical nor can it be called sanitary for the reason that the handling of ice and salt on the premises is conducive of much uncleanliness. The only efficient process of cooling large quantities of water to low temperatures is by means of mechanical refrigeration. Very few bottlers stop to think that it is not only a question of obtaining superior and more uniform results with the use of an ice machine, but that the method of carbonating and bottling at low temperatures has the further advantage of preventing excessive breakage, reducing the cost of power required for the operation of the carbonating machinery, thereby diminishing wear and tear of this apparatus greatly. The mechanical process of cooling the water by machinery is absolutely sanitary, owing to the fact that the dirt and moisture which is inseparable from the use of ice and salt is eliminated. There is particularly one system of mechanical refrigeration, which is highly commendable for use in bottling establishments and this system is known as the "Carbonic Acid System of Mechanical Refrigeration." In this machinery carbonic acid is employed as the refrigerating medium and, as it is the same gas which is used for carbonating purposes, it is most suitable for use on the premises of a bottling establishment.

The simplest device for cooling water by means of mechanical refrigeration is one similar to that illustrated in Fig. 109. In the equipment provided with mechanical refrigeration brine is chilled in one tank and is then allowed to circulate through the cooling tank in which the block-tin coil is placed, from whence it returns to the brine tank. This arrangement is shown in Fig. 111, and consists of a compressor, *c,* a condenser, *d,* a brine tank, *e,* and a water cooler, *f.*

In the brine tank, *e*, the cooling coil, *t*, in which the liquid carbonic acid is made to evaporate, is located. The process of evaporation is regulated by the valve, *r*, which is interposed between the condenser, *d*, and the cooling coil in brine tank, *e*. During the evaporation of the liquid carbonic acid the heat is removed from the brine, or in other words, it is cooled down to a low temperature; the evaporated carbonic acid returns through the suction line back to the compressor, *c*, to be again discharged into the condenser, *d*, for purposes of liquefaction.

The cold brine flows from brine tank, *e*, into the cooler tank, *f*, and picks up the heat from the water passing through the block-tin coil, *t*, which is submerged in the brine. It is advisable when brine is used, to adjust the pressure of evaporation so that the temperature of the brine can not be reduced below 25° F. To do this it is necessary to evaporate the liquid carbonic acid in the evaporating coil in tank, *e*, at a back pressure of about twenty-eight atmospheres. When this simple rule is observed, it is not possible to reduce the temperature of the brine so low as to cause a freezing of the water in the coil, *t*. In some instances it is preferred to use sweet water instead of brine in the cooling tank, because the temperature of the sweet water could not be reduced as low as the brine without causing it to freeze.

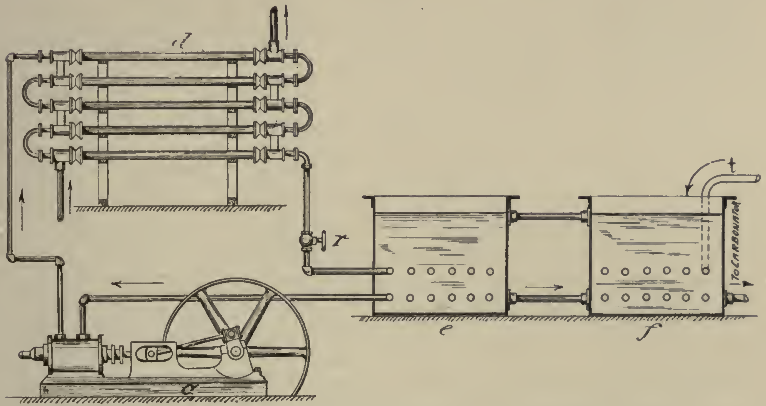


FIG. 111.—MECHANICAL REFRIGERATION SYSTEM FOR WATER COOLING.

When this system is employed it will be necessary to place the cooling coil, in which the liquid carbonic acid is made to evaporate, as well as the block-tin coil, *t,* in the same tank. This tank is then simply filled with sweet water and the water immediately surrounding the evaporating coil will be transformed into ice. This system does not give as good results as the one described above, and can not be recommended for efficient water cooling purposes.

When the water passes through the coil, *t,* in a continuous stream there is very little danger of freezing it within the coil, even if the temperature of the brine surrounding it is low. On the other hand, the water will be reduced in temperature more efficiently, and the danger of freezing it may be overcome by draining the coil before stopping the operation of the plant.

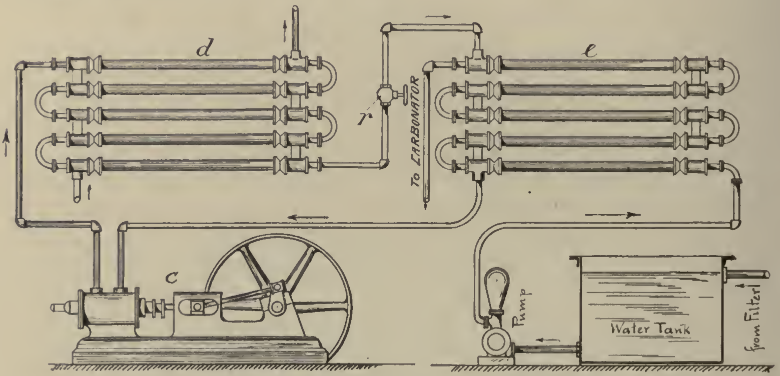


FIG. 112.—DOUBLE-PIPE CONDENSER AND WATER COOLER.

When the natural circulation of the brine, as illustrated in Fig. 111, is not sufficient, it can be increased by raising the cooling tank, *f,* to a higher level and interposing a pump in the cold brine line between brine tank, *e,* and cooling tank, *f,* allowing the brine to return from the latter by gravity.

The double-pipe water cooler is without doubt the most efficient of all coolers that can be used. The water is enclosed and does not come in contact with atmospheric air at any point. One disadvantage of this cooler which is often cited is that care must be taken in order to prevent freezing of the water within the cooler pipe. This disadvantage can not be considered a serious obstacle to its use, inasmuch as the water can be positively prevented from freezing by adjusting the flow of the refrigerating medium through the cooler and by starting and stopping same after the water has been turned on and before the water circulation is shut off.

A method showing the double-pipe cooler used to best advantage is shown in Fig. 112. In this system the compressor, *c,* discharges the carbonic acid gas into the condenser, *d,* in which it is liquefied. The liquefied carbonic acid is then evaporated in the annular space between the inner and the outer pipe of double-pipe cooler, *e.* The vaporization of the liquid carbonic acid in the double-pipe cooler, *e,* is controlled by the regulating valve, *r.* The water to be cooled enters the double-pipe cooler at the lower inner pipe and travels upward through the inner pipes to the top from whence it is conducted to the carbonator. It will be seen that in order to prevent the freezing of water in the cooler it is only necessary to start its circulation through the same before opening regulating valve, *r,* and again the same valve, *r,* should be closed at the end of the operation before the circulation of the water through the cooler is stopped. By means of this simple precaution, the freezing of water in the cooler is effectually prevented.

When a distillate of a high temperature is to be cooled from the temperature of the distilling apparatus to the temperature of carbonating, it is advisable first to remove the excessive heat from the water by means of ordinary cooling water. Assuming that the temperature of the distillate in the condenser is slightly below 200° F. a proper cooler should be employed whereby its temperature can be reduced to nearly the temperature of ordinary hydrant water. For further cooling, *i. e.,* for cooling it below the temperature of ordinary hydrant water by means of the latter to that of carbonating, a special cooling process should be employed. This process may consist either of the use of cold brine, a mixture of ice, water and salt or the more efficient method, and by far the most preferable, mechanical refrigeration.

With an increase of temperature after carbonating, the pressure within the bottle increases at the rate of a little over one pound for each degree rise in temperature. This rule is only empirical, however, and the rise in pressure in a bottle of water carbonated at 45° F. with a gas pressure of sixty to seventy-five pounds may be as much as three to four pounds for every degree increase in the temperature.

The coefficient of expansion of carbonic acid gas of atmospheric pressure is 0.00370 and 0.004 at seventy-five pounds pressure, showing the necessity of keeping the bottles, after filling, in a cool room, pref-

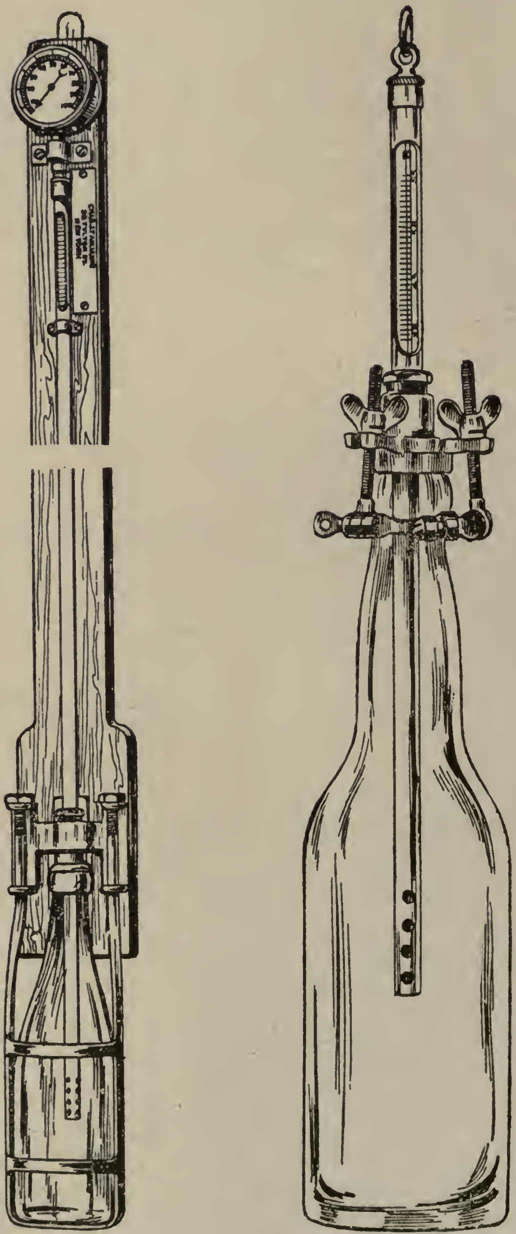


FIG. 113.—BOTTLE TESTING APPARATUS.

erably in a cold storage room at a temperature of 40° to 45° F. The goods will keep much better, the gas will be bound more firmly with the water and there will be very little or no breakage.

It is advisable to test the strength of the bottle as well as rise in pressure during a corresponding rise in the temperature by means of a thermometer and gauge, such as is shown in Fig. 113. The gradual rise in the temperature and, with it, that of pressure can be read direct as shown.

CARBONATING MACHINERY AND APPLIANCES IN GENERAL.

The carbonating equipment is divided into two distinct classes, one for carbonating with generator gas and the other with liquid carbonic acid. The generator system may be used with or without a gasometer. When the gasometer is employed, gas and water together are drawn into a carbonating pump, which forces it into a mixer, in which saturation takes place assisted by gentle agitation. The complete equipment is shown in Fig. 114. *A* is the generator, which generates and purifies the gas; *B,* the gasometer, in which it is stored; *C,* the carbonating pump, which forces gas and water into the mixer in which saturation takes place. The air forced from the water may be discharged into the atmosphere, while the balance of the unabsorbed gas blows back into the gasometer. *D* is the filling apparatus, to which a syrup pump is attached; in communication with

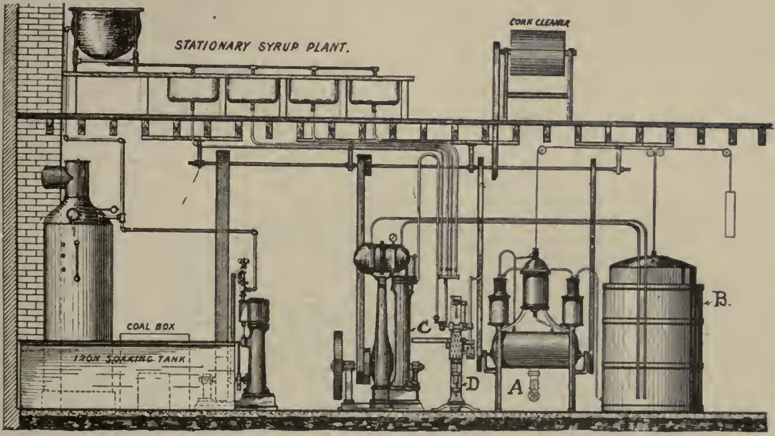


FIG. 114.—CARBONATING EQUIPMENT USING GENERATOR GAS.

the latter are a number of syrup tanks, containing the extracts to be added to each bottleful of the beverage. The syrup pump discharges a fixed quantity of extract into the bottle to which the carbonated solution is then added. The filler is frequently equipped with a stoppering mechanism, so that the operations of charging, filling and stoppering may be done with one machine. The power required for the operation of the complete equipment is furnished by a small vertical engine and upright boiler as shown.

Generators which deliver the purified carbonic acid gas to the carbonating apparatus under pressure, must be constructed considerably stronger, as the pressure developed frequently reaches 100 pounds and more. Seltzer syphons require a carbonating pressure of not less than 100 pounds, and as the gas pressure should be slightly superior to the water pressure the generator must be constructed for working pressures up to 150 pounds. The apparatus is shown in Fig. 115. It consists of a horizontal cylinder made of copper and lined with lead to withstand the action of the acid, which is stored in lead-lined iron reservoirs overhead. The acid flows by gravity into the generators. Bicarbonate of soda in the powder form is poured into the generator

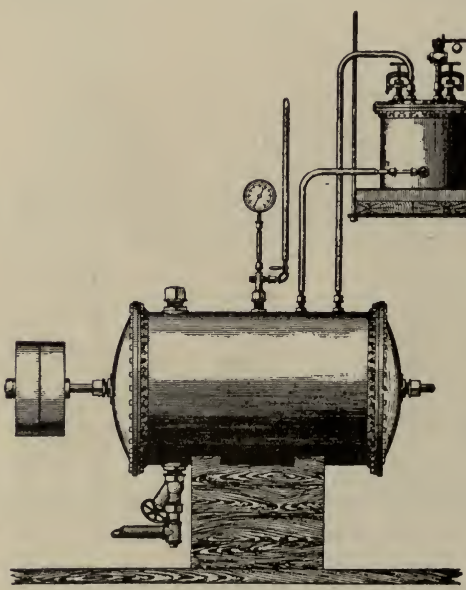


FIG. 115.—CARBONIC ACID GAS GENERATOR.

through a hand-hole, which is then closed. The contents are kept in motion by a paddle driven by belt and pulley. As fast as the CO_2 is generated, it is passed through an effective washing and purifying apparatus in which the acid that may have been carried over with the gas and other impurities are absorbed. After purification it passes under its own pressure to the carbonating apparatus, as shown in Fig. 116.

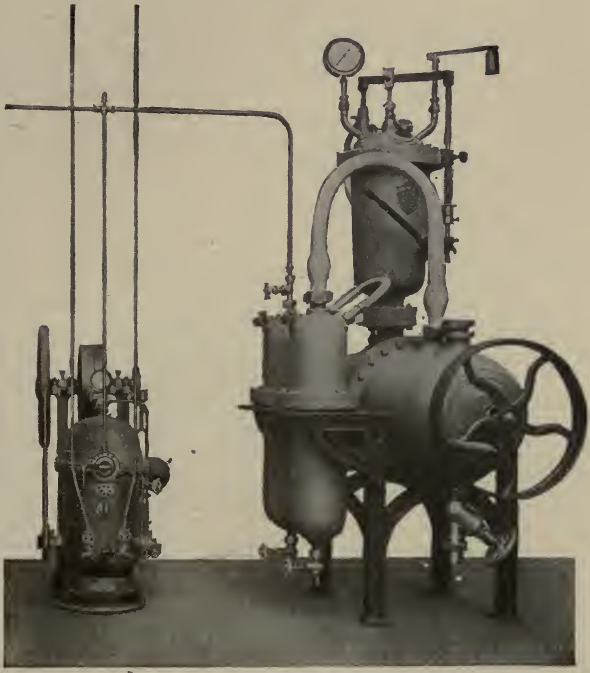


FIG. 116.—GENERATOR CONNECTED UP FOR SUPPLYING CO_2 UNDER PRESSURE.

Since liquid carbonic acid could be furnished at low cost and of great purity, it has nearly entirely displaced the generator gas. In countries which have particularly rigorous pure food laws the use of generator gas is forbidden, owing to its contamination with lead compounds, which can not be entirely avoided when lead-lined generators are employed, and as these compounds are extremely injurious to health the use of liquid carbonic acid for carbonating purposes is enforced.

DR. RAYDT'S CARBONATING SYSTEM.

Dr. W. Raydt, the pioneer in the art of producing liquid carbonic acid, advocated, as early as 1880, its use for carbonating purposes, and he designed and invented a system which had the advantages of cleanliness and simplicity of operation, besides producing a thoroughly carbonated water, over the old method of using a generator, gasometer and compression pump. (See Fig. 117, generator gas equipment, and Fig. 118, Raydt's liquid CO_2 outfit.) His system was used for the first time in 1883 in the mineral water factory of Wolff & Calmberg in Berlin, and a lengthy report explains the method of operation as well as the results obtained. The water was carbonated at a pressure of about 70 pounds gauge; its taste and degree of saturation with carbonic acid was pronounced decidedly satisfactory, and the manner of operation during the process was strikingly simple. The price of liquid carbonic acid at that time was 25c per pound and exceeded the usual cost of gas produced by a generator about three times. However, it obviated the necessity of operating a gas pump for compressing the gas from the gasometer to the carbonating pressure, and it saved the power required to revolve the agitator wings of the generator, for which reason, together with the advantages of cleanliness and simplicity, many manufacturers abandoned the generator outfit and installed the Raydt system of using liquid carbonic acid. Yet, the high price of the liquid CO_2

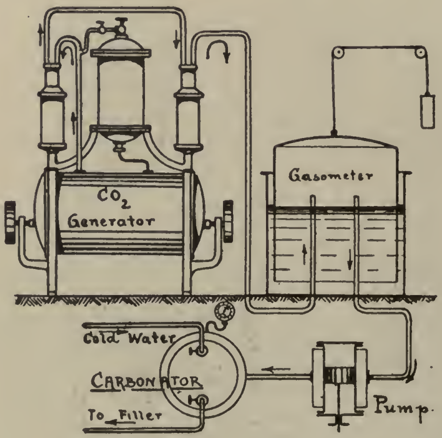


FIG. 117.—GENERATOR GAS EQUIPMENT.

prevented its general adaptation. Carbonated waters are a summer drink for the populace, therefore their price must be reasonable, and as their calculations showed that 150 quarts distilled water at a temperature of 65° F, when carbonated at a pressure of 75 pounds gauge and filled with an additional overpressure of about 25 pounds gauge, consumed for its saturation nearly five pounds of liquid CO_2, the cost price per quart of water impregnated amounted to 18c for CO_2 alone. Generator gas, on the other hand, only cost one-third of the price asked at that time for the liquid gas, or 8c per 9 cubic feet, which is equal in weight to one pound, hence the item of cost weighed heavily against the liquefied product.

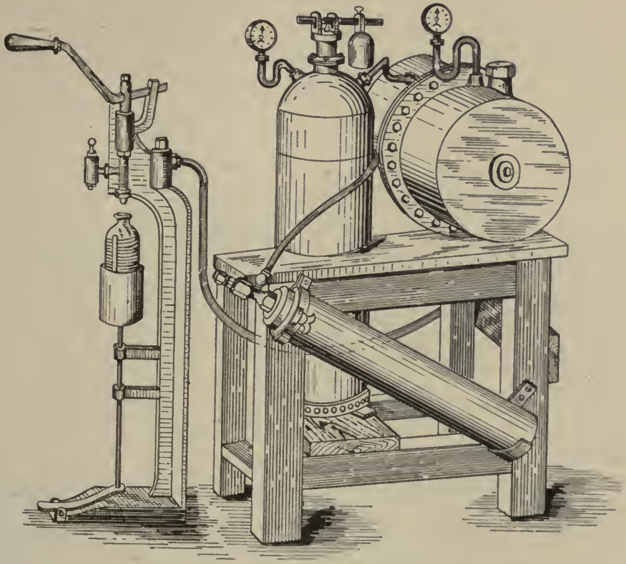


FIG. 118.—RAYDT'S LIQUID CO_2 CARBONATING OUTFIT.

In spite of the disadvantage of its much higher cost price, liquid carbonic acid made steady gains in its use for carbonating purposes. This increase in the consumption was at the same time instrumental in developing the methods of production, purification and liquefaction of the gas, which in turn made possible its more economical manufacture, so that in a few years the market price of liquid CO_2 dropped from 25c to 18c per pound. At this price it was possible to replace its competitor, the generator gas, which has since nearly entirely disappeared from the premises of mineral-water factories.

When liquid carbonic acid is filled into a cylinder, the part of the liquid which enters the cylinder first evaporates until a pressure is reached equal to that at which the CO_2 is liquefied; after this the CO_2 enters the receptacle in the liquid form, compressing the gaseous CO_2 into a small space in the upper part, at a pressure which corresponds with the temperature of the liquid. At a temperature of 32° F. of the liquid, this pressure is 36 atmospheres, or 530 pounds gauge, and at a temperature of 60° F. it is not less than 52.5 atmospheres or 772 pounds gauge pressure. By opening the valve of a CO_2 cylinder a part of the gaseous CO_2 escapes and this part is immediately replenished in the cylinder by the evaporation of a corresponding quantity of liquid, which maintains the pressure within. This change of the liquid CO_2 into the gaseous state under maintenance of pressure and temperature continues until every pound of liquid has changed into a gas, and only then will be noticeable a reduction in the pressure within the cylinder. The relation of pressure and temperature during the change remains at a fixed proportion; a very rapid discharge of CO_2 from the cylinder reduces the temperature of the remaining gas and liquid, and with this reduction of temperature a drop in the pressure will occur, but as soon as the necessary quantity of heat can be picked up by the liquid, additional evaporation takes place until all the liquid has changed into a gas. In this manner one volume of liquid changes into 430 volumes of gaseous CO_2 of atmospheric pressure.

The CO_2 gas is handled in a very simple manner. Owing to the high pressure at which it escapes from the cylinder, it can not be discharged into the mixer without a reduction of same, and as the "reducing" valve of today did not exist at that time, it was necessary to connect up a gas receiver between the mixer and the CO_2 cylinder. This receiver was filled with gas from the cylinder up to a certain pressure, which gas was then taken into the mixer with the water to be impregnated, as illustrated in Fig. 118.

The general practice was to use mixers designed for a working pressure up to about 250 pounds, but in order to discharge the gas directly into the mixer without the necessity of employing an intermediary gas receiver, Dr. Raydt designed the first pressure reducing valve. This valve embodied the same principle as those that are in universal use today, *i. e.,* it allowed only such quantity of gas to enter the mixer as was required for carbonating purposes, taking into consideration the character of the beverage to be charged, as well as its temperature, and it maintained the above volume and pressure automatically. The connection conducting the gas from the reducing valve to the mixer entered the latter through a stuffing box, the gas escaping into the mixer through a number of perforations in said pipe.

As soon as there was sufficient gas in the mixer under the requisite pressure, the reducing valve shut off the gas opening automatically, until, through absorption by the water, the gas pressure was reduced sufficiently to open and discharge more gas into the apparatus, thereby maintaining an even gas pressure, as well as the same degree of impregnation.

FIG. 119.—PRESSURE REGULATOR.

Fig. 119 represents one of the latest makes of reducing valves constructed upon Raydt's principle.

The mixer was a stationary affair and was not provided with any means of agitating the water. On account of this fact it was not possible to impregnate the water with gas up to, or even near, its point of saturation. Another condition which operated decidedly against obtaining satisfactory carbonating results was the inadequate cooling of the water before carbonating. Temperatures of 60° F. were as low as could be obtained in even the best equipped factories, for proper cooling machinery to reduce the temperature of the water was hardly known at that time.

In this particular case the gas bubbled through the water and filled the upper part of the mixer at the pressure fixed for carbonating, immediately closing the reducing valve, and as it had been in contact with the water only during its passage through the latter, very little of it was absorbed. Saturation is obtainable only when gas and water are thoroughly mixed by means of an agitator, and this operation must be continuous for a considerable length of time, because the water absorbs the gas rather slowly. After mixing, the water with the gas should be discharged into another large receptacle, where it should be kept under pressure in a state of rest, and, if possible, at a temperature not higher than the carbonating temperature of the water.

Dr. Raydt soon realized the unsatisfactory arrangement of his first carbonating equipment, and to improve it he provided his mixer with a proper agitating device. His reducing valve did not give him satisfactory results and he replaced same again with the intermediate gas receiver, which had been abandoned upon the invention of the reducing valve.

This improved outfit was sold in large numbers. The method of its operation was as follows: The distilled water, after cooling, was pumped into the mixer and a requisite volume of CO_2 was allowed to evaporate from the liquid CO_2 cylinder into the intermediate gas receiver. This receptacle was provided with a safety blow-off valve, and a pressure gauge recorded the pressure in the gas receptacle as well as in the mixer. The gas receiver was then used to supply the gas to the mixer, and the agitator facilitated the absorption of it by the water. The receiver was supplied with an additional volume from the liquid cylinder whenever the pressure in same dropped to nearly that in the mixer. It will readily be seen that it was possible to carbonate at any desired pressure with an outfit of this kind, as the regulation of the gas pressure was entirely under the control of the operator.

DR. LUHMANN'S CARBONATING SYSTEM.

The impregnation of water with carbonic acid gives the best results when a cold, highly concentrated gas is used. During the evaporation of the liquid carbonic acid into the gaseous form a large amount of heat is rendered latent and temperatures considerably below zero may be obtained. This cold gas is very dense and when used in that condition for carbonating purposes binds much more readily with the water than a gas that has been allowed to acquire the atmospheric temperature and that has lost its density in consequence thereof.

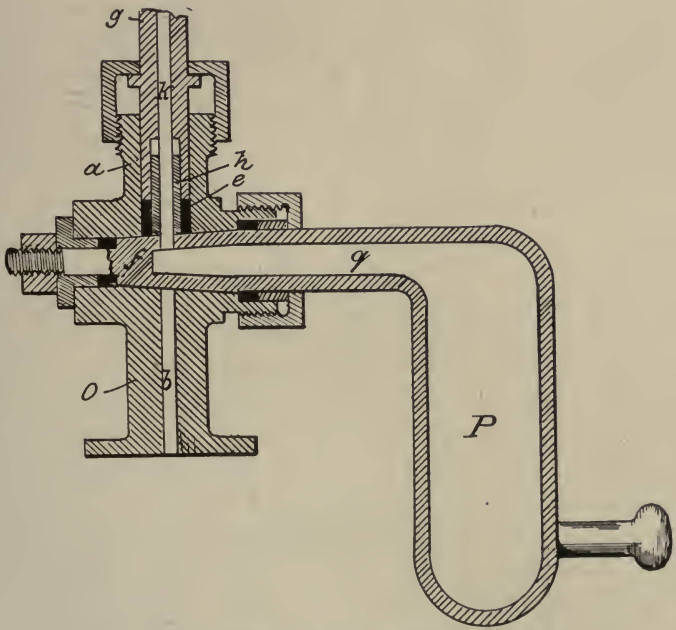


FIG. 120.—LIQUID CARBONIC ACID MEASURING DEVICE.

Dr. Luhmann was well acquainted with that fact, but it appeared to him that a cold liquid ought to possess this characteristic in a still higher degree. It has since been established that a liquid combines with the water more effectively than a gas of the same pressure, and it was Dr. Luhmann who originated the idea of impregnating beverages with liquid carbonic acid instead of first evaporating and then using it.

To obtain this end, it was necessary to manipulate a carefully measured quantity of liquid carbonic acid into a receptacle containing the solution to be impregnated, and he constructed an apparatus which measured the desired quantity of liquid CO_2, and subsequently injected same into the beverage without danger to the manipulator. Fig. 120 shows the apparatus in cross section. Receptacle *P*, which is made of composition, having walls of sufficient strength, fits with its tapered nozzle, *g*, into the housing, *O*, making a carefully ground joint. This housing is also made of composition; it has a small opening leading into the hollow part of *P*, establishing communication with canal *k*; canal *b* remains closed while the apparatus is in the position as shown.

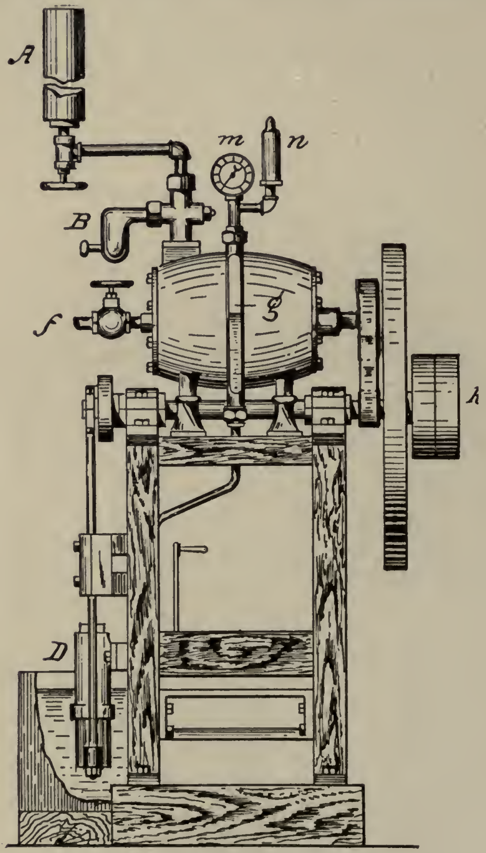


FIG. 121.—DR. LUHMANN'S·CABRONATING EQUIPMENT.

To prevent escape of gas along the tapered joint, stuffing boxes are provided. Communication, *k,* supplies the liquid carbonic acid. Its termination on the tapered connection is packed with leather packing in order to prevent leakage around the tapered seat through canal *b* into the mixer. Tube *h* fits with its upper end into sleeve *g,* the continuation of the latter being a connection with the liquid carbonic acid cylinder.

A cylinder is placed in an upright position, with its top down, as shown in Fig. 121. The communication between the cylinder and the space in receptacle *B* being established, the latter receives a charge of carbonic acid at the cylinder pressure, and as the temperature in *B* is naturally low on account of the evaporation of a part of the liquid CO_2 within same, the space is almost entirely filled with a measured quantity of liquid CO_2 at a low temperature. By turning receptacle *B* half way around its axis communication through canal *b* (see Fig. 120) with a mineral water mixer is established and the CO_2 escapes into the latter. The paddles of the mixer accomplish immediate absorption of the CO_2 by the water, and the result of charging a measured volume of CO_2 into a known quantity of water has been obtained.

The diagram illustrates the complete apparatus. A liquid CO_2 cylinder *A* is connected to the appliance for measuring the carbonic acid volume, *B*; the latter is mounted on top of the mixer, which is provided with a gauge, *m,* a blow-off connection, *n,* and the charged water outlet, *f.* The water is forced into the mixer by means of pump *D,* and a paddle is movable by pulley *k.* Pump *D* fills the mixer to about three-fourths of its volume with previously prepared mineral water, the height of which within the mixer may be ascertained by gauge glass *g.* The space for measuring the CO_2 in *B* is so proportioned that it must be filled about five times to supply the quantity necessary for the proper impregnation of the liquid in the mixer.

To this quantity of CO_2 should be added the volume of gas that fills the upper part of the mixer, as this volume will not be absorbed and only serves the purpose of maintaining the carbonating pressure. For instance, if a mixer has a capacity of eighty quarts of water, it is filled only with sixty quarts, the remaining space being allowed for a gas cushion. In connection with this size of mixer a measuring valve of 10 cubic inches in volume is used, and it will be necessary to discharge this volume of gas five times into the mixer before saturation at a pressure of five atmospheres or about seventy-five pounds can be obtained. The pressure within the mixer would then register only fifteen pounds after the first discharge of gas; during the second discharge, the pressure will at first rise to seventy-five pounds, which pressure drops back to about thirty pounds as soon as the gas is absorbed by the water, until the final discharge produces at first a pressure of about 120 pounds, which drops back to the saturation pressure of seventy-five pounds.

CLASSIFICATION OF CARBONATORS.

Carbonators may be divided into four classes, as follows: Mixers, where the water is saturated with the CO_2 gas in a closed vessel by being mixed with the gas by means of a stirring device; shakers, where saturation is accomplished through shaking of the closed vessel; cascade carbonators, where the water trickles through an upright cylinder filled with CO_2 gas; and gas circulating carbonators, where CO_2 gas is circulated through an upright cylinder filled with water.

The three last mentioned types are of a relatively later date. All carbonators, including the type known as mixers, are nearly always employed in connection with the use of liquid CO_2.

With a generator plant, the gas in the generator as well as in the gasometer is under low pressure and only after continued pumping of the gas into the carbonating machine, is the required pressure gradually reached. By the use of liquid CO_2, however, the pressure exists already in the CO_2 cylinder, and only a fraction of it is needed for carbonating purposes.

In order to avoid any danger from the sudden release of pressure, a safety device is interposed between the CO_2 cylinder and the carbonating machine, whereby the CO_2 pressure is reduced and regulated. The laws in Germany, regulating the use of liquid CO_2, provide that there must be a pressure reducing valve together with a receiver, or at least one of the two between the CO_2 cylinder and the carbonator. The receiver must be provided with a pressure gauge and a safety valve. The receiver is a strong vessel made of copper or iron and should hold about twenty-five gallons. It is equipped with a pressure gauge and a safety valve and has inlet and outlet connections for the compressed CO_2 gas, serving as a storage vessel for the latter.

When carbonating machines were first used in connection with liquid CO_2, these receivers were always used, as the pressure reducing valves at that time were not up to the required state of perfection and reliability. But immediately after the development of the reducing valves for beer-drawing devices, which brought about a great many improvements in valves and other important parts, the automatic acting reducing valves have more and more received the preference by bottlers over the large and expensive receivers, and during the last ten years the latter have almost entirely disappeared. It is, of course, possible that some still better device will be invented and supersede the present method.

A modern carbonating outfit using liquid CO_2 consists, in its principal parts, of the following apparatus:

The carbonating machine.
The pressure reducing valve.
The CO_2 cylinder, and
The filling stand.

The carbonators, as specified in their order heretofore, are constructed in accordance with the manner in which they are to be used and will be described consecutively.

MIXING MACHINES.

The complete arrangement, comprising all the important parts, is illustrated in Fig. 122. It consists of the carbonating machine, shown partly in section, the liquid CO_2 cylinder, and the receiver, both visible behind the carbonating machine, the water pump, which appears to the right, and the filling stand to the left in the illustration. The apparatus shown is made by N. Gressler, in Halle, Germany.

The operation of the apparatus is very simple. The carbonator is filled with water by means of the pump, the water inlet valve is then closed and the valve of the CO_2 cylinder opened, which permits the CO_2 to enter the receiver, until the gauge shows a pressure of from five to six atmospheres. The CO_2 cylinder valve is then closed and the gas is permitted to leave the receiver and enter the carbonator.

In order to remove the air from the latter, before starting to carbonate, it is necessary to charge the water with CO_2 gas at a pressure of from twenty to thirty pounds by turning the crank of the paddle-work, and allowing the air to escape through an air vent. After this

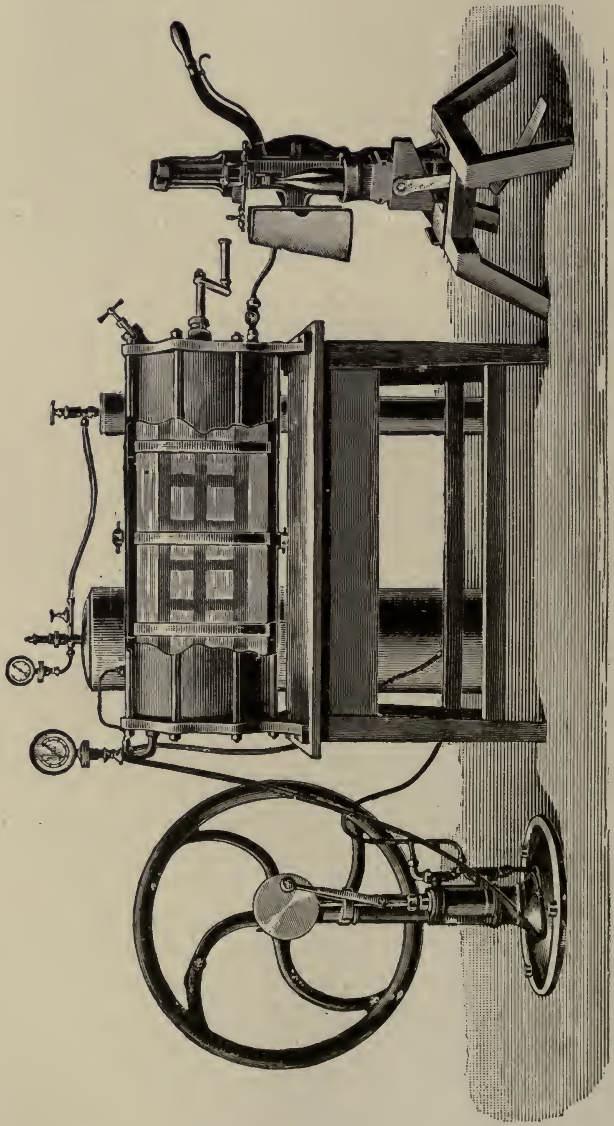


FIG. 122.—DIAGRAM OF CARBONATING PLANT WITH PRESSURE TANK.

has been accomplished, the air vent is closed and more CO_2 gas is admitted into the carbonator. The crank is then turned, until the gauge of the carbonator shows a constant pressure of sixty pounds.

The whole process requires but a few minutes, after which time the saturated water may be filled into bottles. During bottling the pressure in the carbonator is maintained at the pressure of saturation and the deficiency caused by the exit of the charged water is made up by gas from the cylinder.

After the carbonator is emptied of charged water, the excess of CO_2 gas remaining is utilized by pumping fresh water into the carbonator. The volume of gas remaining in the carbonator is ordinarily sufficient to expel the air from the water and after the latter has passed out through the air vent, the new charge is carbonated as above.

It is of great importance in order to preserve the taste, purity and stability of a carbonated beverage, that the liquid does not come in contact with the metal of the carbonating machine during impregnation. The ordinary carbonators made of copper, when tin-lined, furnish as a rule a water free from metal; it is, however, of frequent occurrence that the action of a salt solution, if required in the preparation of the beverage, destroys the lining, in the course of time, and makes relining necessary.

It will readily be seen that relining of a machine will put the latter out of commission for the time being, thereby crippling the regularity of the process of manufacture. For this reason it has been the aim of manufacturers to construct a carbonator made of material not affected by acids or salts. N. Gressler, in Halle, was the first to place a machine on the market constructed in accordance with this theory. His carbonator is illustrated in Fig. 123. It consists of an inner cylinder of earthenware, glass or some other non-corrosive material, with a smooth inner surface, which is surrounded by a protecting or cooling jacket of copper, leaving a free space between them. The open ends of the cylinder are closed tight by two strong head plates, secured to each other by longitudinal anchor bolts.

The space between the inner and the outer cylinder serves as a cooling jacket and may be filled with ice water or a cold brine. This space is connected with the interior of the inner cylinder by means of a pipe, thus maintaining an equal pressure in both compartments and preventing the possibility of a flow of liquid from the inner into the

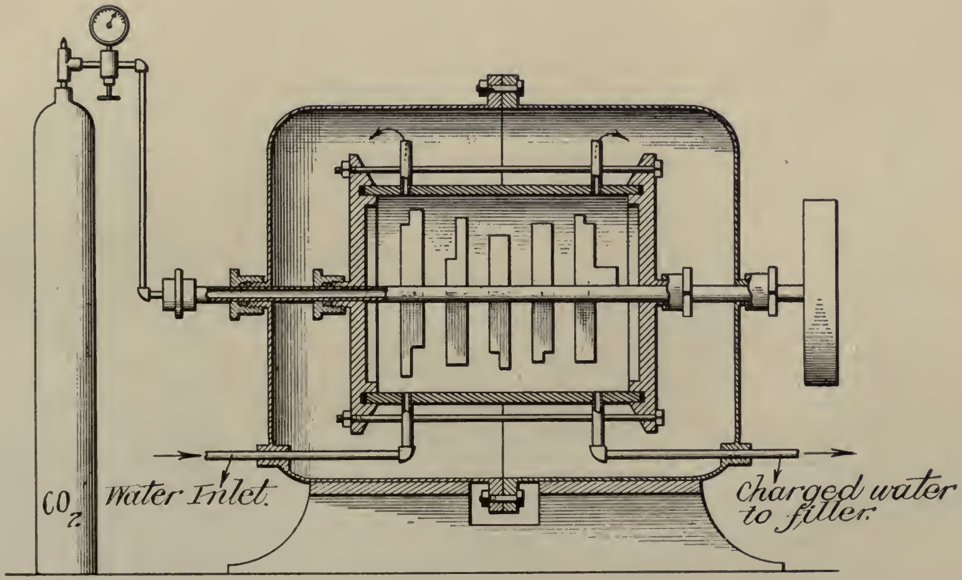


FIG. 123.—SPECIAL CARBONATOR MADE OF MATERIAL NOT AFFECTED BY ACIDS OR SALTS.

outer space. This pressure equalization is for the purpose of relieving the inner cylinder from the stress of pressure, and as the pressure surrounding it is the same as the pressure within, it is not subjected to pressure and strain at all, and can therefore be made of a material which ordinarily could not withstand a high carbonating pressure. In a carbonating cylinder of such material, strong brine, or even acids, can be used without danger and with no effect upon the material of the carbonator, which therefore is much more durable than one made of metal.

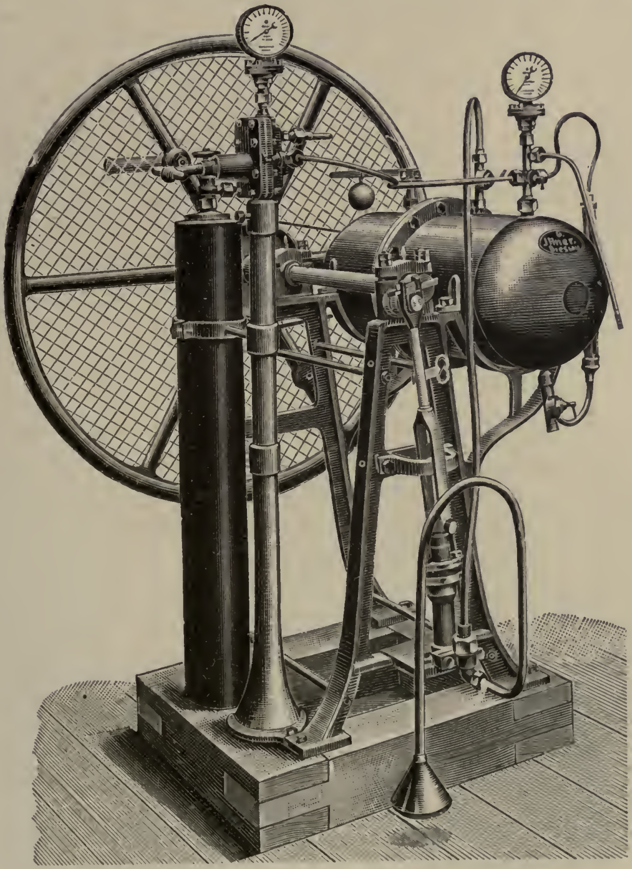


FIG. 124.—MIXER TYPE OF CARBONATING MACHINE.

A further advantage is the use of paddles made of wood, glass or similar material, the shaft of which is extended through the two head plates and provided at one end with a crank or pulley. The liquid inlet and outlet is located at the pulley side, while the other head plate is provided with a pressure gauge, blow-off valve, CO_2 inlet valve and the pressure equalizer. The whole carbonator rests on an iron or wooden stand.

By employing a reducing valve the construction and manipulation of the apparatus becomes safer and much simpler, for which reason it is preferred by manufacturers as well as users at the present day.

A carbonating equipment with liquid CO_2 cylinder and reducing valve is shown in Fig. 124. The reducing valve is attached directly to the liquid CO_2 cylinder and the latter is located immediately above the carbonator. This machine is manufactured by Illner, in Breslau, Germany. As will be seen from the illustration, the mixing cylinder is composed of two halves fitted with flanges which are packed with a rubber gasket and bolted together. The construction is very simple and allows it to be easily disconnected for repair or relining.

Great care has to be taken, that the tin lining remains perfectly intact. As a test the apparatus, filled with mineral water, is left standing over night and a sample of about 500 grams is taken the next morning, to which some salicylic acid is added, the whole being mixed with a solution of hydro-sulphuric water. If, within a few minutes, a dark sediment or even a dark color of the liquid appears, it must be clarified, which takes several days. After clarification the water is poured off and the residue is tested in the ordinary way for copper. If the test shows copper, it proves that the tin lining is defective, which must then be removed and renewed. The best lining is a silver lining, this, however, owing to its cost is used only in exceptional cases.

SHAKING MACHINES.

In the majority of these machines the stirring device, or paddles, of the mixer, is replaced by a mechanical contrivance which produces a rocking movement of the carbonator. The contents of the cylinder are thereby thoroughly shaken, whereby the absorption of carbonic acid gas by the water is greatly facilitated. The older carbonators of this type generally were of the same form as the mixers and consisted of a horizontal cylinder provided with pivots, which were suitably journaled so as to enable the operator to swing the cylinder around its pivotal point by means of a handle.

The developed construction of the shaking machine abandoned the clumsy swinging cylinder and adopted means for the same purpose which are extremely small in body and much more convenient in operation. It will not be amiss to state here that nearly all of these shaking machines are constructed with the view of furnishing a simple and inexpensive apparatus for small requirements, enabling the operator to prepare a fresh supply of a carbonated beverage immediately upon demand. These machines have found their greatest field of usefulness in drug stores, hotels, restaurants, bakeries, confectioners and similar establishments. The most important detail in the construction of these machines consists of a mixing ball. One of these machines is shown in Fig. 125 and represents a small type of a ball shaking machine manufactured by Malmendier, Cologne, Germany. The whole equipment is mounted on a simple flat iron stand, and placed upon any suitable base. It consists of the liquid carbonic acid cylinder with the necessary pressure reducing valve, and a flexible connection between the carbonic acid cylinder and the shaking device. The latter carries the ball, which serves for the

FIG. 125.—BALL SHAKING MACHINE.

purpose of carbonating, and the bottle filling attachment. The liquid to be carbonated is first admitted into the ball, a bottle is then placed upon the rubber plate of the bottle stand with its mouth forced against the rubber gasket of the water outlet. A simple lever device accomplishes this purpose. As soon as the bottle is put in its place the filling attachment is swung around its pivot so that the ball is at the lowest point. Carbonic acid gas of a predetermined pressure is then admitted, and the rocking device is swung to and fro for a period of fifteen to twenty seconds. This time allowance is ample to impregnate the liquid with the necessary volume of carbonic acid, and after the rocking device has again been placed in its upright position the carbonated beverage is discharged into the bottle. It will be seen that a part of the ball as well as the volume of the bottle serves as a receptacle for the gas until the gas has been absorbed by the water. The filling valve remains open during the carbonating process, and when the liquid is finally discharged into the bottle the unabsorbed gas and atmospheric air escapes into the ball and the carbonated beverage runs partly by its own gravity and partly under the existing pressure into the bottle. The outlet valve is then closed and the bottle removed for corking.

This machine is particularly adapted for bottles provided with patent china and ball stoppers. Owing to its great simplicity and the small amount of space required it has found an extensive field of application. A further advantage is found in the low price at which it is sold. The complete apparatus, which has a capacity of 800 bottles per day, costs only thirty dollars. It can also be arranged for filling two or three bottles at a time. When so equipped, its capacity is raised to 1,200 and 1,800 bottles respectively per day. The ball serving for the purpose of carbonating is made of copper and heavily tin-plated inside. In place of a copper ball, a glass ball made of strong syphon glass is frequently used.

A more compact apparatus is shown in Fig. 126. This machine is manufactured by Kueken & Halemeier, Bielefeld, Germany. Instead of using the ball device as in the former machine, it is arranged with a mixing cylinder, which, however, is small enough to allow it to be rapidly swung around a pivot. This cylinder is made of copper, lined with block-tin and rotably secured to axle *l*. This axle is journaled in a solid cast iron stand *B*. A flexible connection is made between the axle and a liquid carbonic acid cylinder.

The latter is provided with the usual pressure reducing valve, and the gas is admitted through the hollow axle *l,* into the carbonating cylinder. Outwardly of this cylinder is the bottle stand and filling valve. The height of the bottle stand can be readily adjusted by means of hand screw *k*. The bottle rests upon bottle stand *c,* and is surrounded by a suitable shield. Lever *i* provides the handle whereby the cylinder is rotated. The water is admitted through connection *d,* and as soon as the cylinder is revolved around axle *l,* the necessary contact between water and gas is provided, and the water is thoroughly carbonated within a very short period. The gauge *f* registers the carbonating pressure and the bottle may be filled through filling valve *h,* either in the position as shown when the cylinder is nearly full, or it may have to be swung into the

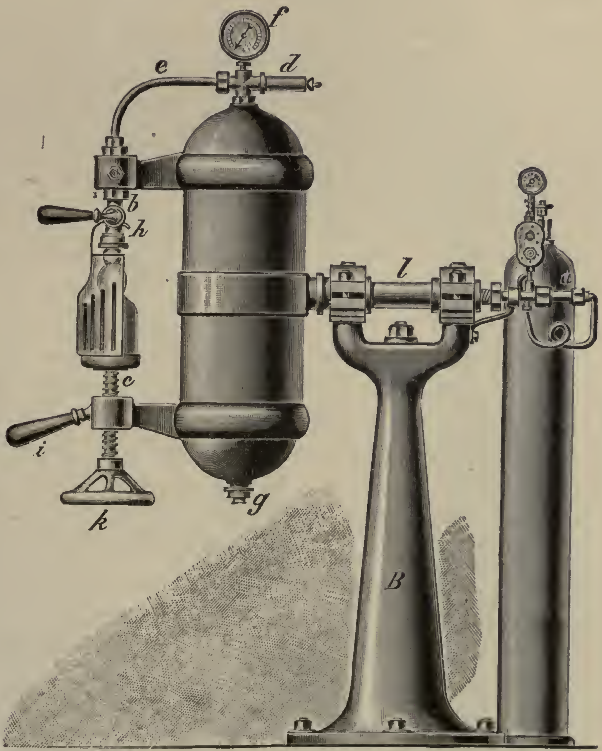


FIG. 126.—SHAKING MACHINE FOR ROTATING MIXING CYLINDER.

reversed position, in order to admit of the filling into bottles of all of the carbonated beverage contained therein. Connection *e* is a blow-back through which the surplus of gas and air can be blown back into the cylinder. In operation the cylinder is filled to about five-sixths of its height, which is equivalent to a carbonated liquid of four gallons for each filling. The complete machine is offered for

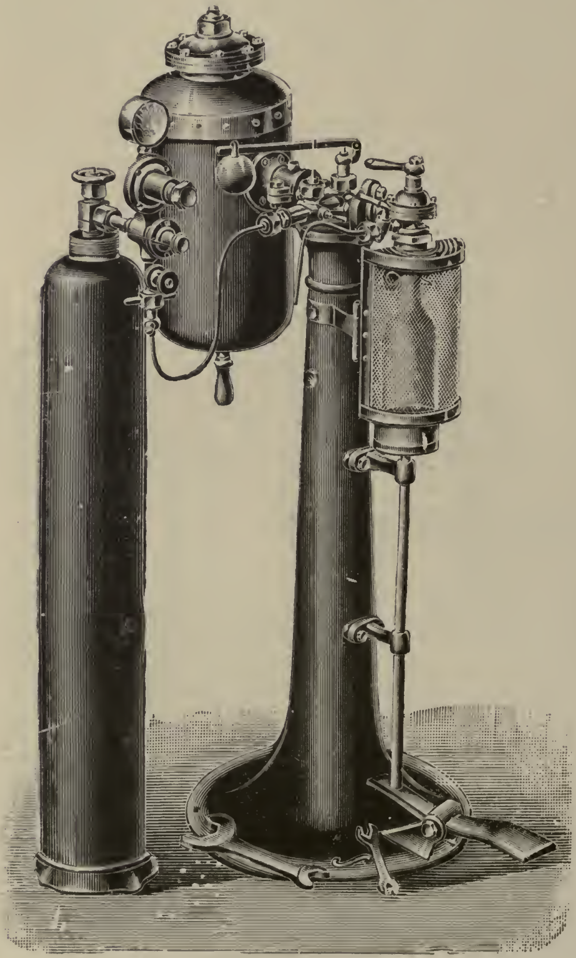


FIG. 127.—SHAKING MACHINE OF SMALL CAPACITY AND SIMPLE CONSTRUCTION.

sixty-five dollars, which, however, does not include the liquid carbonic acid cylinder and reducing valve.

A very simple shaking machine of small capacity is shown in Fig. 127. This machine is made by C. Deiters, Berlin, Germany, and differs from the former construction in so far as the filling adjustment is separate from the shaking device. The latter is mounted separately to the stand and the bottle is adjusted to the filling outlet by a simple foot attachment. A handle secured to the bottom of the cylinder furnishes the means whereby the latter may be swung around a stationary axis. This apparatus is very light in weight. It can be readily transported and put in operation almost at once, owing to which fact it has found much favor for temporary and other small requirements. Its price is very low, as the complete equipment, exclusive of the liquid carbonic attachment, is sold for forty dollars.

CASCADE MACHINES.

A type of carbonator which has found great favor during the last few years is known as the "Cascade Machine." In this carbonator the counter-current principle of carbonating is employed, *i. e.,* the CO_2 gas passes upward and is met by a finely divided spray of descending water.

The water is admitted into the upper part of a tower and during its descent, it does not fall uninterruptedly into the lower part of the tower, but is broken and divided into numerous parts before it reaches the bottom. In this way the water is spread over a large surface in a thin layer, thereby facilitating the absorption of the gas by the water.

This principle of absorption was first introduced by Dr. E. Luhmann, who employed it originally for the absorption of carbon dioxide from flue and lime-kiln gases in the manufacture of CO_2. When first placed on the market these machines met, like most things new, with but little favor, however, the advantages presented in the embodiment of the counter-current cascade carbonator were soon realized and the revulsion of opinion set in so energetically that nearly all the manufacturers of carbonating machinery have adopted it since. The steadily growing number of these machines in practical use today is in itself ample evidence to eliminate all doubts as to their utility.

In the construction of a carbonator the principle aim must be to offer to the gas to be absorbed the greatest possible surface of the liquid. It is evident, therefore, that when the liquid is divided into very thin layers and percolating from cascade to cascade, it is exposed to the action of the gas in such a way that the most perfect saturation must be accomplished. It appears that the simplest way to obtain this end is by the use of a cascade machine in which the stream of water is broken at every inch of its downward course.

In a machine of this construction the process is as follows: The liquid is pumped into the upper end of a tall, vertical cylinder and flows in the form of a cascade from tray to tray, or from resistance to resistance. Gas enters at the lower end of the cylinder and travels upward. The air contained in the water being lighter than CO_2 gas is forced out and collects in the upper part of the cylinder. A blow-off valve, located at this point, which is opened from time to time, allows it to escape. A machine of this kind can be operated without interruption, besides having the advantage that nearly all of the gas is absorbed by the water, so that the waste is very small.

Tests have shown that practically all of the gas is absorbed and that the air which accumulates in the top of the cylinder contains only a slight percentage of CO_2. A 20-pound cylinder of liquid CO_2 contains about 5,000 liters of gas at atmospheric pressure, which quantity is sufficient to carbonate about 1,000 liters of water or 3,000 bottles at five atmospheres pressure. Converted into United States units it means that twenty pounds of liquid CO_2 evaporates into 5,000 quarts of gas, which is sufficient to carbonate 1,000 quarts of water at a pressure of sixty-five pounds and a temperature of the water of 45° F., a result which can be obtained readily with any cascade machine.

A common type of this carbonator is illustrated in Fig. 128. It is manufactured by Fischer & Kiefer in Karlsruhe, Germany, and consists, in its principal parts, of the cascade tower cylinder, which is provided with trays or filled with some suitable material such as pebbles, agate spheres and broken marble, the water pump, the water reservoir, a liquid CO_2 cylinder and a pressure reducing valve.

The method of operation is exceedingly simple: The CO_2 gas, leaving the cylinder, passes through the reducing valve, *J,* and cock, *H,* and enters the cascade tower at a reduced pressure, while the

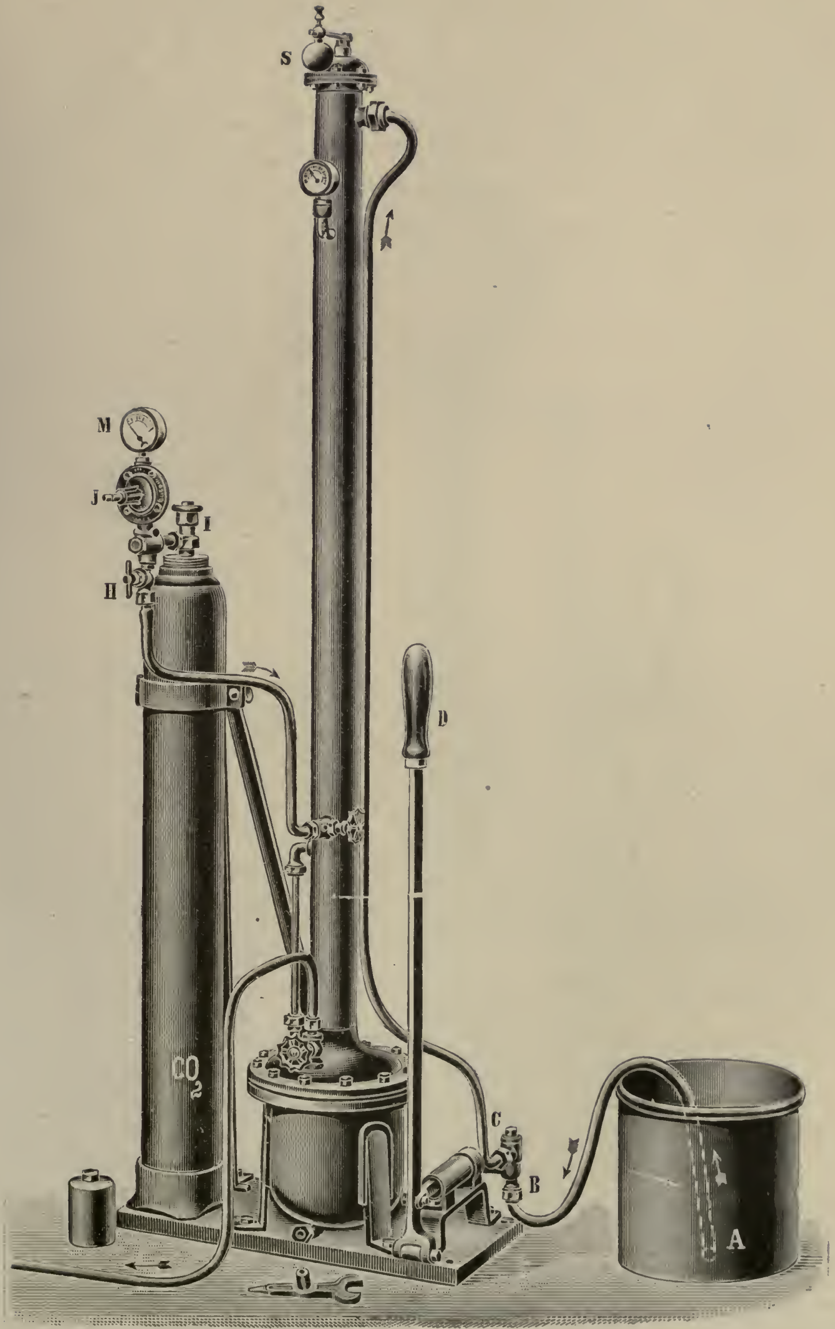


FIG. 128.—CASCADE CARBONATOR, FISCHER & KIEFER, KARLSRUHE, GERMANY.

water is pumped continuously from receptacle, *A,* into the upper part of the machine. After entering the tower it flows downward within the same, its fall being frequently broken and interrupted by pebbles, broken marble and the like. The CO_2 gas meets it in a counter-current, it mixes thoroughly with the water and is rapidly absorbed by the latter. The carbonated water is drawn off at the bottom and conducted to the filling stand, where it is filled into bottles. The valve, *S,* at the top of the cascade tower serves as a "blow-off" for the air expelled from the water. In larger machines, as will be described later on, the flow of water is regulated by means of an automatic water controller in such a way that the same quantity of water that can be bottled is being pumped. Such machines, therefore, require no further attention than the periodical opening of the blow-off valve, all other functions being perfectly automatic.

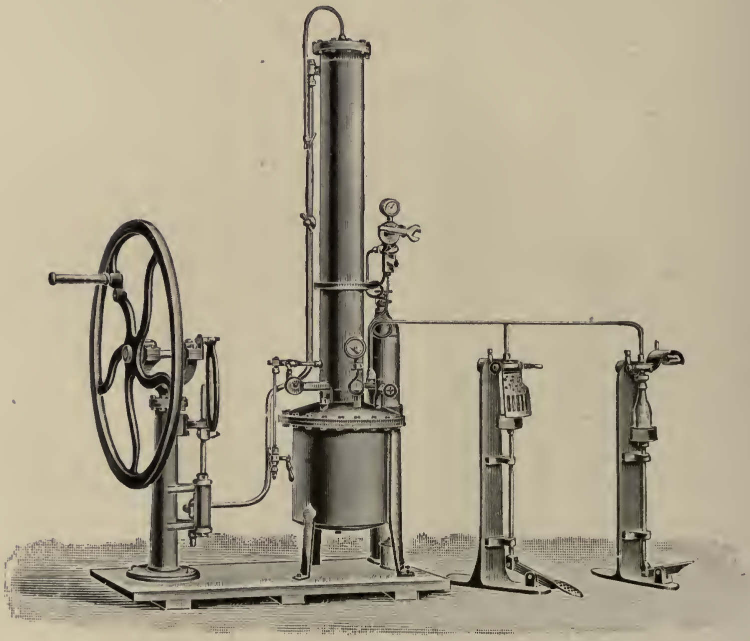


FIG. 129.—CASCADE CARBONATOR, KUEKEN & HALEMEIER, BIELEFELD, GERMANY.

Fig. 129 illustrates a machine of larger size, capable of supplying carbonated water to two or more separate filling stands. It is

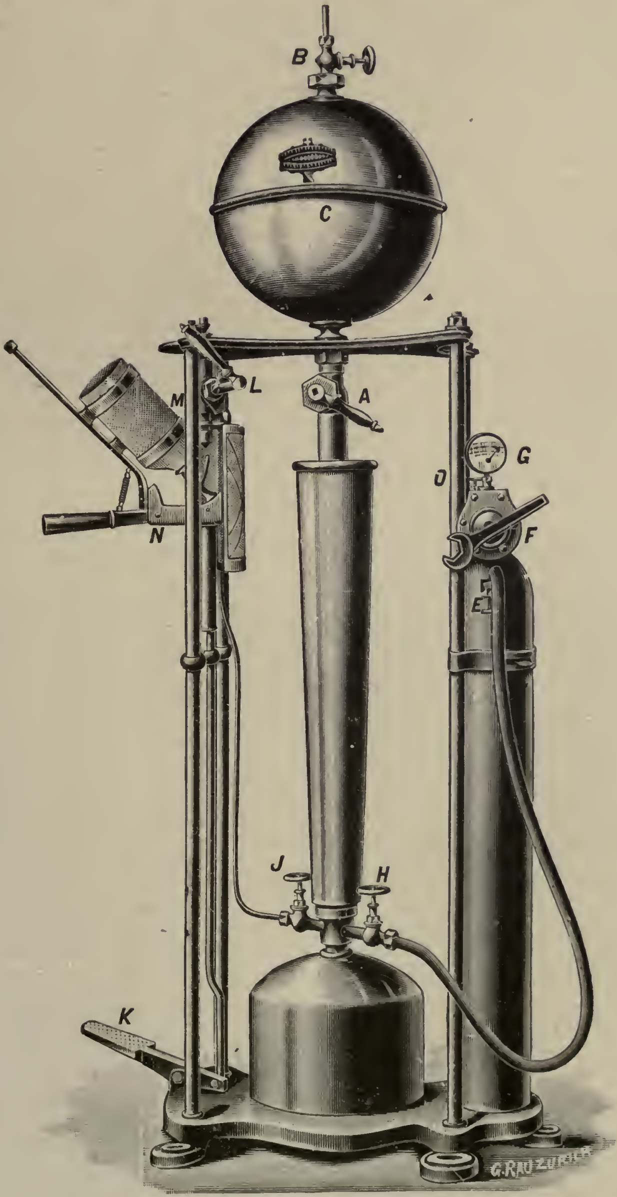


FIG. 130.—DR. BERTHA'S CASCADE CARBONATOR.

built by Kueken & Halemeier, Bielefeld, Germany. In this machine the cylinder is provided with close-meshed sieves. The water inlet is provided with a pressure valve, which terminates in a very effective spraying nozzle, by means of which the water is divided into a very fine spray or mist. This finely divided stream of water may be further divided by placing within the cylinder the above mentioned pebbles, so that the gas and water is forced to pass over the latter's surface, whereby a thorough impregnation is effected.

A valuable addition to the cascade machines above described is a device by means of which the water is de-aerated automatically from time to time. This automatic device is decidedly more reliable than the work of de-aerating entrusted to the man who operates the carbonator. In some machines de-aerating is provided in the form of a combined blow-off and safety valve, which is acted upon either directly from the shaft of the machine by means of a gear transmission, or the air vent is arranged in the upper part of the cascade tower and actuated by a vertical shaft.

The cascade carbonating machine, illustrated in Fig. 130, is constructed by Dr. Bertha of Zurich, Switzerland. Its saturator is surrounded by a cooling jacket and surmounted by a ball water receptacle *C*. Its operation is as follows: Before starting, ball *C* is filled with water from the source of water connected at cock *B*. Cock *A* remains closed during this period. After being filled, the water supply is shut off by closing *B*. Carbonic acid is then admitted into the machine as follows: Valve *D* of the CO_2 cylinder is slowly opened and the required volume of carbonic acid passes through the pressure reducing valve *F* and valve *H* into the cascade cylinder. As soon as the cylinder is filled with gas, cock *A* is opened and the gas passes through the water in ball *C*, forcing it into the cascade cylinder, thereby carbonating it. The finished carbonated beverage may now be filled into bottles through valve *J*.

After bottling, valve *D* of the CO_2 cylinder is closed, as are also the cocks *A, H* and *J*. Next, the gas line is closed tight by using a wrench on valve *F*. Attached to the stand of the machine is a simple filling apparatus, as shown in the illustration.

The spherical water receptacle, *C*, mentioned in the previous description, is also employed by the American Soda Fountain Company. In this machine the water receptacle is known as the absorption dome and is located above the saturating column. The latter has been greatly reduced in size and performs merely the duty of a reservoir. A number of special atomizing and spraying tubes are contained within the spherical receptacle, whereby the water is divided into a fine mist. The machine is constructed of heavy hammered copper lined throughout with sheet block tin. A triplex pump operated by a ½-horsepower enclosed electric motor is located on the platform of the carbonator, and provided with an automatic shifter, which opens and closes a switch, shutting off or turning on the electric current and stopping or starting the pump. The machine has a capacity of two and one-half gallons of water per minute and is designed for service in large bottling establishments. It is provided with a spider, connecting five soda draft tubes or bottling tables.

One of the latest designs of carbonators of the cascade principle is illustrated in Fig. 131. It is known as the "Original-Automat," and is built in the factory of Otto Vogel, Berlin. The machine possesses several special features, which makes it particularly useful in the manufacture of carbonated beverages. On account of its improvements it furnishes an always uniformly carbonated product even under the most unfavorable conditions.

The novelty of the machine lies principally in the fact that the water on its way from the pump to the saturator is repeatedly subjected to the pressure of carbonic gas in a manner that is at the same time simple and efficient, so that the water is already highly impregnated with carbonic acid before it reaches the saturator. The machine is provided with a double acting piston pump, which draws and discharges gas on one end of its cylinder and water on the other. In this way gas is discharged while water is drawn in and vice versa.

At each stroke of the piston carbonic acid gas is discharged through the body of water which was previously discharged by the water end of the pump and which is contained in the connection, *D,* between the carbonator and the pump. Interposed in this connection is a receiving ball, *C,* and as gas is periodically discharged into the latter, the process of saturation which takes place in the discharge line is greatly augmented.

The mixture of gas and water passes through a sight glass, located on top of ball *C* and passes through pipe connection *D* into the upper part of the cascade or percolating tower. Additional

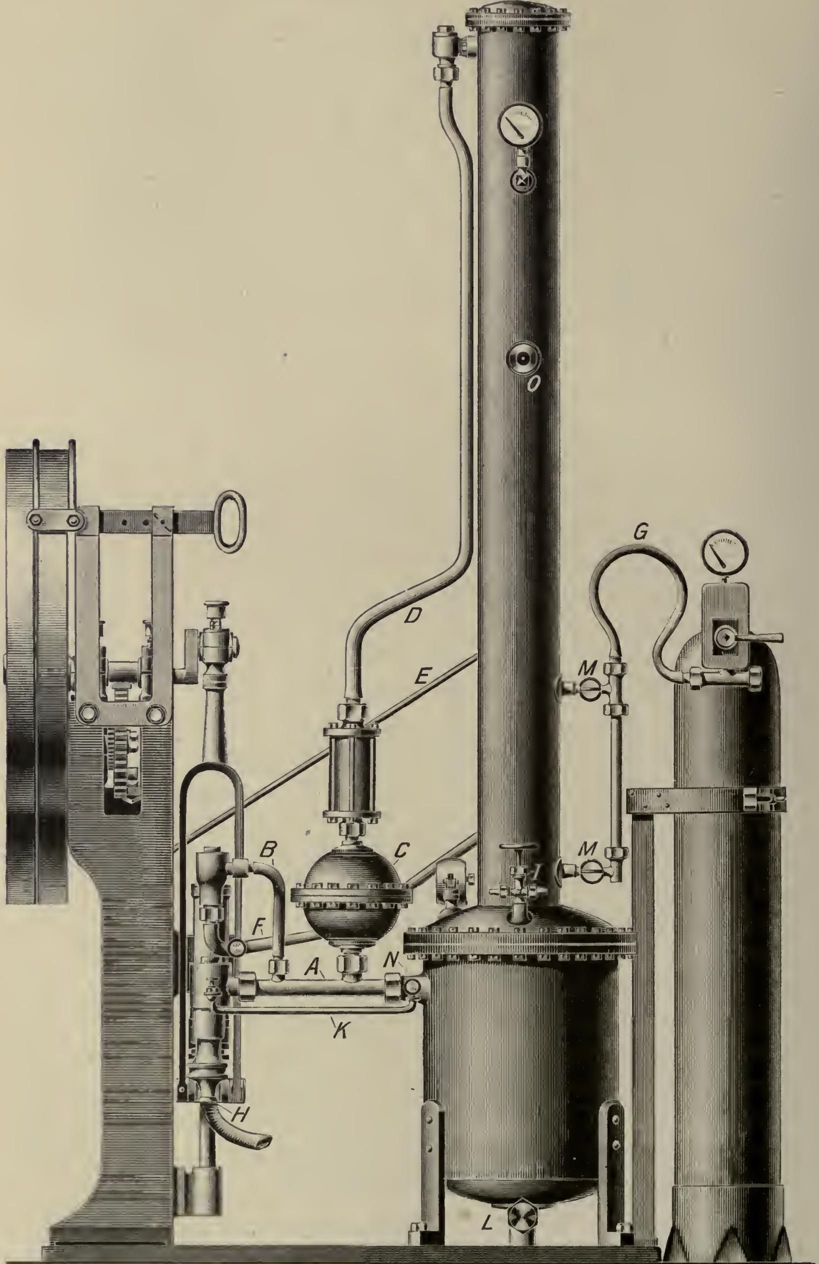


FIG. 131.—CASCADE CARBONATOR, OTTO VOGEL, RERLIN, GERMANY.

CO_2 gas is admitted through valve connections, *M,* at and near the bottom of the cylinder, the water as it falls from cascade to cascade within the cylinder meets the incoming gas, it intermingles thoroughly with the same and absorbs a full volume. The impregnated water finally enters the water receiver, upon which the cascade cylinder is mounted and from this receiver a suitable connection conveys it to the filling tables.

Owing to a misconception by the manufacturers of cascade carbonators regarding the principle involved, many were of the opinion that the water and the gas should be kept in contact for as long a period of time as possible. For this reason they reduced the diameter of the saturating tower and increased its height. The consequence was that the area, and with the area the cubical content of the saturating tower, was greatly reduced. As a result the water accumulated at the lower part of the tower in a solid column. This deprived the saturater of its principal saturating element, which is the spreading of the water in a fine coating over a large surface, and the gas passing upward simply bubbled through the solid column of water, thereby coming in contact with only a small surface of the latter. For this reason the absorption of the gas and impregnation of the water was entirely deficient. The disadvantage of the small diameter saturater was greatly aggravated when the water pump in connection with the same handled much more water than could be drawn off. In such cases the whole saturater column was readily filled with water to the top before the operation of the pump could be stopped, and the process of carbonating consisted then simply in the discharge of a small volume of carbonic acid gas into a solid column of water.

Dr. Luhmann very readily realized these defects and he endeavored to design a cascade machine obviating them. His machine had a saturating tower of a conical form. The diameter at the top was considerably smaller than the diameter at the bottom. By reason of this construction the water column which gathered at the bottom of the tower never reached a height which was detrimental to the carbonating process in the balance of the tower, even if the water pump was of a larger capacity than necessary and operated at a speed higher than the normal. The percolating water spread out through the small area at the top of the tower and as it descended, it spread out in a still finer coating owing to the gradual increase in the area of the column. A very fine filling material was used which also effected an increase in the total surface of water. As the absorption of carbonic acid by the water is facilitated when the latter's surface is increased it will be readily seen that the carbonating efficiency depends solely upon the total contact surface between water and gas and therefore upon the cubical volume of the saturater column.

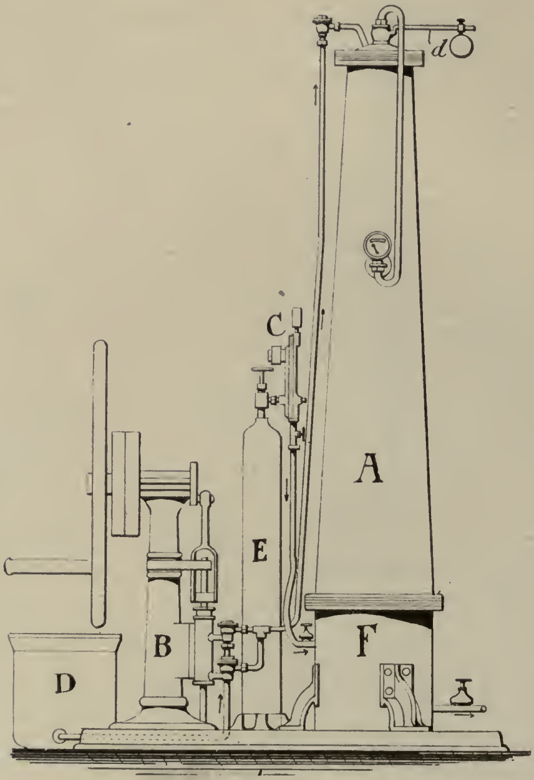


FIG. 132.—DR LUHMANN'S CASCADE CARBONATOR.

Dr. Luhmann's cascade carbonator, as built by N. Gressler, in Halle, a. S., is illustrated in Fig. 132. It consists of the saturater column *A*, with the receiver *F*, the water pump *B*, and the water tank *D*, and CO_2 cylinder *E*, with pressure reducing valve *C*. In the interior of the column a screen is interposed between the saturater column *A*, and the receiver *F*. Upon this screen is placed the filling material which usually consists of pumicestone or of carefully prepared and purified pieces of coke. The size of these pieces decreases gradually toward the bottom, and the difference therein is determined by an accurate calculation. A screen of fine mesh in the top of the tower *A* effects a uniform distribution of the water. Special care is taken that the downward flow of the water is not hindered in any way by the rising gas.

The receiver, *F,* is provided with a water gauge which shows the height of the water column therein. The saturater column, *A,* is furnished with a gauge showing the carbonating pressure, and a safety valve, *d,* offers the necessary protection against excessive pressure. The water leaves the lower part of receiver *F* through a suitable conductor and passes to the filling apparatus.

Machines of larger capacity are provided with an automatic arrangement to control admission of water to the saturater tower *A*. By this arrangement the water level in receiver *F* remains at the same height. All air which collects in the upper part of the tower is periodically discharged through safety valve *d*.

The Cataract carbonator built by the American Soda Fountain Company is constructed largely upon the recommendations advanced by Dr. Luhmann. The shape of the machine is similar to the one described in Fig. 132. A special agitating device is placed in the receiver so as to finish the process of gas impregnation. It is claimed that this agitating device is not necessarily required, on account of the fact that the water enters the top of the saturater column in a very finely divided spray, whereby the required volume of gas is absorbed by the water before the latter enters the receiver. The water level in the receiver is automatically controlled by a balancing weight operating the belt shifter for the pump. This balancing weight operates in the following manner: It is connected with the receiver by means of flexible connections. When the water level rises in the receiver, water passes from the latter into the balancer. The weight of the latter increases until it finally drops, whereby shifting of the belt from the tight to the loose pulley of the pump is effected, which results in stopping the pump. The water passes continually to the filling apparatus, and as its level in the receiver recedes, part of the water leaves the balancer, relieving the latter of its weight. As soon as the weight of the balancer has been sufficiently reduced it is made to rise by a counter balancer, whereby the

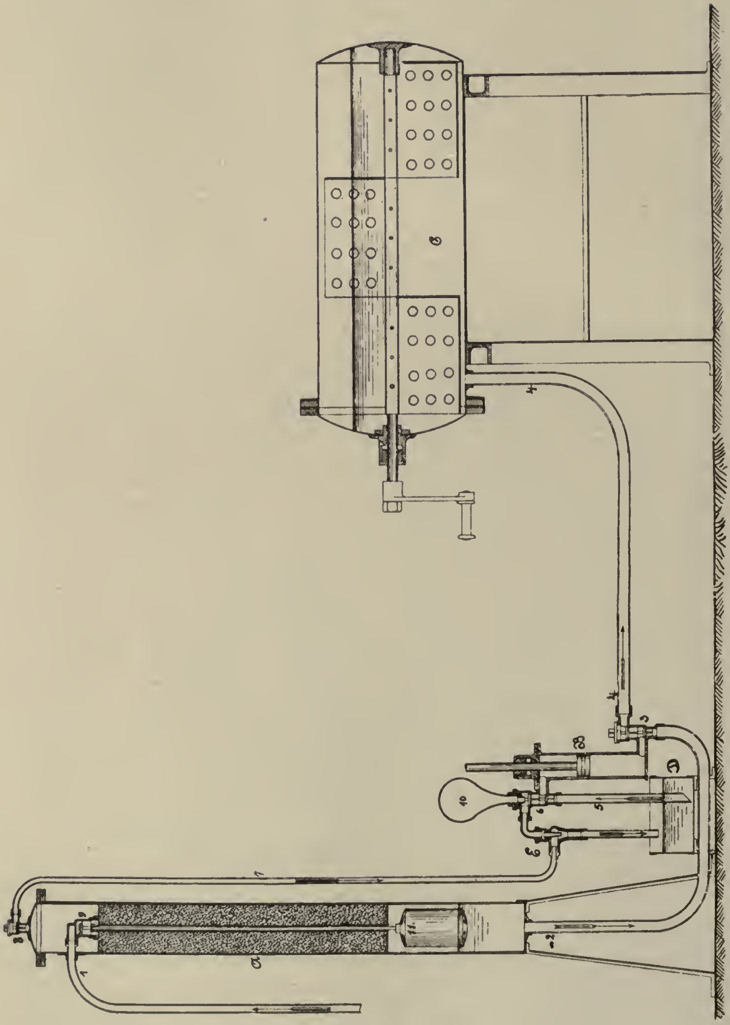


FIG. 133.—DIAGRAM ILLUSTRATING PROCESS OF DE-AERATING WATER BEFORE CARBONATING.

belt is again transferred from the loose to the tight pulley of the pump, thereby starting the latter. The principle of this shifting device has been adopted since with slight variations, by almost every manufacturer of carbonating machinery.

This cataract carbonator is one of the largest machines built for the purpose. When operated at sixty revolutions per minute it supplies six filling machines and produces as much as 2,400 gallons of soda water in ten hours, or 240 gallons per hour. When operated with a carbonating pressure of sixty pounds it consumes two horsepower, and when this pressure is increased to 180 pounds for the purpose of filling siphons, the power necessary to operate it increases to four horsepower. The machine is placed on the market at $800.

Among the thousands of bottling and carbonating equipments, many will be found which are still using the old style mixer. The principal disadvantage of the mixer lies in the fact that it is very difficult to expel the air from a solid body of water, and when it has been forced from it by the superior pressure of the carbonic acid gas charged into it, it can be expelled only by sacrificing considerable quantities of CO_2 gas at the same time. It is stated that the waste of gas which results in order to expel the small quantity of air contained in the water amounts to from ten to twenty times the volume of the latter. This enormous waste together with the unsatisfactory results in carbonating has now been successfully overcome by the construction of a de-aerating device which removes the air from the water before introducing it into the mixers by simple mechanical means. Since no air needs to be expelled from the mixer, waste of gas is entirely avoided, the carbonating pressure does not need to be as high as formerly and the water absorbs the corresponding volume of carbonic acid gas readily.

The apparatus which is now successfully used for this purpose is illustrated in Fig. 133 and consists principally of a cylinder *A*, in which the rarefication of the air is effected. Water is admitted into this cylinder through pipe 1, it passes valve 9 and enters the upper part of the cylinder where it spreads upon the filling material and percolates through same into the lower part of the cylinder. The filling material may consist of any suitable substance, such as pebbles, etc., which affects the purpose of dividing the water into fine layers, and provides at the same time sufficient resistance during the flow of water into the lower part of the cylinder to aid in effecting the liberation of the air from the water. The de-aerated water accumulates in the lower part of cylinder *A* and finally raises swimmer 11, and as the latter is connected with valve 9 by a rod, it will close the valve and shut off the water supply. A double-acting pump is connected with its water suction to the lower end of cylinder *A* by means of suction pipe 2, the water enters this pipe and passes through suction valve 3 into the pump cylinder *B,* from which it is discharged through discharge pipe 4, into the mixer *C*.

The other end of double-acting pump *B* is connected by its suction pipe 5 with a water receptacle *D;* it draws up the water through this pipe and a suction valve 6 into its cylinder and discharges it upon the return stroke of the piston through injector nozzle *E,* back into the same receptacle *D*. The force of the stream of water passing the nozzle creates an air suction, whereby the air in the upper part of cylinder *A* is rarefied. The partial vacuum so produced draws the air contained in the water into it and deaerates the water thereby. In order to produce an uninterrupted stream of water in the injector, air chamber 10 is interposed in the discharge line. In this air chamber sufficient water is stored under pressure to maintain the stream in the injector during the suction stroke of the pump. Air suction pipe 7 establishes connection between injector *E* and the highest point of cylinder *A* at which point a check valve 8 is interposed.

The method of operation is as follows: As soon as the pump is started and before the lower part of cylinder *A* is filled with water the injector *E* creates a suction of air and draws the latter from the upper part of the said cylinder. In so doing it immediately creates a partial vacuum therein. Meanwhile water passes into the cylinder through supply pipe 1, it spreads into the filling material and gives off its air, by reason of the vacuum which exists in the cylinder and which is continually maintained through the action of the injector. The incoming water is thereby de-aerated without interruption. As soon as sufficient water has accumulated in the lower part of *A,* it raises swimmer 11, passes into suction pipe 2 and finally into pump *B,* which discharges it into mixer *C*. The latter is operated by belt in the customary manner, the crank being shown merely to indicate that it may also be operated by hand, if required. In the mixer liquid carbonic acid is added at a pressure which corresponds

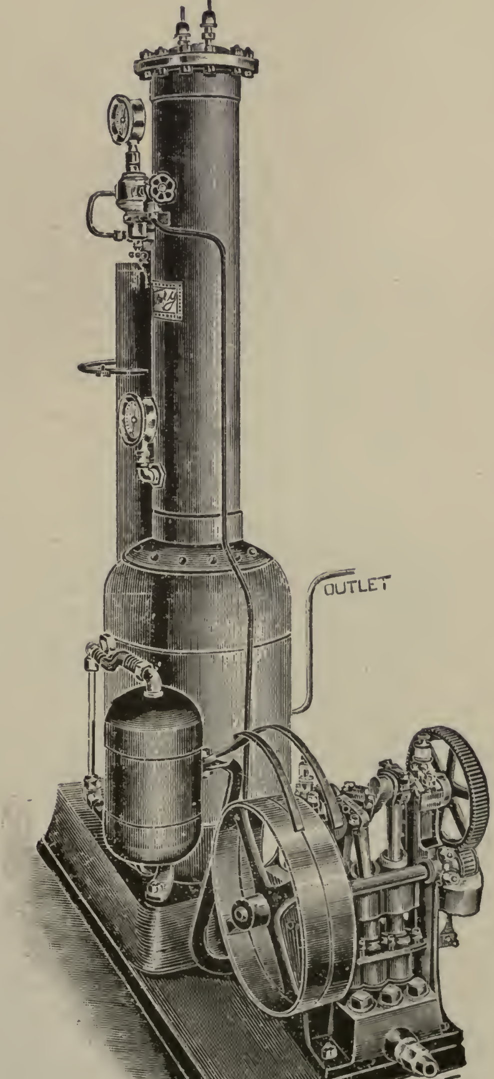


FIG. 134.—FERRY CARBONATOR, NEW YORK.

with the respective temperature of the water, and as the latter is poor in its required contents of air or gas, it absorbs the CO_2 readily and thoroughly. The de-aeration of the water has been accomplished so thoroughly that no air need be blown off from the mixer and the loss of gas is avoided. Both ends of the pump are always under water, whereby this end of the air line is effectively sealed so that it is impossible for atmospheric air to enter the vacuum in cylinder *A* through the pump or its connections. The same apparatus can be attached to any other carbonator in which connection its work is said to have been equally thorough and successful.

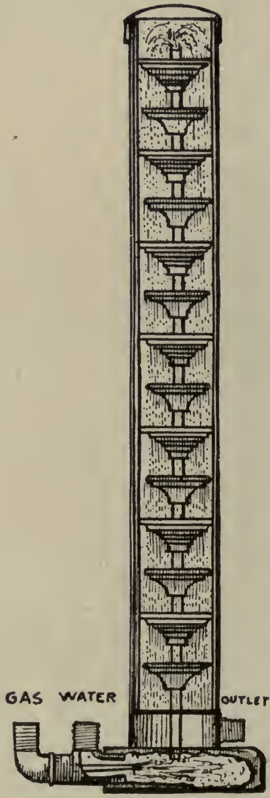


FIG. 135.—DIAGRAM FERRY CARBONATING SYSTEM.

The Ferry Mfg. Co., New York, have designed a carbonator which is illustrated in Figs. 134 and 135. Their method of carbonating as shown in the sectional view, Fig. 135, has the water and gas inlet at the bottom of the tower. The water enters a chamber at this place and a gas connection is made into the water line on the injector principle so that the gas will be drawn into the stream of water by the latter's suction. From the chamber the mixture of gas and water rises through a vertical pipe in the center of the tower and is discharged at the top over a tray.

Below the top tray are located a number of similar trays so arranged that the water on its downward descent falls from tray to tray. In this way it offers continually new surfaces to the gas until when it finally reaches the bottom it is very thoroughly carbonated.

FIG. 136.—POWER-DRIVEN CARBONATOR—AMERICAN SODA FOUNTAIN COMPANY'S TYPE.

This tower is enclosed within the form of the saturater as shown in Fig 134. It is also possible to arrange this machine in such a way that one receiver serves for a number of saturater columns, which may be placed on top of the receiver beside one another. The usual means for reducing the gas pressure are employed. The carbonator pump shown is of the well known triplex power pump construction. The power is transmitted to the pump by means of a tight and loose belt, and an automatic shifter is provided to shift the belt from the tight to the loose pulley and vice versa, whenever required.

It has already been explained that any degree of saturation may be obtained simply by regulating the carbonating pressure with reference to the temperature of the water, and all modern machines are constructed upon that basis.

One of the latest types of carbonators is illustrated in Fig 136. It consists of a power-driven carbonating pump and a carbonator body, which is provided with an agitator, water spray, gas chamber and automatic starting and stopping device. Pump and agitator are connected together, so that when the pump stops, agitation of the water also ceases. The starting and stopping is accomplished by a balancing device, which shifts the belt over to the loose pulley, thereby stopping the pump when the water level in the carbonator is sufficiently high; as soon as the water recedes the decreased weight of the water-ball of the balancing device is overcome by the counterweight, the belt is shifted back and the pump is again set in motion. This device is so designed that the highest possible absorption of the gas has been accomplished when the pump is stopped, further admission of water as well as agitation ceases and the gas is retained by the water. Water supplied by the pump enters through the top, passes a spraying device which forces it through the gas space in an atomized spray or mist, thereby increasing its surface of absorption, so that only a gentle agitation by means of the agitator is required to finish its saturation.

A carbonator which embodies the principle of absorption, which is so successfully used in the absorption tower of the carbonic acid manufacturing equipment, viz., the division of the water in very fine units by percolation, is shown in Fig. 137. The pump is constructed with a heavy frame, which also supports the power attachment consisting of tight and loose pulley. The carbonator body is equipped with an agitator and a starting and stopping device. The latter is of an improved construction, inasmuch as it starts and stops the pump as well as the agitator instantaneously by means of a gas pressure valve which connects the carbonator body with the starting and stopping device and which operates the latter as soon as the water chamber of the regulating device fills with water. When the water leaves it, it again acts upon the valve by releasing its pressure, a counter-weight immediately shifts the belt over on the tight pulley and the pump is again set in motion. In this way rubbing and slipping of the belt, with consequent loss of power and unnecessary wear and tear is avoided.

The water, as it enters the dome, passes through a moleculator, in which it is broken up into a fine spray, so that each individual atom absorbs its maximum of gas. The cylindrical tower is filled with agate spheres, over which the water in its descent passes in a thin film, thus being brought into intimate contact with the gas and retaining the highest percentage possible. In the water line between the pump and dome of the carbonator an air chamber is interposed which provides an air cushion and prevents hammering. A blow-off pipe through which atmospheric air may be expelled is connected near the top of the tower. The pump has a composition cylinder, plunger and

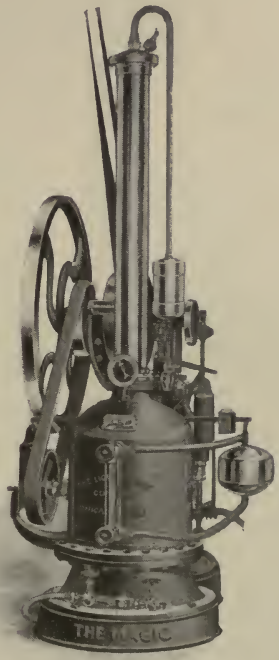


FIG. 137.—CARBONATOR WITH PERCOLATING TOWER—LIQUID CARBONIC COMPANY'S TYPE.

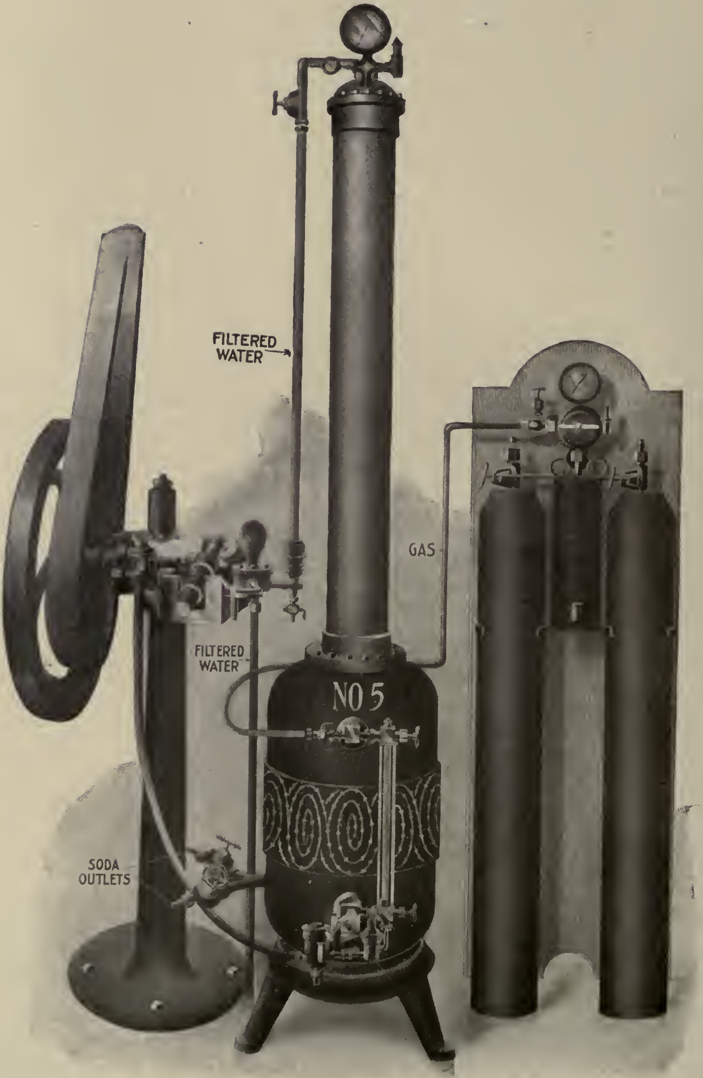


FIG. 138.—BISHOP & BABCOCK'S CARBONATING EQUIPMENT,

valves and the interior of the machine is provided with a heavy lining of pure block-tin throughout.

Fig. 138 illustrates another well-known construction. This carbonator relies solely for a thorough saturation upon the tower through which the water percolates. The tower is filled with glass balls, pebbles, or agate spheres. The pump consists of two cylinders, in each of which the plunger has an oscillating movement. Either belt or electric power may be used. When the water reaches a certain height in the base of the carbonator, a float rises which closes a valve and throws off a clutch on the pump, so that it stops working. Whenever several gallons of carbonated water are drawn the float drops, opening the valve and throwing in the clutch so that the pump again begins to operate and fills the carbonator.

The No. 12 "Eureka" carbonator made by the Bishop & Babcock Co., Cleveland, consists of the usual percolating tower, which is mounted on the lower base, forming the receiver of the carbonated water and in which is located a special agitating device. The exterior view of this carbonator is shown in Fig. 139. The complete equipment consisting of the carbonator with its double oscillating belt-driven pumps is mounted upon a substantial cast iron base plate. The pumps are constructed of bronze throughout and are provided with metal suction and discharge valves. These pumps are connected with the float ball in the receiver part of the carbonator as shown in Fig. 140. This float ball rises with the accumulation of water in the receiver and closes the water inlet valve as soon as the receiver is filled up to about its height, opening it again immediately after a few gallons have been withdrawn. Simultaneously with the closing of the valve the belt operating the pump is shifted accordingly. Special care has been exercised to insure the best possible lining of the carbonator tower.

To begin with the inside of the latter is tin flooded, over which is placed a heavy triple silver plate.

A special spraying device is situated in the top of the tower. This device forces the water in the form of a finely divided spray into the tower and during its downward course it absorbs as much carbonic acid gas as it can obtain through the surface of each individual drop of water, in accordance with the prevailing temperature and pressure. In descending, the water is caught by the agitator shown in the illustration. The agitator consists of a number of spoon shaped paddles which are keyed upon a rotating shaft. Whenever any of the spoons is dipped into the water it carries with it a small

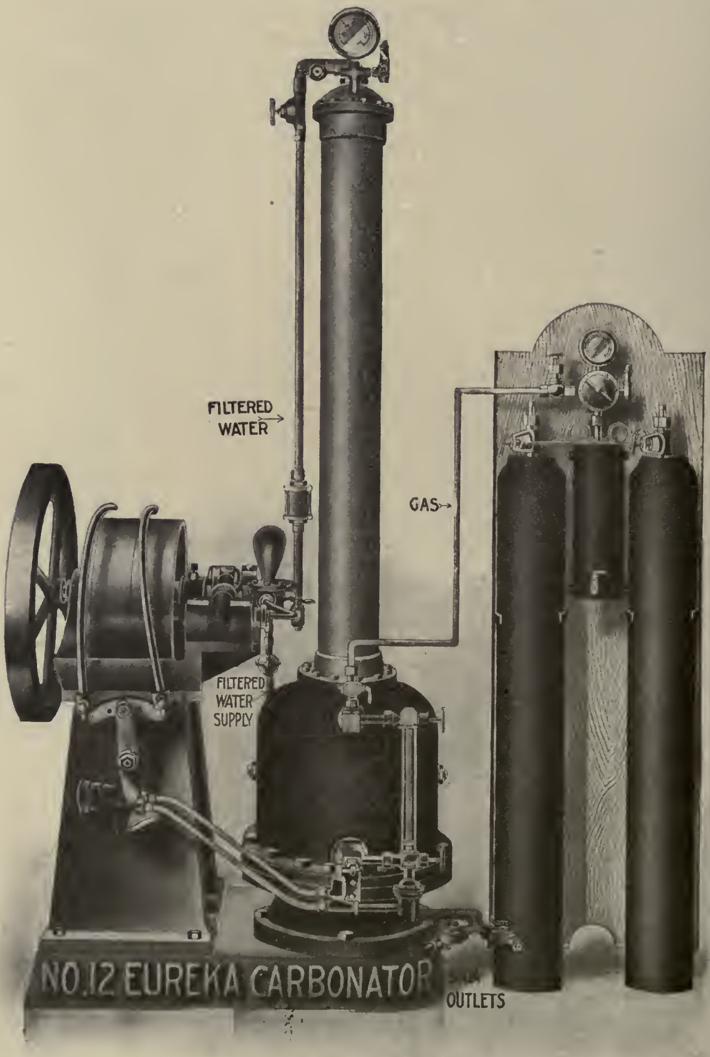


FIG. 139.—NO. 12 "EUREKA" CARBONATOR, BISHOP & BABCOCK CO.

volume of carbonic acid gas, thereby supplying additional gas to the water until the process of carbonating is completed.

The type of carbonator, illustrated in Fig. 141, operates on the mixture principle of carbonating, *i. e.,* pumping carbonic acid gas and water simultaneously, by means of the same pump, thus commencing to unite the gas and water at the very start. It then

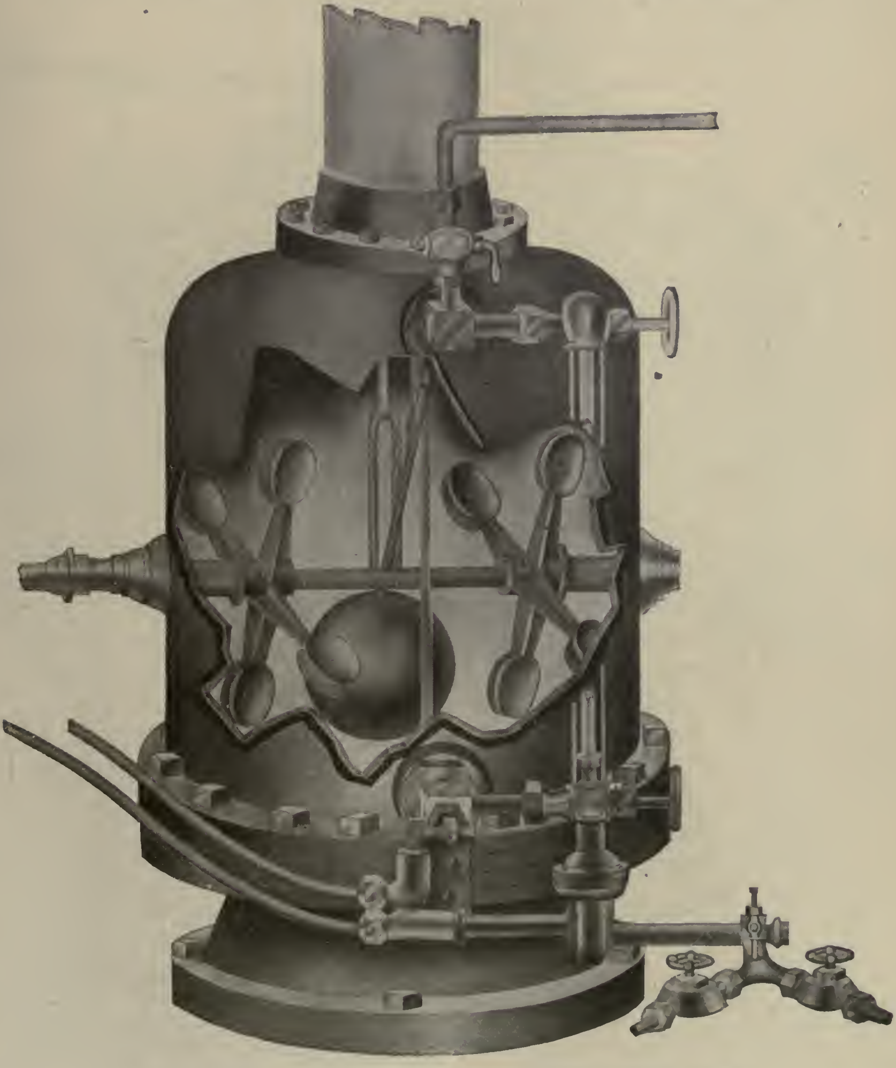


FIG. 140.—"EUREKA" CARBONATOR, SHOWING POSITION OF AGITATOR INSIDE.

discharges the gas and water through sprays, dividing the same into a perfect mist.

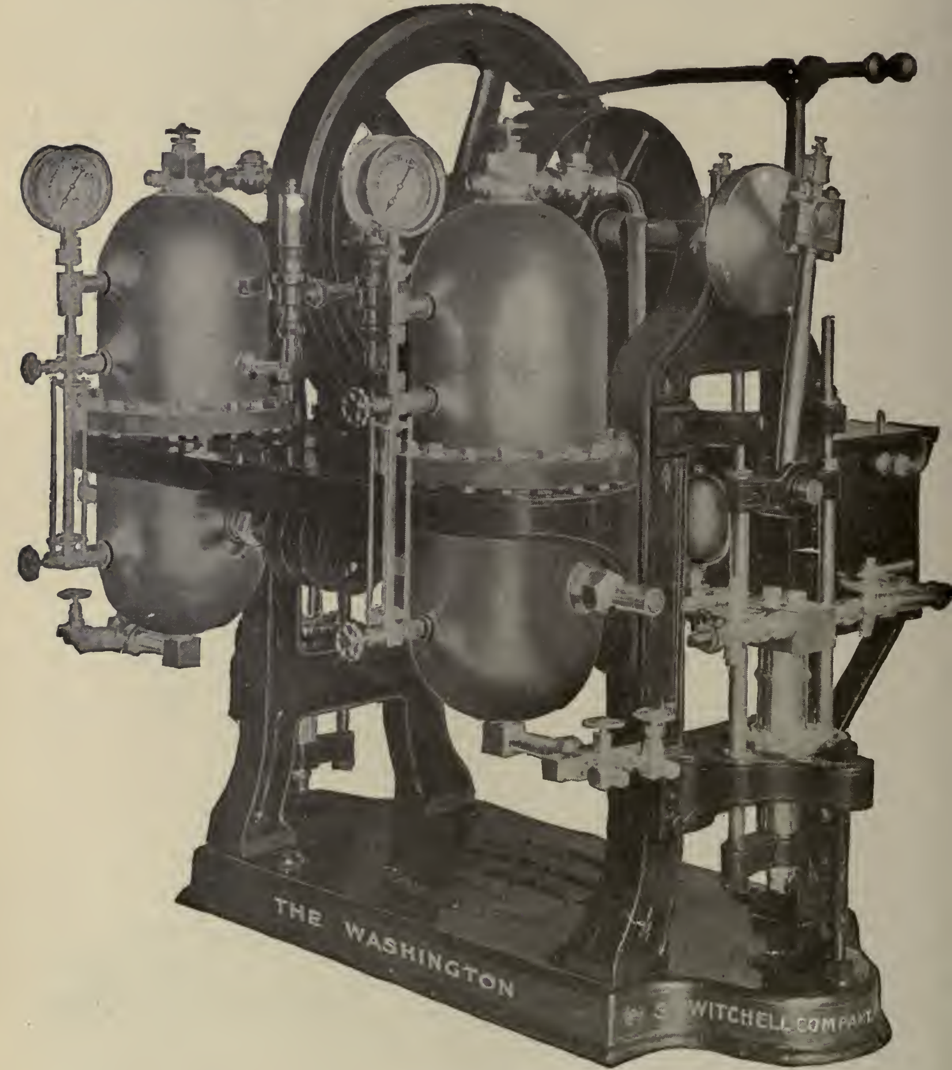


FIG. 141.—TWITCHELL'S "WASHINGTON" CARBONATOR.

The sprayed water then falls through a column of gas, which permits the water to absorb more gas. Specially constructed agitators return the water continuously through the gas space.

This carbonator separates the atmospheric air from the water as it enters the carbonating cylinder and returns the same to the gasometer where it collects at the top, being of a lower specific gravity than carbonic acid.

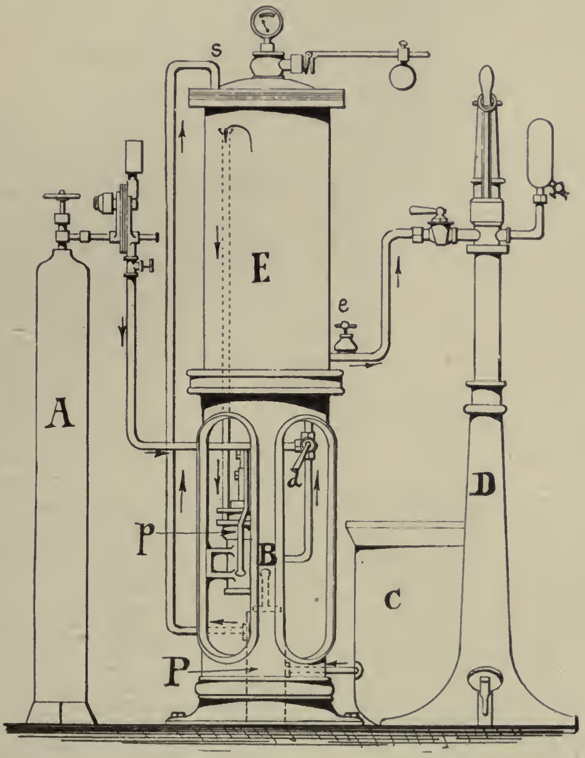


FIG. 142.—GAS CIRCULATING CARBONATOR.

GAS CIRCULATING MACHINES.

Fig. 142 illustrates a carbonator based on the gas circulating principle—a Luhmann product. It consists of the absorption cylinder *E,* mounted on a cast iron column, *B.* The water pump *P* with the water tank *E,* the liquid CO_2 cylinder with pressure reducer and the filling stand *D* are located as shown.

The water to be carbonated is taken by the pump from the tank, *C,* and introduced into *E* at *s.* The circulation of the carbonic acid gas, which is admitted into the saturator at a predetermined pressure, controlled by the pressure reducer, is effected by the gas pump, *p*. The suction of this pump extends through a stuffing box in the bottom of the saturator and is carried upward through the sieve to nearly the upper head of the saturator. The discharge pipe is connected to the bottom of the saturator. As soon as the gas pump is started, the gas which rests upon the surface of the water in the saturator, is drawn into the suction of pump *p* and discharged into the saturator below the sieve through which it passes in fine bubbles into the column of liquid. The absorption of the gas being continuously circulated through the saturator is rapidly effected without requiring much power by gas pump, *p*.

FIG. 143.—BOTTLING TABLE.

BOTTLING APPARATUS,

When the water has been prepared and carbonated it must be filled into the bottle. As the latter contains atmospheric air, however, and as the presence of air is undesirable in all cases, and detrimental in many, it should be removed before filling. The best way to remove the air is by charging the bottle with carbonic acid gas and allowing air and gas to escape during filling.

The process of filling and stoppering is ordinarily accomplished by a bottling table, Fig. 143, which is provided with a syrup gauge for adding the extract, a liquid connection with the carbonator and a "snift" valve for discharging atmospheric air. It has an adjustable bottle-rest so as to accommodate any size of bottle.

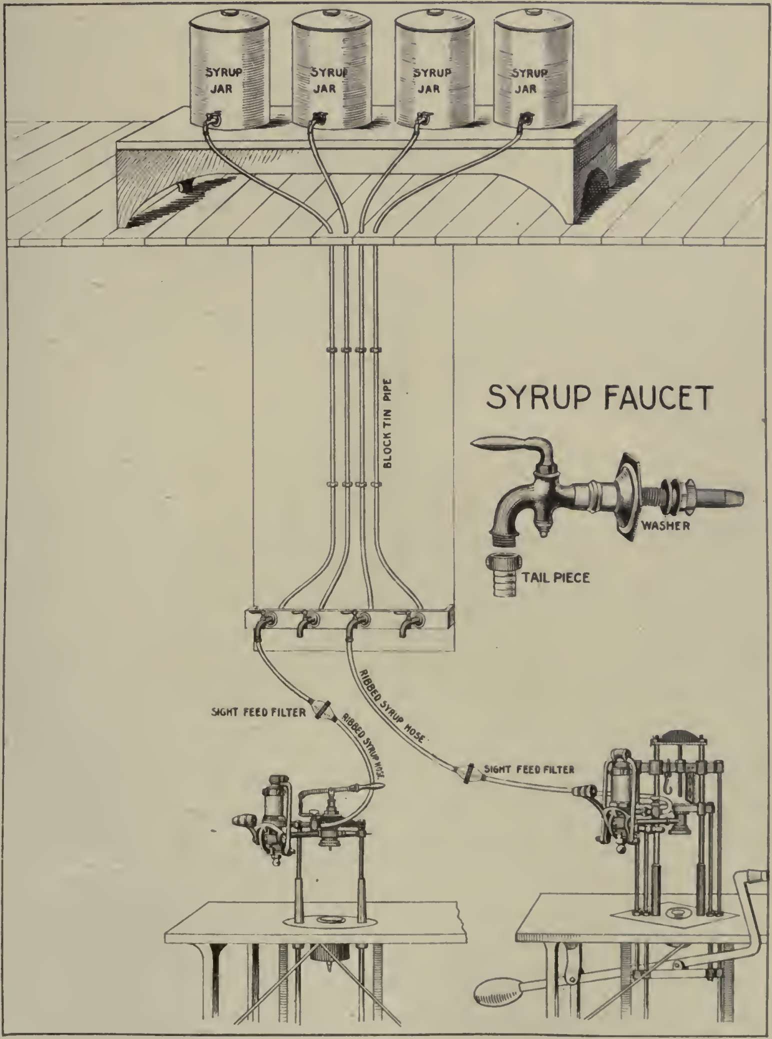


FIG. 144.—DIAGRAM OF CONNECTIONS BETWEEN SYRUP JARS AND FILLING APPARATUS.

Fig. 144 is a diagram showing the connection between the syrup jars and filling table. In practice the syrup jars should be placed in a cooler. A quantity of four ounces of syrup of an average summer temperature of 75° F. affects the balance of twelve ounces of water at a temperature of 40° F. very materially; it will produce an average temperature of 50° F. and this rise in the temperature will liberate a certain volume of gas from the water. The syrups should be of nearly the same temperature as the water and the bottled goods should be stored in a cool room before shipping. It works strongly against the success of the operation to mix a warm syrup with cold water saturated with carbonic acid gas, and afterward subjecting the goods to the temperature of a storage room which is considerably higher than the temperature of the bottled goods.

FIG. 145.—SELTZER SIPHON FILLER.

Seltzer syphons are filled in a special apparatus shown in Fig. 145. The syphon is inverted and placed at an agle in a forked rest. The lever is depressed as the valve is opened to allow the influx of water.

Many bottles containing carbonated beverages are closed by caps, special machines being provided for this work.

In conclusion, it may be permissible to say a few words regarding cleanliness.

In many instances an otherwise pure and carefully prepared article is spoiled by improperly cleansed bottles. The most careful attention should be devoted to this department. All bottles should be thoroughly soaked in a strong solution of soda lye; after soaking, they must be washed with clean water and finally rinsed with pure filtered water. In some cases it may be advisable to use distilled or pure mineral water for rinsing. This depends entirely upon the character of the liquid which the bottles are to contain. A medicinal water must be free from bacteria of any kind, and as recent investigation has shown that the source of impurities in a number of waters could be traced in nearly every case to the method of bottle and apparatus cleaning, it shows that too much stress can not be laid upon this point. Tubs, filters, measures, gauges, tin piping and the various appliances through which the beverages pass should be sterilized and otherwise cleansed thoroughly. If this is not done they will be fruitful sources of fermentation, causing ropiness. The walls and ceilings of the premises should be kept clean, floors must be scrubbed and washed regularly and the atmosphere must be kept clear by proper ventilation.

Fig. 146 is an interior view of a complete bottling plant.

A MODEL MINERAL WATER FACTORY.

One of the best equipped mineral water factories in the United States which is conducted upon strictly scientific and hygienic principles is that of Carl H. Schultz, New York, a descriptive illustration of which is given below. The various stages of the operations conducted in this establishment are shown by the diagram, Fig. 147. All the water used is taken direct from the Croton main, *A,* and conducted through coke filters, *B,* which remove all matter in suspension. These filters are so constructed that the filtering material can be easily cleansed and sterilized with live steam, thereby destroy-

FIG. 146.—INTERIOR VIEW OF A COMPLETE BOTTLING PLANT.

ing all organic substances. They are cleansed and sterilized twice daily by opening the inlet and blowing steam through the coke.

The water is then pumped to the top of the building, passing through heat exchangers *C*, which will be referred to later, and enters the fore-heaters *D*, which are heated by the exhaust steam from the ice machine and pumps. From these it passes into the storage tanks *E* and then into the fore-boiler *F*, where the water is boiled by means of steam coils in a partial vacuum, produced by rapidly revolving fans in the exhaust pipe *G*. The impurities still contained in the water are driven to the surface and carried away by skimmers, while the volatile matter and odors escape through vents on top of the tanks.

The water then flows by gravity to the feed boxes, which supply ten large stills, *H*. The feed boxes, *K*, are so constructed as to maintain a constant level of water in the stills.

The stills are arranged in five sets of two each having a total capacity of 60,000 gallons per day. They are made of copper and thoroughly tinned inside. A dome on the top is provided with a separator which prevents any solid particles from being carried over with the steam. A peculiar feature of these stills is the absence of coils. It is very difficult to clean a still containing a coil; and as these stills have to be cleaned daily, its designer, Dr. Hallock, fitted them with a pair of hollow, lens-shaped vessels in the place of coils, through which steam under high pressure passes direct from the steam boilers in the power house. This steam, being confined to the inside of the lenses, does not come in contact with the water to be distilled, therefore all contamination from boiler steam is avoided.

After distillation the vapor from the stills is condensed in steam condensers, *L* (tinned inside), by means of cold water passing through the tubes in the condensers in counter-current. This cooling water is city water which has previously been chilled by means of a cooling tower, *O*, constructed by Edwin Burhorn, New York, having a capacity of 150 gallons per minute.

The hot distilled water leaving the condensers gives up part of its heat in the heat exchanger to the Croton water, and is further cooled in several sets of coolers, *M*, consisting of pure block-tin pipes, where it is cooled down as much as possible by the cooling water from the ice machine. From there it is led to the cold storage tanks, *N*, where its temperature is kept slightly above the freezing point by

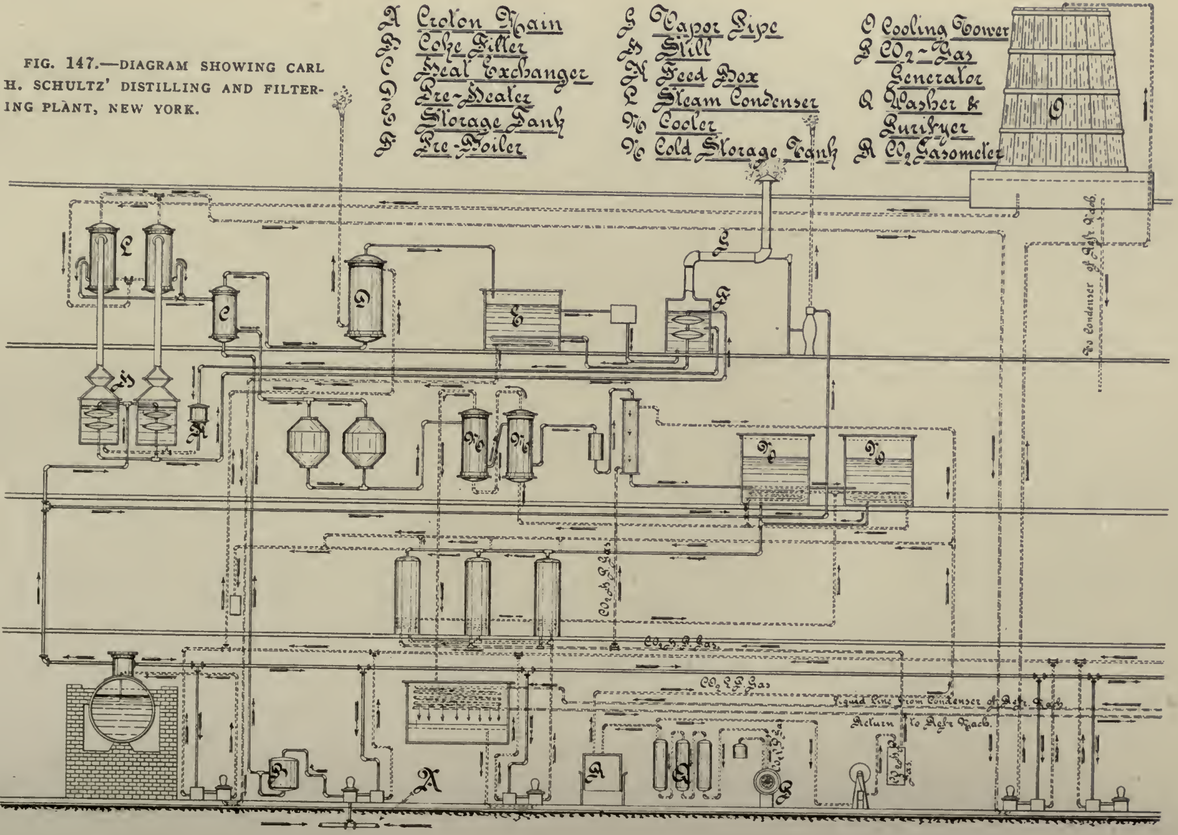


FIG. 147.—DIAGRAM SHOWING CARL H. SCHULTZ' DISTILLING AND FILTERING PLANT, NEW YORK.

means of coils, through which water circulates, which has previously been cooled by the refrigerating machine in a fresh water cooler equipped with direct expansion coils. The storage tanks are covered and provided with cotton plug vents to prevent any re-absorption of air. The coils are lined with block-tin or they are silver-plated, as are all the fittings, to withstand the action of the distilled water, which is much stronger than that of ordinary water. From the storage tanks, the water is drawn as it is needed by the different carbonating machines, or it is filled into large demijohns for the use of those who desire a water that is neither carbonated nor aerated.

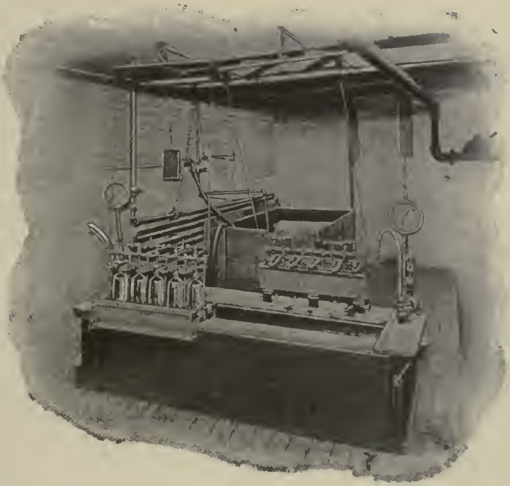


FIG. 148.—SIPHON TESTING DEPARTMENT CARL H. SCHULTZ' PLANT, NEW YORK.

The carbonic acid gas is produced in five large generators, *P*, by the action of sulphuric acid upon bicarbonate of soda. The generators are horizontal cylinders made of copper and are lead-lined. The acid is stored in lead-lined iron reservoirs overhead, from where it flows by gravity into the generators. The bicarbonate of soda is ground and poured into the generators through a hand-hole, which is then closed. The contents are kept in constant motion by a paddle driven by belt and pulley. As fast as the CO_2 is produced it is passed through an effective washing and purifying apparatus, *Q*, in order to remove all impurities which might give the gas a bad odor and impart a disagreeable taste to the water. The gas, after purification, is stored in large gasometers, *R*, from which it is allowed to enter the various carbonating machines.

The solutions which are used in making the various mineral and other waters are compounded in the laboratory and sent to the bottling department. Here they are introduced into the vertical, tin-lined, graduated vessels, which are filled up to the mark with cold, distilled water. This mixture is carbonated as much as possible under atmospheric pressure by a stream of carbonic acid gas. After samples taken from these tanks have been reported by the chemists to be correct, the water is drawn into the carbonating machines and thoroughly carbonated with CO_2 gas under pressure.

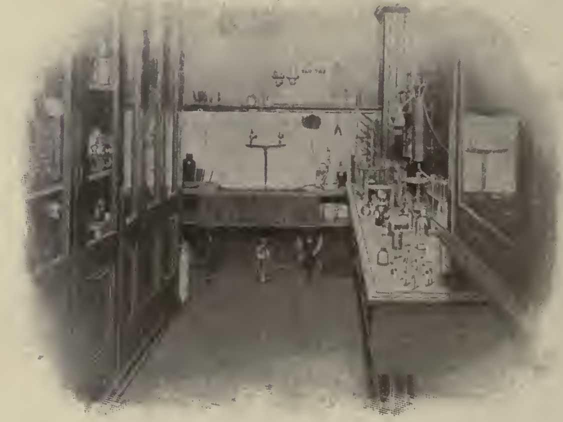


FIG. 149.—BACTERIOLOGICAL LABORATORY CARL H. SCHULTZ' PLANT, NEW YORK.

The water, now ready for bottling, is forced into siphons or bottles as required. All siphons and bottles are thoroughly cleansed and re-labeled before they are filled. The bottling machines are provided with valves and means for compressing and inserting the cork. The bottling plant consists of twenty bottling and carbonating machines with a daily capacity of fifty thousand siphons and bottles.

The carbonated water flows from a reservoir at the top of the machine under pressure to the bottling machine, which does both filling and corking. In bottling club soda, peculiarly-shaped tongs are used, which hold the cork in position until it can be wired. As the neck of these bottles is not parallel but conical, the cork is expelled immediately after unwiring. The pumps for handling the charged water are lubricated with water, so that no carbonated water can come in contact with grease.

There is an excess of carbonic acid gas in all bottles and siphons, as they are filled at a pressure of from 60 to 120 pounds per square inch. The lower pressure is used for the filling of bottles only. Special machines are used to fill the siphons. The siphon is inverted and placed at an angle in a forked rest. The lever is depressed as the valve is opened to allow of the influx of water which is being forced in by pumps.

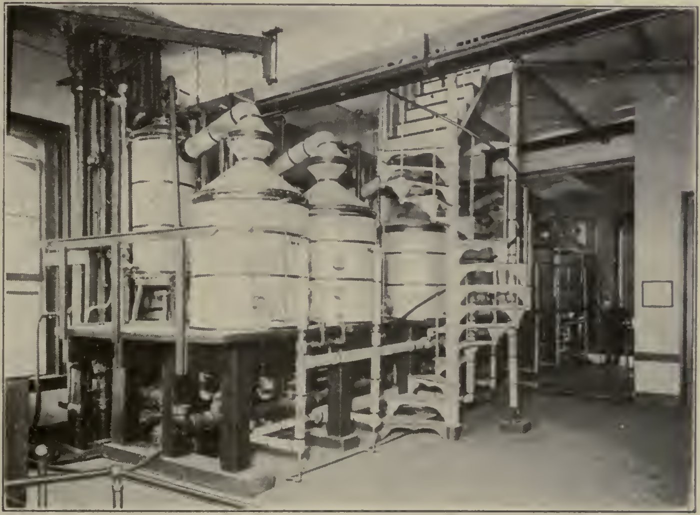


FIG. 150.—WATER DISTILLING EQUIPMENT CARL H. SCHULTZ' PLANT, NEW YORK.

All possible precautions are taken to guard against accidents through breaking of bottles. Before leaving the premises they are subjected to a thorough test.

The siphons are imported from Bohemia in large casks. After they are unpacked they are filled with water at a temperature of from 98° to 100° F. Then they are put in cases and subjected to a hydrostatic pressure of 350 pounds per square inch. This pressure is allowed to remain for about thirty seconds, when it is reduced to 100 pounds and the entire cage, containing five siphons, is then submerged in a tank containing cracked ice and water. Any defect in the glass will cause the siphon bottle to break instantly on account of the sudden change of temperature. The second step is the only definite method to discover flaws in the anneal of the glass, and is, by far, severer than any conditions a siphon is ever subjected to.

With the exception of the glass all the remaining parts are manufactured on the premises and contain only pure metal. All working parts that come in contact with the water are heavily silver-plated. The siphon head is made of tin and is kept bright by being buffed each time it is returned to the factory. The name of the firm is etched upon the glass with the aid of a sand blast.

The chemical laboratories are among the finest and most thoroughly equipped in existence in connection with the manufacture of mineral waters. They contain all the latest forms of apparatus for careful work and scientific investigation.

There are practically five separate departments:

1. The preparatory solution department, where the solutions are made up which are used in preparing the various mineral waters.

2. The compounding laboratory, where the solutions are measured out and combined.

3. The analytical department. Here all of the salts are analyzed for purity, and the finished product is subjected to a constant scrutiny, the water being tested for each thousand siphons. Twenty-five reproductions of spring waters are made, each one naturally differing in composition and effect from the other.

4. The bacteriological laboratory for special investigations.

5. The photographic department, containing a dark room for photographic work and spectroscopic investigations.

These departments are under the supervision of Dr. Hallock, aided by a staff of skilled analytical chemists, who are not only engaged in a ceaseless scrutiny of every step in the process to guard against possible error, but also in making analyses of all the materials used and of every lot of finished product before bottling. The complete analysis of each water is on the bottle and the waters are guaranteed to agree with these analyses.

The following waters of which the analysis made by some of the most prominent chemists is appended, are made in this establishment:

COMPARATIVE TABLE OF ANALYSES OF ARTIFICIAL VICHY MADE BY CARL H. SCHULTZ.

Grains per U. S. Gallon:	Dr. Endemann	Dr. Hallock	Frazer & Co.	Average	Bauer*
Potassium sulphate	12.426	12.094	11.946	12.155	11.8990
Sodium sulphate	6.845	6.928	6.867	6.886	6.8645
Sodium phosphate	0.170	0.187	0.233	0.196	0.2460
Sodium chloride	33.528	33.719	33.696	33.648	33.7531
Sodium bromide	0.030	0.017	0.016	0.021	0.0076
Sodium iodide	0.006	0.003	0.004	0.004	0.0015
Sodium carbonate	221.230	221.492	221.923	221.548	221.6842
Ammonium carbonate	0.249	0.303	0.228	0.260	0.2735
Calcium carbonate	14.076	14.474	14.259	14.269	14.5813
Strontium carbonate	0.121	0.132	0.075	0.109	0.1352
Magnesium carbonate	2.229	2.029	1.843	2.034	2.0580
Iron and manganese	traces	traces	traces	traces	traces
Alumina	0.044	0.041	0.092	0.059	0.0455
Silicic acid	2.880	3.137	3.668	3.228	3.7359
Totals	293.834	294.556	294.870	294.417	294.2853

* Bauer's analysis is the recognized standard analysis of the vichy, "Grande Grille."

The following table shows the total mineral ingredients in 100,000 parts of Carl H. Schultz's artificial mineral waters:

Bitter-Waters:	
Pullna	3,272
Kissingen Bitter-Water	2,529½
Alkaline Saline Waters:	
Quadruple Carlsbad	2,206½
Double Carlsbad	1,103
Marienbad (Kreuzbrunnen)	859
Muriated Waters:	
Homburg (Elizabeth Quelle)	1,330
Artificial Saratoga	1,047
Kissingen (Rakoczy)	855½
Alkaline Waters:	
Artificial Vichy	506
Bilin	495½
Obersalzbrunn	256
Muriated Alkaline Waters:	
Selters	370
Gleichenberg (Constantin Quelle)	540½
Ems (Kränchen)	280
Lithia Waters:	
Lithia Water	272
Contains Bicarbonate of Lithium	146
Lithia-Vichy	543
Lithia-Carlsbad	610
Chalybeate Waters:	
Pyrmont (Neubrunnen)	316
Schwalbach (Stahlbrunnen)	43
Iron Water	17 76-100
Pyrophosphate of Iron	44 06-100
Earthy Waters:	
Wildungen (Helenen Quelle)	350½

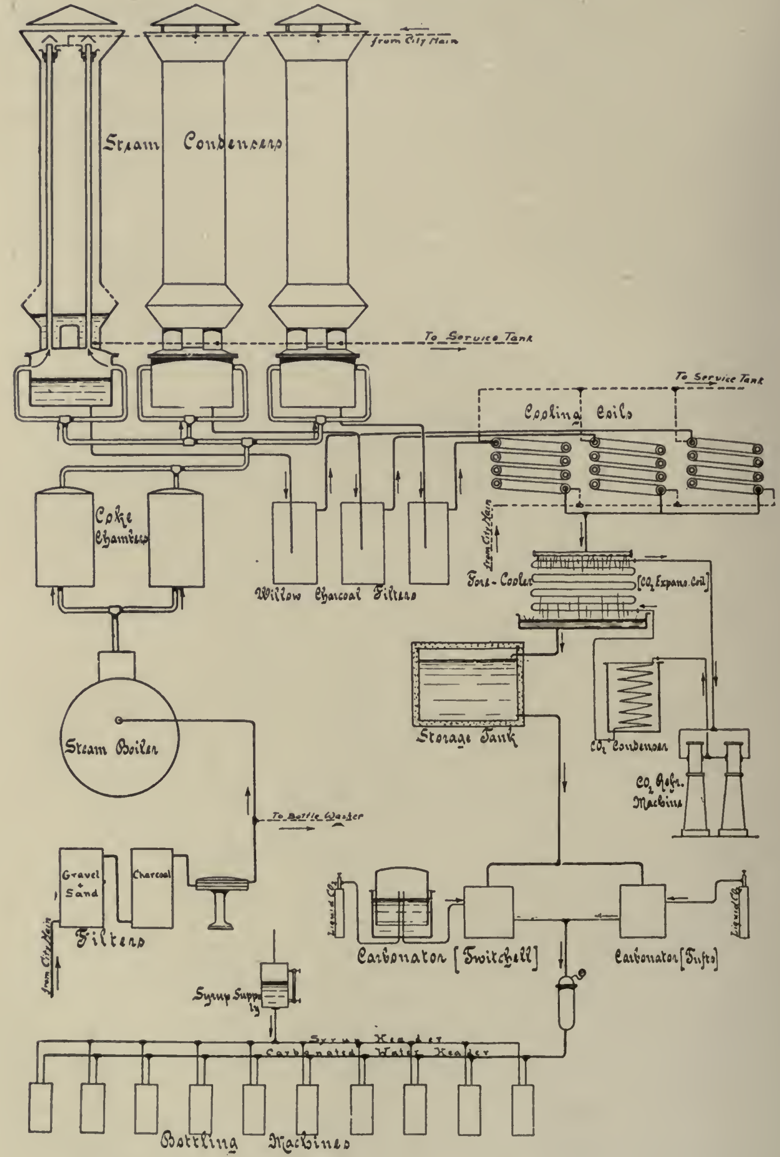


FIG. 151.—DIAGRAM WATER PURIFICATION, COOLING AND CARBONATING APPARATUS "MOXIE" PLANT, NEW YORK.

THE "MOXIE" HEALTH BEVERAGE FACTORY.

The diagram, Fig. 151, illustrating a plant, located in New York, which is exclusively devoted to the manufacture of one of the many summer health beverages is shown on the following page.

All the water used in this plant is taken from the city main. Before entering the boiler it is passed through three different filters in order to remove all matter held in suspension. In the first filter the water is forced through layers of gravel and sand; from there it passes through a charcoal filter and is subjected to a third purification in the "International" filter, where it passes through discs made of compressed cotton fibre and a perfectly pure water is produced. This filter is shown in Fig. 152 and is one of the largest size made by the International Filter Co., Chicago.

This water would be of a quality fit for carbonating purposes, but in order to fulfill all sanitary conditions, which is a matter of importance when the use of city water comes into question, the water undergoes a process of distillation.

It leaves the boiler in the form of live steam and naturally under a high pressure, as part of the steam is used for power purposes. As steam of such high pressure and consequently high temperature is less pure than steam generated at low pressure, the steam, before being condensed, enters special coke chambers, which act as scrubbers and most effectively absorb any impurities and gases still contained in the steam.

The steam condensers are furnished by the Palatable Water Still Company and are so constructed that the steam enters the lower ends of the condensers, where its surplus heat is lost by expansion in these vessels as well as in the interior of the condensing tubes, which are thus heated by the steam, causing a strong upward draft through the enclosing chimney, which extends their entire length. Both pipes and chimney are open at the top and covered by a hood to keep out dust and rain. The outside of each condensing tube is wound spirally with burlap, which is constantly kept wet by water sprayed upon the top. The draft in the chimney causes a rapid evaporation of the water on the burlap and produces an intense cooling effect on the condensing tubes. The latent heat of vaporization represents the actual work of condensation. This method greatly reduces the water consumption, which is the principal item in the production of distilled water. Another advantage of this kind of condenser is, that whatever gases are present in the steam will rush rapidly upward in the center of the tube, where the greatest draft prevails, and escape into the open air. Condensation and de-aeration thus take place simultaneously and a pure distillate is obtained.

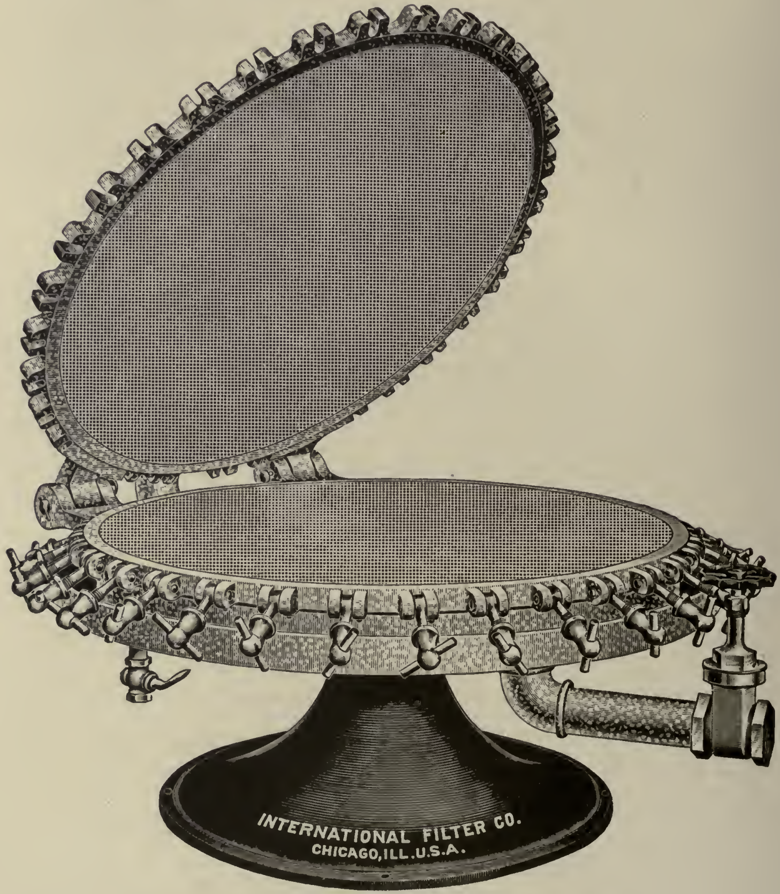


FIG. 152.—INTERNATIONAL FILTER, "MOXIE" PLANT, NEW YORK CITY.

As an extra precaution the distilled water is forced to pass through the willow charcoal filters. This charcoal acts as a deodorizer and removes the slightest traces of impurities which may have remained after the process of condensation.

The distillate at nearly boiling temperature enters a double pipe cooler, called the "Economy" cooler, where it transfers its heat to the cooling water, passing through the coil in a counter-current. These coolers have the advantage of obtaining a perfect heat exchange. They are exceedingly small in comparison to their capacity, no tank of any kind being required.

The distillate receives a final cooling in the fore-cooler by trickling in a fine stream over vertical continous-wound, tinned copper coils, in which liquid CO_2 is allowed to expand.

This method of cooling by a CO_2 refrigerating machine is one of the striking features of the Moxie plant. Up-to-date bottlers should devote their attention to this method of refrigeration, as it is the only safe one and the only system that can be recommended in connection with a bottling plant. Wherever there is an ammonia machine there is constant danger of a leak, and in that case the products would be totally spoiled, if they are not enclosed air-tight, as the water will absorb ammonia rapidly.

The refrigerating plant as designed by Wittemann Brothers and remodeled by the author is shown in diagramatic form in the accompanying illustration, Fig. 151. Its total refrigerating capacity is ten tons. It consists of two vertical double-acting cylinders $2\frac{7}{16}$ inches diameter and 9½ inches stroke, mounted on one base, each having a displacement of 76 cubic inches per revolution. The cylinders are made of special composition bronze and provided with safety caps.

The CO_2 condenser is of the submerged type and is made of 1-inch extra heavy pipe of a total surface of 250 square feet.

The expansion side consists of two sets of 1¼-inch tinned copper coils. These coils are thirty-six pipes high and form a nest of three continuously wound coils each twelve pipes high. The expansion coils are enclosed in a well insulated box to prevent any radiation of cold. After being cooled the distilled water collects in the drip-pan and enters the cold water storage tank, from where the chilled distillate is drawn as it is needed by the carbonating machines.

The value of a "health" drink depends not only upon the purity of the water, but also in a great measure upon the purity of the carbonic acid with which the water is to be charged. No gas is manufactured on the premises, as the company prefers the use of liquefied CO_2, prompted to this step by the fact that the average CO_2 generators often produce a gas containing more or less constituents which impair its purity.

Two carbonating machines of approved design charge the water with the necessary amount of CO_2. The carbonators are furnished by the S. Twichell Company, Philadelphia, and James W. Tuft, Boston, respectively.

Twitchell's "Washington" carbonator is working under the low pressure principle. The machine is automatic in its action, easy to operate, and impregnates the water thoroughly, pumping gas and water together and spraying the mixture simultaneously through the gas chamber under pressure. As this machine is of very strong construction and is safe-guarded in every way, there is no possible danger of accident or over-charging when using carbonic acid gas under high pressures.

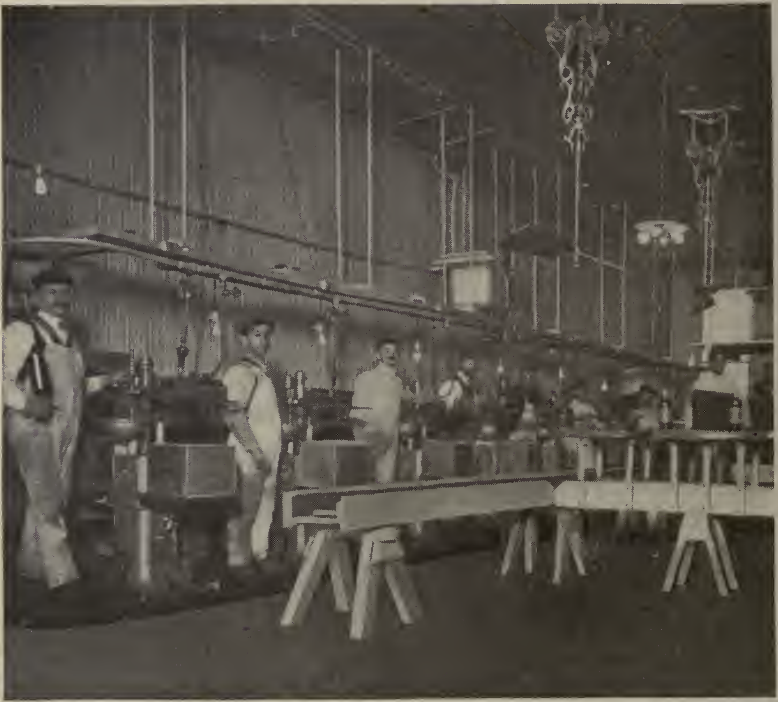


FIG. 153.—BOTTLING DEPARTMENT, "MOXIE" PLANT, NEW YORK.

Tuft's "Cataract" carbonator is provided with an automatic regulating valve, which may be set for any desired pressure between 40 and 180 pounds.

The bottling department (Fig. 153) is equipped with ten bottling machines furnished by the Crown Cork and Seal Company, Baltimore.

The carbonated water is admitted under pressure to the bottling machine, which does both filling and corking. A second pipe header carries the Moxie syrup, with which the bottles are first filled about two inches high, after which carbonated water is added.

FIG. 154.—BOTTLE WASHING DEPARTMENT, "MOXIE" PLANT, NEW YORK.

The machines are especially designed for filling and crowning carbonated beverages while under pressure, without loss of gas. An automatic gravity device for measuring and discharging any required amount of syrup takes the place of the usual syrup-pump, the amount of syrup required being quickly and accurately determined by an adjustable screw gage in the top of the syrup cup.

The table on which the bottle stands when the machine is being operated is adjustable to any height of bottle.

The crowns are contained within a cup in front of the machine, at the most convenient point for the operator.

Two bottles are always in use when the machine is being operated, which are moved from left to right across the table of the machine, the case of empty bottles being placed on the left-hand table leaf, and the empty case to be filled on the right-hand table leaf.

In operation the right-hand bottle under the head of the machine receives its required amount of water, while by the same operation, and at the same time, the bottle at the left, under the syrup cup, receives its measured quantity of syrup.

The crown is placed in the throat of the machine before the bottle is filled, and when the head of the machine is brought down to the bottle by pressure of the foot on the treadle, a gas and water-tight joint is made between the head of the bottle and the rubber gasket contained at opening of throat, thereby preventing any escape of gas or water during filling. When the bottle is filled, a quick downward pressure of the foot on the treadle crowns the bottle.

Scrupulous cleanliness is observed in the manufacture of the syrup. A special room is set apart as a laboratory, where the various ingredients are compounded. The solutions are subjected to a severe filtering process before they are admitted to the bottling machines.

The bottle washing department (Fig. 154) is equipped with all the latest improved apparatus. All bottles are washed with thoroughly filtered water, which is supplied by a branch pipe, shown in the diagram. An "Eick" bottle washing machine washes and rinses sixteen bottles at a time. Special machines have been constructed for washing and sterilizing bottles automatically on a large scale.

CHAPTER XI.

UTILIZATION OF FERMENTATION CARBONIC ACID.

COLLECTION OF FERMENTATION GAS.

Owing to the active demand for liquid carbonic acid, especially during the summer months, and in further consideration of the importance of this gas for various purposes in the brewery, the question of the advisability of installing a fermentation gas collecting outfit deserves careful consideration.

Fermentation carbonic acid is given off in enormous quantities from the fermenters. The interesting question of how much carbonic acid gas is produced during the fermentation period of 1 hectolitre of wort of 12° Beaume has recently been explained by Dr. Doemen of Munich. According to Dr. Doemen's calculation, 1 hectolitre = 26.4 gallons of wort of 12° Beaume produces between 12 and 15 hectolitre = 42 and 53 cubic feet of gas. About 10 per cent of this gas remains in the wort, so that the quantity expelled amounts to between 38 and 47 cubic feet for every 26.4 gallons of wort fermented; 8.5 cubic feet of this gas at atmospheric pressure furnish one pound of liquid carbonic acid, hence we may obtain one pound of liquid carbonic acid from every five to six gallons of wort of 12° Baume. Thus a brewery of 100,000 barrels annual capacity would be able to furnish about 500,000 pounds of liquid carbonic acid per year.

The fermentation gas is a by-product and diffuses into the air ordinarily. A modern brewery equipped with the proper machinery would be in a position to collect this gas and put it in a marketable condition at a slight cost, thereby making this by-product a source of additional revenue too valuable to be neglected. But—it is argued—the mineral water trade, which would be the principal consumer of the gas, demands a product which, next to being absolutely pure, is also to be free from all by-odors, and as this gas is produced by means of an alcoholic fermentation it is bound to have a slight fusel-oil odor. The impure gas does have such an odor, but this odor may be entirely eliminated by means of a proper deodorizing apparatus. On the other hand, if the brewery does not care to enter into the supply of gas for the mineral water trade, there are many other branches of industry which can make use of it where a slight odor is no detriment to its use. It is also a fact that new uses are being constantly discovered for carbonic acid gas.

Fermentation gas has a splendid field of usefulness, in the first place, within the walls of the brewery where it is originated. Secondly, it may be used in every saloon supplied with beer by the brewery, for the purpose of raising the beer to the faucets, and third, it will find a ready market for use in a constantly increasing number of industries where it may be utilized for power and chemical purposes.

Authorities declare that beers which are not so highly fermented are much better suited for carbonating than are beers with a high percentage of alcohol. Experiments which date back as far as 1882, made by Langer, in Munich, conclusively show that absorption of the carbonic acid gas by beer decreases with an increased percentage of alcohol, and is in direct proportion to the amount of extract and the quality of the extract, especially the quantity of malto-dextrines.

Carbonating has of late made considerable progress, and where suitable methods of brewing have been adopted, and efficient plant and machinery introduced, it can be truly said that the process of carbonating has proven a great success. That the process at certain times is unfavorably commented upon, is partly due to defective machinery, generally, however, to a lack of knowledge of the necessary methods of brewing. There are as many methods of carbonating as there are of mashing, and what has worked successfully in one brewery, may not necessarily be successful in another. The beer can be either carbonated from fermentation or carbonated after storage or into the kegs. Mr. Carthaus, some years ago, in Buffalo, carbonated the beer directly from fermentation after cooling it to near freezing point and brought it to the chip casks where he fined and bunged it. He made a great reputation with this beer, which possessed remarkably good stability. It was the type of beer most suited for carbonating; a wort rich in dextrine, fermented with a yeast of high attenuation, so that the resulting product showed final attenuation and still a low degree of fermentation.

Mr. Schwartz, of New York, recently added his testimony on behalf of the advantages of carbonating bottle beer. When kraeusening the beer, he said, we add fresh quantities of yeast, hop rosin and albuminoids. All these have to be eliminated again by prolonged storage on chips, so that the advantage of storing the beer is practically lost. Not so with carbonating. The beers after fermentation, can be subjected to cold temperatures, whereby the albuminoids and hop rosin are eliminated, and as no addition of yeast and fermentable matter is to be made, naturally such a beer will be less sensitive to cold, and will have much better keeping qualities than kraeusened beer.

Although many brewers still object to carbonating, preferring to adhere to the older methods, a larger percentage of alcohol and high attenuation, still it cannot be denied that the carbonated beers are growing in favor and the brewers, in spite of their conservatism, are gradually coming to understand that it is the consumer who ultimately decides the question.

With the loss of the carbonic acid, taste, effervescence, foam stability and aroma disappear, often to such an extent that the beverage is not only unfit for drinking purposes, on account of its flatness, but it may even create disturbances in the digestive organs. Beverages highly charged with carbonic acid, on the other hand, are palatable and refreshing, they act in a stimulating manner upon the digestive functions, and owing to their energetic action upon the circulatory system, they produce warmth, even though the beverage may have been colder than the ordinary drinking temperature. Draught beer should be kept under a continuous pressure of carbonic acid in order to maintain its full saturation with the gas, so that the last drawn glass may be as effervescent as the first. Beer and other beverages kept under air pressure will lose their carbonic acid in the same proportion as the contents of the barrel become less, because the gas diffuses into the air and in its place the beverage absorbs the air. As a result the beverage becomes stale and flat and produces a "nachtwæchter," as the Germans call it; hence it is absolutely essential to exclude the air and at the same time to retain the carbonic acid.

Another point of importance to be carefully looked after is the aroma of the gas used for carbonating the beer, and this is one of the instances where it is desirable to use a gas that contains the full flavor of the wort from which it originated. This flavor will then be re-incorporated in the beer with the gas and add considerably to its excellence. A foreign—made by another process—carbonic acid gas does not possess this quality in the same degree as the gas obtained from the brew which is to be re-saturated with it before racking into the packages. These flavors are the products of the fermentation and contain the volatile oils and resins of the hops. Care must be taken that they are not destroyed during the subsequent handling of the gas after it leaves the fermenters. Carbonic acid has a great affinity for flavors, acquiring the same readily, and this facility is increased when the gas is in a moist condition. Therefore it is of advantage to keep the gas humid until after compression. During compression this humidity should be made to disappear, so that the gas will enter the storage tanks in a nearly dry condition. Then there will be no deposits of water which, if present, would have a tendency to become stagnant, although the gas acts as a preserver and prevents the water from getting foul for a considerable time.

The tendency during the last five or six years has been to collect and store the fermentation gas and re-incorporate the same with the finished beer, rather than to continue the "kraeusen" process with its well-known disadvantages. The use of carbonic acid gas for the purpose of raising the beer to the faucets is today almost universally employed in the United States, much to the advantage of the beer so handled, and as a small quantity of the gas will be absorbed by a beverage poor of gas before the barrel is emptied, it would certainly be advisable to use fermentation gas with its close relation to the beer for this purpose, instead of doing this work with a gas made by another process. In the former case it would be necessary to liquefy the fermentation gas, which may be easily accomplished, as will be explained later on in this chapter. A steel cylinder containing liquid carbonic acid is readily transported and can be delivered, as may be required from time to time, with the beer. In a barrel half filled with beer, kept under carbonic acid pressure, the contents will remain fresh and palatable for a long time, because the gas keeps the air out of the barrel and prevents the escape of the gas contained in the beer.

The method of gas collection, purification, compression and storage is a very simple proceeding, and the machinery required for this purpose is such as every brewery engineer is fully acquainted with.

In operation it is necessary to prevent any possibility of an admixture of air with the gas, and it is therefore essential to have the fermenters made air tight. The principle of an air-tight gasometer being well known, the idea of applying same to the fermenters was naturally conceived. Such gasometer had its hood suspended over the fermenter, its lower rim entered the wort, and it was movable by means of light cables running over suitable pulleys. A hose connection entered the hood at its highest point and conducted the gas to a gasometer of larger proportions, used for the purpose of storing the gas collected from a number of fermenters.

This system was cumbersome in its practical handling; it did not allow of an effective discharge of air developed during the first stage of fermentation, and it was soon replaced by a stationary cover. This cover was simply set into a groove *g*, as shown in Fig. 155, and fastened to the outside, near the top of the fermenting vat. The groove was about 4 inches high, and a water seal of 3 inches prevented the escape of gas from the inside, as well as entrance of air from the outside. The only advantage to be gained by the use of this removable cover was the possibility of the gas escaping during a rapid development of same, without bursting the tank. In order to guard against this danger, reliable safety blow-off valves have since been designed, and the general practice of today is to use a stationary cover was simply set into a groove *g*, as shown in Fig. 155, and this cover is provided with a man-hole, at other times it is solid

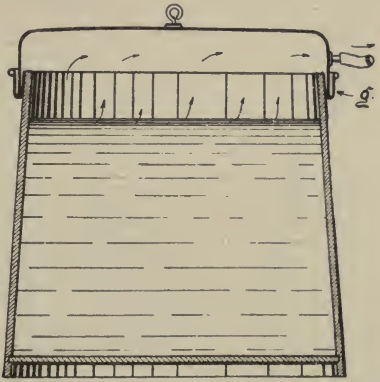


FIG. 155.—FERMENTER WITH HOOD SET IN SEALED RIM.

throughout, containing only a flange opening with nipple to make a hose connection to the gas suction line.

Closing the vats in this manner met at first with some hesitancy on the part of the brewers, because it precludes the chance of observing the progress of the fermentation, as is the case with open fermenters. At the present time it is not at all necessary that the process of fermentation should be watched; the brewmaster of today is enabled to calculate the beginning as well as the end of the fermentation with absolute certainty, for the reason that the surrounding conditions of temperature, removal of the heat of fermentation, etc., are under his positive control.

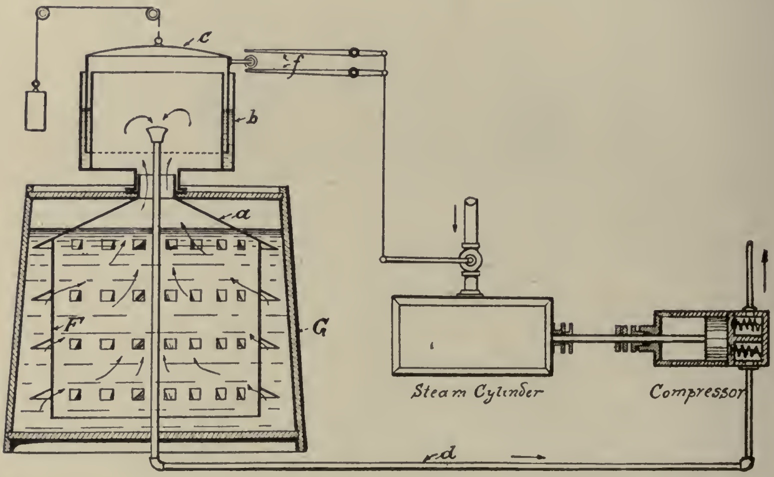


FIG. 156.—FERMENTER WITH GASOMETER AND SPEED REGULATOR.

Alois Grauaug suggested the use of a small gasometer mounted on top of a closed fermenter, to control the speed of a compressor used in connection with the fermenter in such manner that a rapid development of fermentation gas increased the speed of the compressor, which in turn removed the gas rapidly. Also during the latter stages of fermentation, when the gas production becomes slower, the speed of the compressor is made to decrease in a manner as shown in Fig 156. Cylinder *F* having a number of awning-shaped openings grouped around its circumference, is submerged in the wort contained in vat *G*. These openings act as a collector of the gas, the latter enters the inner part of said cylinder *F* and rises through the hood *a,* into the gasometer *b.* An active gas development lifts the gasometer dome, *C,* which on its part operates levers, *f.* The latter are connected to the steam admission valve of the engine operating the gas compresosr so that a rise and fall of the gasometer dome directly increases or decreases the speed of the engine and indirectly that of the compressor. The gas is conducted to the compressor through pipe connection *d.*

The device has many disadvantages; it is complicated, difficult to clean, and as it connects only one fermenter to the compressor, while it would furnish a rich gas during the first stage it would furnish a poor gas during the subsequent periods of fermentation. One of the principal requirements of the gas collected is a uniform character, and for that reason it is necessary to connect a number of fermenters—the contents of which are at different stages of fermentation—to the compressor. This gas, varying in character according to the degree of fermentation in the individual fermenter, will be collected, purified and compressed, rich and poor properly admixed, and when stored will be a gas of uniform character.

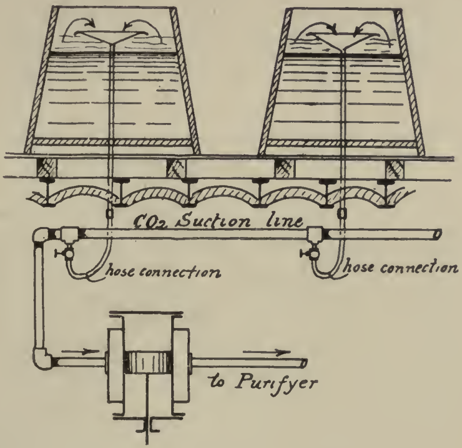


FIG. 157.—OPEN FERMENTERS.

Following is a description of a method for absorbing the fermentation gas from the open vats employed by an English firm and is worked on the theory of the high specific gravity of the gas. Fig. 157 shows several fermenters filled to about three-fourths of their height with the wort. The gas conducting pipes enter the vats through the bottom and are provided with a flat funnel-shaped disc just above the level of the wort. The gas compressor produces a slight suction; the fermentation gas falls into the funnel and is carried off into the compressor. This method requires the employment of mechanical as well as chemical purifying apparatus in order to expel the air which is bound to enter the pipes together with the gas, and as such purification deprives the gas of its aroma and should be used only in the manufacture of chemically pure CO_2, it does not enter into consideration in the case, where an aromatic fermentation gas for carbonating purposes is desired.

As has already been stated, the vessel generally employed for the collection of fermentation gas is a closed fermenter, the gas connection from which remains open during at least thirty-six hours after filling the vat with a wort fresh from the hop strainer and cooler. Every closed fermenter should be filled only to about three-fourths of its height to allow sufficient room for the collection of the gas, and as many fermenters may be connected to the same suction as may seem desirable according to circumstances. The time allowance of thirty-six hours is sufficient to expel the air from the vat, by this time high kraeusen has set in and the gas produced is of a rich, heavy and aromatic character. If there is any doubt as to the purity of the gas, a test to establish this fact can readily be made. As soon as the quality of the gas is found to be satisfactory the vat is connected to the suction line by means of a flexible connection, a number of additional vats are connected to the same line and it will be noticed by observing the gauge that the gas pressure in this line rises slowly. The compressor must then be started and the gas is taken away from the fermenters as fast as it is produced. Various devices are used to control the speed of the compressor, so that the gas may be taken away from the vats as fast as generated, which allows the fermentation to proceed in a normal manner. A slight increase of pressure will do no harm, as most of the fermenters used in a modern brewery easily withstand a pressure of 5 pounds or more, but any increase of pressure retards the process of fermentation, while a decrease below atmospheric pressure precipitates it and at the same time permits the possibility of air leakage into the fermenter, hence it is good practice to maintain a working pressure of about 1 pound gauge. The gas, on its way to the compressor, passes through a foam-trap where foam and small particles of the vegetable ingredients of the beer are deposited, and it then passes through a washer where a spray of water removes all foreign substances which may have been carried over. This water imparts an additional degree of humidity to the gas so that it enters the compressor in a thoroughly humid condition. A humid gas will heat up very little, provided the compressor has an effective water-jacket. If the gas enters the washer at a temperature of 50° F. it is likely to be cooled to nearly 45° F. before it enters the compressor. The moisture contained in same removes a part of the heat of compression, while the water-jacket does the rest. Upon leaving the compressor it should be a dry gas of a temperature not above blood heat, even if the compression at the last stages of filling the storage tanks reaches a gauge pressure of 250 pounds and above. Some manufacturers place the scrubber between the compressor and the storage tank, obviously for the purpose of cooling and re-incorporating some of the volatile ethers with the gas, which can be done very effectively by adding moisture. The objection to the scrubber in this place is the possibility of adding too much moisture to the gas, for the excess would be carried over to the storage tanks and be apt to become foul in an empty tank when no longer under the preserving influence of the gas. On the other hand, there is no chance of escape for the volatile products of the fermentation should they have separated from the gas, which at the above low temperatures is not likely, and as carbonic acid gas has a decided affinity for flavors, the same will be re-absorbed by the gas in the storage tank when the latter is at rest at a low temperature.

VARIOUS TYPES OF FERMENTATION GAS COMPRESSORS.

The compressor used for this work is usually of double-acting construction, actuated by steam. The cylinder should be made of bronze, with as light a wall as is permissible in order to insure efficient heat absorption by the water passing through the jacket. The valves should be made of Tobin bronze, as light as possible—which applies to the suction valves especially. In the case of a horizontal compressor the discharge valves may be placed in a vertical position, when they will hardly need the action of a spring. If a spring is used, however, it should be very light, a heavy spring increases the pressure required to open it against the pressure in the storage tanks, which would mean expenditure of more power than necessary, and the creation of an excess of heat.

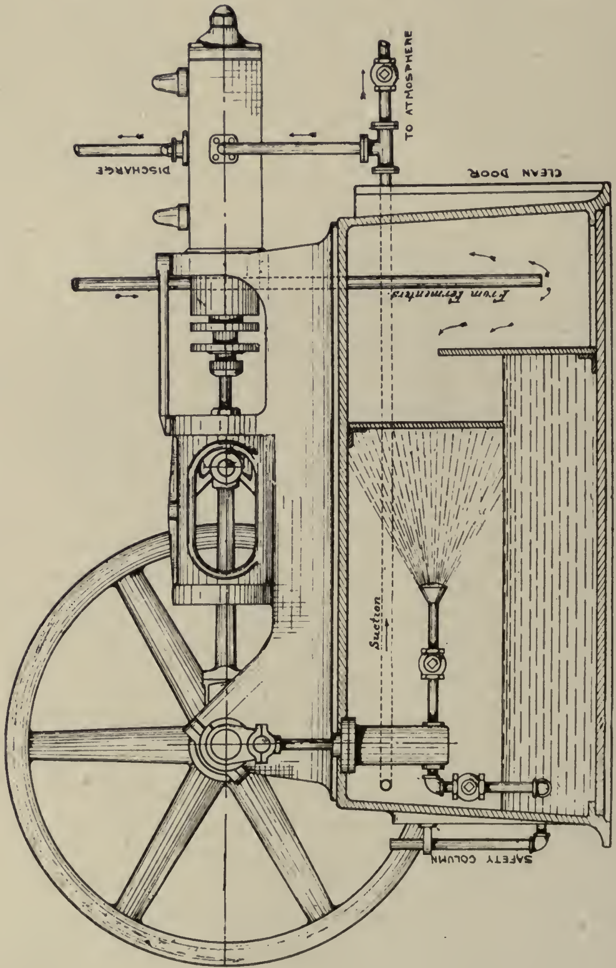


FIG. 158.—FERMENTATION GAS COMPRESSOR WITH SCRUBBER.

A very effective compressor for this work is shown in Fig. 158. It is of a horizontal, double-acting type, having a bronze cylinder, thoroughly water jacketed, with composition piston and rod, Tobin bronze valve and a stuffing box sealed and lubricated with glycerine. The piston as well as the stuffing box packing consists of cupped leathers made of the best center stock, oak tanned, hydraulic leather. Metallic piston packing, consisting of composition spring rings, is also used. The cups remain flexible owing to the action of the glycerine, which absorbs a part of the moisture from the gas without detrimental effect to the leather packing. The efficiency of this compressor is stated to be not less than 95 per cent; its frictional losses in the cylinder as well as in the stuffing box are very small owing to the flexibility of the packing, which produces only a suction fit without a hard friction. As will be seen from the illustration, the compressor is mounted on a sub-base, which latter is used as a foam trap and a scrubber of the gas. Foam and foreign substances carried along with the gas are deposited in the trap, the gas passing through a shower bath, which imparts a small percentage of moisture besides cleaning it. It is this humid condition which binds the fermentation flavors with CO_2 and protects same against overheating during compression.

The Wittemann Company's non-heating fermentation gas compressors are built in three sizes, Nos. 1, 2 and 4, and have a capacity sufficient to supply gas for carbonating thirty-five, seventy and one hundred and twenty barrels, respectively, per hour.

The amount of gas handled by each compressor per barrel of beer to be saturated is based on the theory that it takes about 1 cubic foot of fermentation gas weighing twelve one-hundredths of a pound to sufficiently impregnate one hundred pounds of beer at a temperature of 32° F. and a carbonating pressure of thirty pounds without danger of over-bunging.

Beer impregnated with fermentation gas in accordance with the above practice is by no means saturated and the danger of over-bunging does not enter into the account so long as the amount of gas imparted to the beer does not exceed 3 cubic feet, or one-third of a pound in weight per one hundred pounds, or twelve gallons of the beverage.

Basing the normal speed of these compressors on one hundred revolutions per minute, they would be capable of furnishing 1.5, 3 and 5 cubic feet of fermentation gas per minute. The weight of the gas depends upon the pressure in the closed fermenter, which pressure varies between one and two pounds. The upright compressor, **No. 1,** is connected to the shaft of a vertical engine, while No. 2 and No. 4 are upright machines direct-connected to the crank shaft of a horizontal engine, as illustrated in Fig. 159.

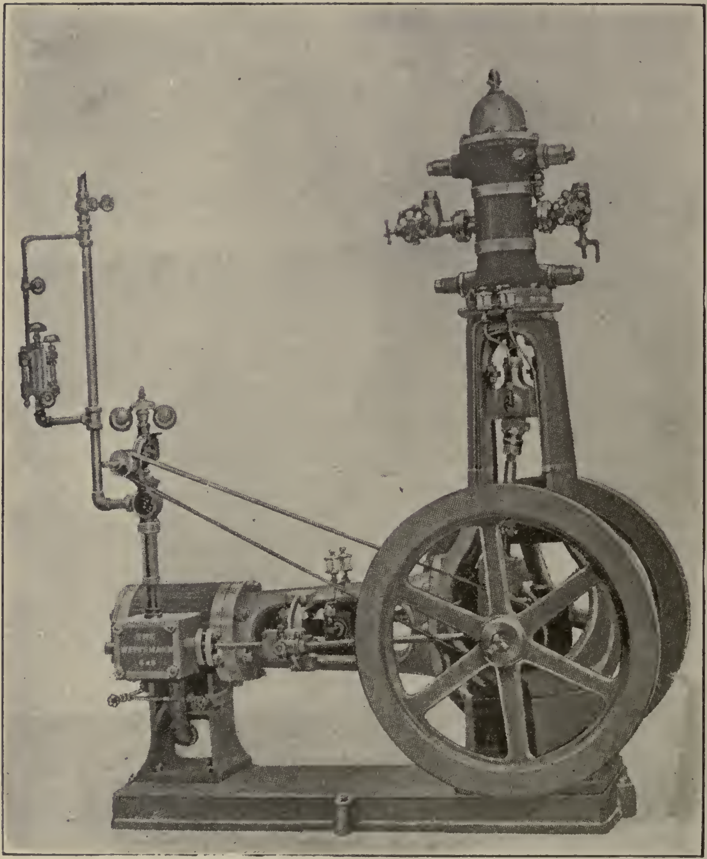


FIG. 159.—WITTEMANN'S FERMENTATION GAS COMPRESSOR.

The cylinder of these compressors is made of special composition, thoroughly water-jacketed and of a double-acting pattern. Valves and piston are of the same material and are so arranged as to be easily removable. The discharge stop valve is provided with a safety disc, which prevents any injury to the compressor in the case of careless handling. Hydraulic leather cups are used as the piston packing. These compressors are called non-heating because they handle a thoroughly moist gas. Special water connections are made to the suction valves and at each suction stroke a small stream of water is injected into the cylinder with the gas. The water so injected, as well as the action of the water flowing through the jacket, prevents any heating of the compressor, hence the volatile ethers contained in the gas remain with it and both are discharged through a cooler into the storage tanks.

The Joseph Schneible Company recommend the use of a two-stage compressor operated by cross-connected steam cylinders (see Fig. 160.) This construction was selected in order to avoid the dead center of the ordinary reciprocating engine, the cardinal feature of the apparatus being its ability to start automatically, no matter what the position of the fly-wheel. This enables the compressor to run as slow as five or six revolutions per minute.

The gas enters the low pressure gas cylinder at the normal fermenting tub pressure. Under a partial pressure it enters the high pressure cylinder and is compressed to the working pressure required in the storage tanks. Both high and low pressure cylinders are water-jacketed. Besides this there is an efficient intercooler between the cylinders.

An automatic regulator on top of the compressor, which acts upon the steam admission valve, is actuated by the gas from the fermenting tubs in such a way that its gas dome rises and falls in direct proportion to the speed of gas generation in the fermenters. As the area of the gasometer dome is large a slight increase or decrease of the gas pressure in the fermenters influences its up-and-down movement, thereby regulating the speed of the compressor so as to correspond exactly with the generation of gas in the fermenting tubs. This allows the fermentation to proceed in the same manner as in an open fermenter. In this way neither pressure nor vacuum can exist on the fermenting beer other than the pressure existing on the beer when in an open fermenting tub; that is, between one twenty-fourth and one twenty-eighth of a pound.

When not compressing gas the compressor is shut down, and the gas from the fermenting tubs is then expelled through a by-pass into the outside atmosphere, thereby removing it from the fermenting cellars.

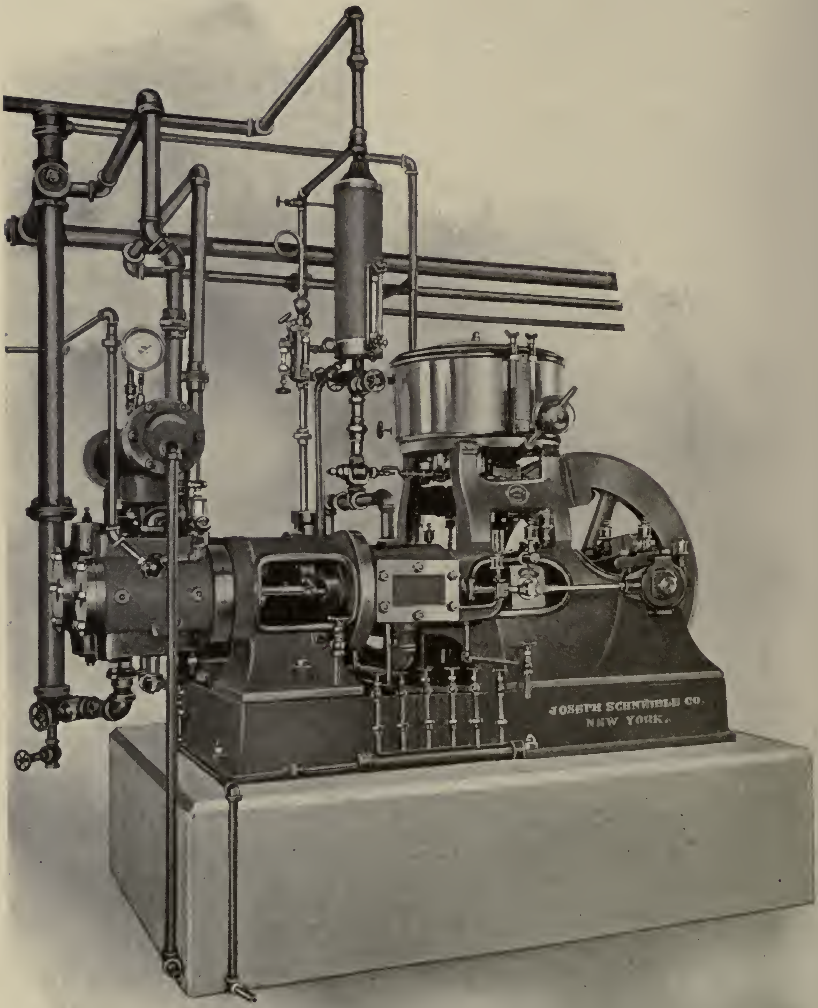


FIG. 160.—SCHNEIBLE'S FERMENTATION GAS COMPRESSOR.

The size of the gas suction pipe to the compressor depends upon the gas generating pressure. A system that operates with a pressure of one or two pounds in the fermenters requires a suction pipe of considerably less area than that drawing the gas at almost no pressure.

Sometimes a small steam pipe is connected to the gas suction line for the purpose of blowing out and sterilizing it from time to time.

MINOR DETAILS OF GAS COLLECTING EQUIPMENT.

The Wittemann Co.'s system has a gas washer and cooler interposed in the connection between the compressor and storage tanks, the gas passing through same being cooled by a spray of water carried over from the compressor. In some of the older Schneible Co.'s equipments water is circulated through the cooler continuously by means of a pump. This arrangement has been discarded, because the water so used becomes impure and consequently does not act as a purifying, as well as a cooling agent. On the other hand, if fresh water is used, difficulties will be met with owing to the usually low temperature of the water which enables it to absorb a considerable volume of the gas during its passage through the washer at the existing pressure, thereby destroying the efficiency of the gas collecting system; hence the value of this kind of a washer is of a more or less problematical nature, whether used as a bath or a spraying device.

Since there can be no doubt as to the disadvantage of a washer in which water and gas are brought into intimate contact, the one using the same water continually lacking cleanliness, and the other employing fresh water resulting in losses of gas, it appears to be logical that the only cooler which should be used on the pressure side ought to be of the surface condenser type, provided it is at all necessary to use a cooler. The proper location of the washer is on the suction side of the compressor. It removes the impurities from the gas before the latter enters the compressor, and as there is very little pressure on this side of the system the gas that can possibly be absorbed when renewing the water frequently will necessarily be an insignificant quantity.

During compression the gas must be so handled that its temperature does not increase materially for the reasons which have already been given, and if heating during compression is avoided as it should be, a cooler between compressor and storage tanks is not needed.

The Schneible Co. avoids heating by using water-jacketed low and high pressure cylinders with intercooler, Wittemann Co.'s compressor is provided with a water injection, while a third construction designed by the author and used by Kroeschell Bros. Co., Chicago, attains the same end by using a cylinder of a small bore and a long stroke, thereby increasing the surface of the cylinder walls and consequently the efficiency of the water-jacket.

In the case that a washer is used on the pressure side of the compressor a small quantity of water will be carried over into the gas storage tanks where it should be drawn off from time to time to prevent its becoming stagnant.

When no washer is interposed, the gas is discharged directly into the storage tanks and remains there until used.

Steel tanks which are so constructed as to withstand a working pressure of not less than 300 pounds are used for the storage of the gas. The standard dimensions are 30 inches in diameter by from 8 to 10 feet in height. Some of these tanks have the heads brazed in instead of being riveted to the shell. This process is more expensive, however, and as riveted tanks of this diameter can be made absolutely gas-tight at pressures of 500 pounds and more, they are perfectly satisfactory and can be used with safety for the purpose. The shell consists of ⅜-inch steel plate, while the heads are made of ½-inch material. Each tank is provided with a hand-hole, usually 9 by 11 inches, a purge valve at the bottom, a "blow off" valve at the top, and a suitable gas connection with valve and gauge. The tanks should be provided with adjustable legs so that they may be set plumb on any floor. (See Fig. 161.)

Three or four tanks are necessary to store the combined fermentation gas from a number of tubs, the latter being at different stages of fermentation; this is done so as to obtain a gas that is at all times as nearly uniform as possible.

Every brewer knows that on the first day of high kraeusen the gases are decidedly richer, more aromatic, heavier and purer than on the second or third day when the kraeusen are collapsing. If the fermentation gas is used at once after collecting, on the first day of high kraeusen fine aromatic beers will result, but on the second and, still more, on the third day, they will be inferior in taste and foam stability. The beer, therefore, will be very uneven in quality, hence in order to avoid this fluctuation, it is advisable to draw the gas from a number of fermenting tubs at the same time, allowing old and young gas to mix and giving it a chance for equalization in the tanks during a short period of rest. In that way the beer, being treated under equal conditions, will always be uniform in taste and foam stability.

FIG. 161.—FERMENTATION GAS STORAGE TANK.

The logical location of the storage tanks is the lager cellar. Fresh from the fermentation the gas has the temperature of the fermenting beer, about 50 to 53° F. or 8 to 9° R. On the way through the collecting pipes and the compressor more heat is added, and in that condition it is unfit for carbonating purposes, as it would effect a rise in the temperature of the beer to be impregnated, which in turn would cause foaming, wildness and unsatisfactory racking.

A period of twelve to twenty-four hours under a pressure of 200 to 250 pounds at the temperature of the lager cellar cools it down to that temperature; it becomes more concentrated, dense and heavy, combines with the volatile ethers from the hop much more satisfactorily, and when used to impregnate cold beer it is absorbed readily without foaming or other disturbance.

A cold, compressed, dense gas is in the most favorable condition for absorption by the beer, and combining with it, causes a much greater foam stability than can be produced by kraeusen, whereas, a warm and volatile gas has a great tendency to escape; a rule which applies to the impregnation of water and other liquids with carbonic acid gas as well.

Stock beer, when sufficiently attenuated, has a decided tendency to absorb air during the lager period in the cellar, which, if permitted, decreases its capacity for absorbing fermentation gas during carbonating. Absorption of air after fermentation is detrimental to its foam stability as well as keeping quality. The best preventive measure against such occurrence consists in a simple method by which the air in the upper part of the cask is replaced by means of cooled fermentation gas from the storage tank. A small pipe line connects the storage tanks with the chip casks and a pressure regulator is so adjusted that the gas pressure in the casks does not exceed 1 pound gauge pressure. This will keep out the air, a small part of the gas will be absorbed during this period and the keeping quality of the beer will be benefited.

The Schneible Co. obtains the same result by adding a small quantity of fermentation gas as soon as the beer leaves the fermenting tubs. Beer and gas are cooled together on their way to the finishing tank by means of a double-pipe beer cooler right after fermentation. A partial saturation takes place and the action of the gas causes the beer to clarify rapidly in the finishing tanks. This period of rest at a low temperature gives the beer a chance to bind the fermentation gas previously charged into it most thoroughly, the albuminous matter precipitates, the atmospheric air is kept out entirely and it requires very little additional gas to saturate the beer sufficiently before filtering and racking. Fig. 162 illustrates the process fully. A carbonating pump forces the liquid, together with a small volume of fermentation gas, through the cooler into the finishing tanks, where it remains until it is ready for filtering and racking.

CARBONATING AND RACKING-OFF PUMPS.

The carbonating pump has its suction connected to the chip casks or finishing tanks; it forces the beer under a steady pressure through a cooler, then through a carbonator, next through the filter and finally supplies the racking apparatus with the cooled, re-saturated, filtered and finished product.

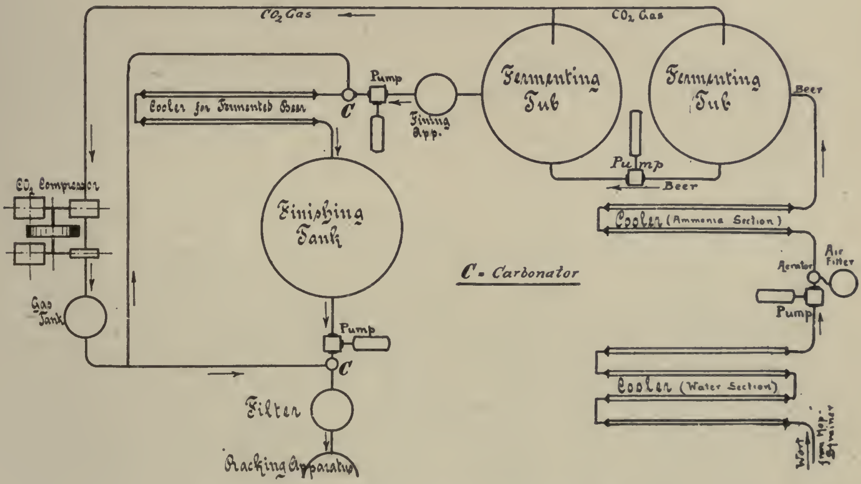


FIG. 162.—SCHNEIBLE'S CARBONATING SYSTEM.

The cardinal point in the work of the pump is the maintenance of a steady pressure regardless of whatever happens at the racking apparatus. The operator of the racker may not work fast enough in drawing off all the beer that the pump is capable of supplying, or the racker may be out of commission periodically. Such irregularities are productive of considerable fluctuation in the beer pressure, hammering in the line and disturbances in the filter in the case of any ordinary pump.

As in all other cases of special conditions under which a certain work is to be performed, a special contrivance for the steam pump and a peculiarly suitable power pump had to be designed to remove the difficulty in this particular case.

The contrivance for the steam pump consists of a steam pressure regulator, the operating part being a movable piston in a bronze cylinder; communication between the latter and the beer or air chamber of the pump is established by means of a suitable pipe connection as shown in Fig 163. The spring of the regulating valve is so adjusted that the slightest pressure above that registered in the carbonator acts upon the piston, which latter shuts off the steam and stops the pump. A reduction of pressure in the air chamber of the pump releases the piston, re-admits steam into the steam cylinder and again starts the pump. The latter is of the duplex type. This construction together with a large air chamber minimizes the fluctuation due to the reciprocating action of the pistons. Instead of steam, air may be used as the motive power, which removes the objection to steam being used in a refrigerated cellar. The use of steam, however, is not the principal objection against the employment of this type of pumps. Their unpopularity is caused rather by the excessive waste of steam with which these pumps are credited, upward of 100 pounds of steam being required per every horse-power per hour.

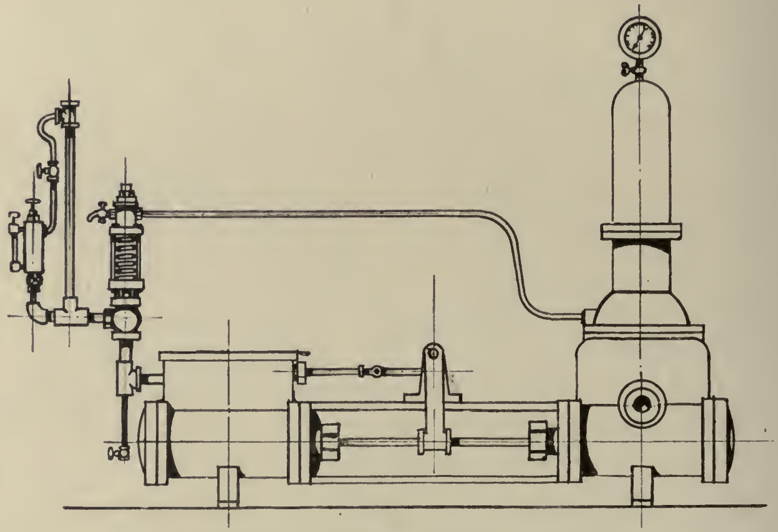


FIG. 163.—AUTOMATIC BEER PRESSURE REGULATING PUMP.

Such extravagance is a serious item in an establishment that requires a large number of pumps for various purposes, and those actuated by steam should therefore not be tolerated in a modern brewery.

The power pump, on the other hand, dismisses the charge of extravagance entirely. It performs the work of a horse-power at whatever rate the power generating unit of the brewery furnishes it, which may be as low as 18 pounds of steam per horse-power per hour plus a slight addition for transmission and frictional losses; it creates no heat in the cellar, for it requires no heat-radiating steam connections.

Considering further that the special work to be performed with a carbonating and racking equipment should be done without pressure fluctuation, if possible, as well as with a positive release at any increase in the pressure, caused through irregularities at the racking apparatus or otherwise, it is reasonable that a pump which embodies these peculiar features in a manner superior to that obtainable by means of the reciprocating steam pump should be preferred.

That a centrifugal or rotary pump maintains a steady head pressure has long been known, and since this pump has been equipped with a release valve which positively prevents any over-pressure, it can safely be said that this pump approaches the ideal apparatus, as set forth, nearer than any other used for the purpose.

Fig. 164 illustrates a rotary power pump of the above design. It is especially constructed for carbonating and racking beer and can be operated by means of any motive power.

In breweries where electric power is available, the pump and a motor are mounted on a suitable bed-plate, the electrical power being transmitted by a speed reducing gear, or, if preferred, by a silent chain.

A by-pass establishes communication between the discharge and suction pipes, controlling it by means of an adjustable release valve, which may be set at any desired pressure. As soon as this pressure is exceeded, the release valve opens and allows the full amount of beer, taken in at the suction, to return to the latter without disturbance. While it is true that the by-passage of the beer does not dispense with the work necessary to operate the pump, and that the beer passes continually through it, returning to the suction until the obstruction in the pipe line is removed, it must be remembered that the power is furnished at the low rate of 20 pounds of steam per horse-power per hour and that said obstruction normally is of a very short duration, hence the waste of power on account of this discrepancy is of little moment.

The pump in itself is very simple; practically but three parts compose it, namely, the shell, the piston and the valves.

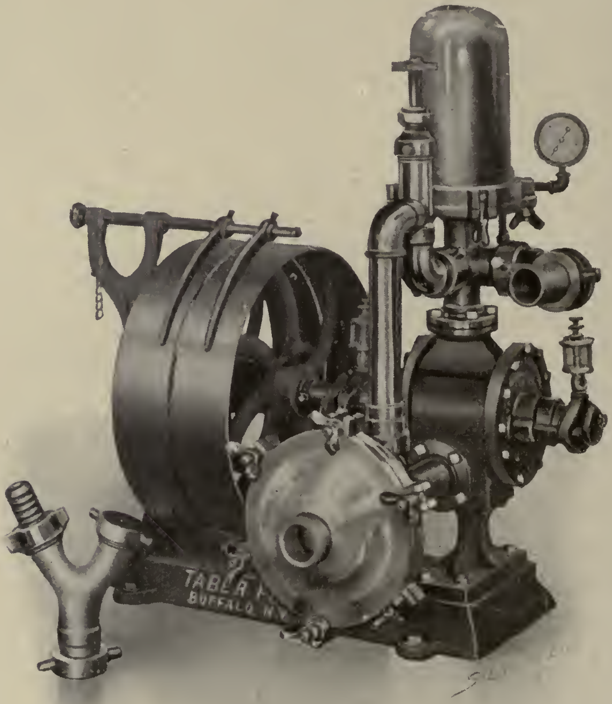


FIG. 164.—TABER ROTARY PUMP.

The shell consists of the casing with its two heads; the piston carries the valves and forms the shaft to which the power is applied; the valves are fitted so as to slide through the ways in the piston, adjusting themselves during a revolution in such a way as to be set tight against the shell, thus creating a vacuum.

When the power is applied the valves make a close contact with the inside surface of the shell without the use of springs and create a vacuum which starts the flow of liquid. As these valves always follow the inner lines of the shell, they are the only parts of the pump subjected to wear and they can be easily replaced at slight cost.

The piston is made of forged steel and is capable of withstanding the heaviest strain that can be placed upon it.

The shell as well as the valves and valve casing of the piston are made of phosphor bronze such as is required for brewery work.

The speed varies between 100 and 150 revolutions per minute, according to size. They require little care in their operation and are inexpensive as to their maintenance.

DOUBLE-PIPE BEER COOLERS.

When the beer is drawn from the chip casks it has the temperature of the cellar, which is 36° to 37° F. In order to prepare it thoroughly for an effective process of carbonating and filtration, it has to be chilled. Beer at a temperature of 32° or 33° F. absorbs the required volume of carbonic acid readily at a pressure of 30 pounds, which is at the same time sufficient to force it through the filter and racking apparatus into the shipping packages.

During the filtration much of the albuminous matter which is still contained in the ready beer is to be separated from it. But the albuminous matter precipitates only at temperatures very near the freezing point, hence the beer must be chilled from 37° to 32° F. by means of an enclosed type cooler.

A number of enclosed coolers have been applied successfully, each of which is distinguished by special features.

Practical considerations require that these coolers are easily taken apart for the purpose of a thorough cleaning after each application and the latest designs have been so arranged that this work can be done readily in a short time.

One of the first in the field was the Deckebach cooler, Fig. 165 *a* and *b*, named after its designer. It consits of a copper shell which forms the housing for spiral cooling coils. The cooling medium, brine or ammonia, passes through the spiral coils, while the beer is forced through the housing. The intimate contact between the beer to be cooled and the cooling medium reduces the temperature of the former and it passes out of the cooler at the required low temperature.

Double-pipe coolers have of late met with considerable favor on the part of the practical brewer because of their efficiency, and simplicity of operation.

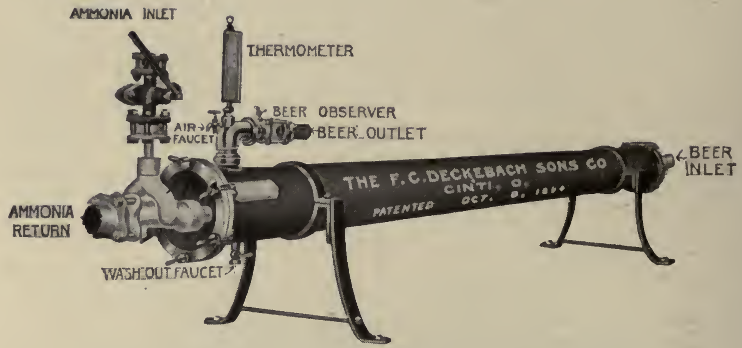


FIG. 165*a*.—DECKEBACH'S DOUBLE-PIPE BEER COOLER, SINGLE TUBE.

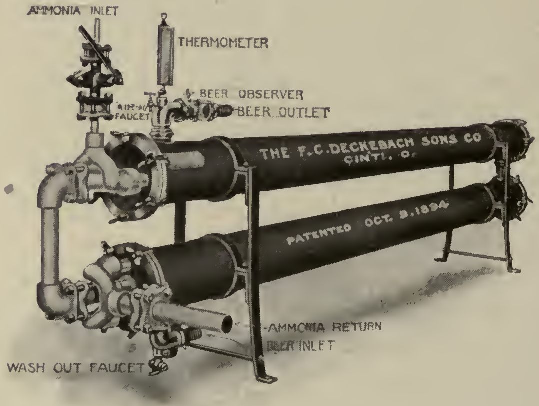


FIG 165*b*.—DECKEBACH'S DOUBLE-PIPE BEER COOLER, DOUBLE TUBE.

These coolers are constructed on the counter-current principle, and can be used either for brine or direct expansion. They consist of one pipe within another, the beer passing through the inner pipe, while the refrigerating medium travels through the annular space between the outside and inner pipe in counter-current fashion. The inner tubes extend through suitable stuffing boxes on both ends and are connected by means of fire-tinned, bronze return bends. These bends are so fastened as to be easily removable so that the beer passage may be washed and brushed out without difficulty.

When these coolers were first placed upon the market the constructors seemed to be more or less at sea concerning the required cooling surface for a given quantity of beer to be cooled, although the conditions of temperature, radiation and quantity are fixed in every case.

The generally accepted dimensions now are a 1¼-inch inner tube and a 2½-inch outside pipe. The lengths over all vary between 11 and 16 feet, according to space obtainable and other surrounding conditions.

To determine the size of the cooler the quantity of beer to be cooled per hour from a temperature of 37° to that of 32° F. must be given.

Presuming that fifty barrels of beer are to be cooled from 37° to 32° F. in one hour by means of the direct expansion ammonia system, it is only necessary to calculate the heat transmission by the number of B. T. U. which pass through a square foot of tubular surface in one hour for each degree of difference in temperature between the beer and the ammonia gas. Assuming that the final difference in the temperature between the beer and the ammonia does not exceed 15° F., the heat transmission in one hour by each square foot of cooler surface for each degree of average difference in temperature will be approximately 125 B. T. U.

The beer enters at......................................37° F.
and leaves the cooler at..............................32°

Difference = 5° F.

The ammonia enters at.................................0° F.
and leaves the cooler at..............................18°

Difference = 18° F.

Average difference = 23 ÷ 2 = 11.5° F.

Hence one square foot of surface transmits 11.5×125 B. T. U. =1,438 B. T. U.

Fifty barrels of beer are to be chilled five degrees per hour, which equals 58,500 B. T. U. in round figures; 58,500÷1,438=40 square feet.

Converted into cooling effect per ton ice machine capacity, we require 8 square feet of cooling surface per ton of refrigeration.

The Witteman Co.'s coolers (Fig. 166) are made in lengths of 11 feet over all by four, six, eight and ten pipes high respectively. The inner channel consists of light-weight, fire-tinned, steel tubing, which is fluted into the shape of a rounded cross for the purpose of slightly increasing the surface. While this object is obtained to a very small degree, the peculiar shape of the tube reduces the area of the beer passage.

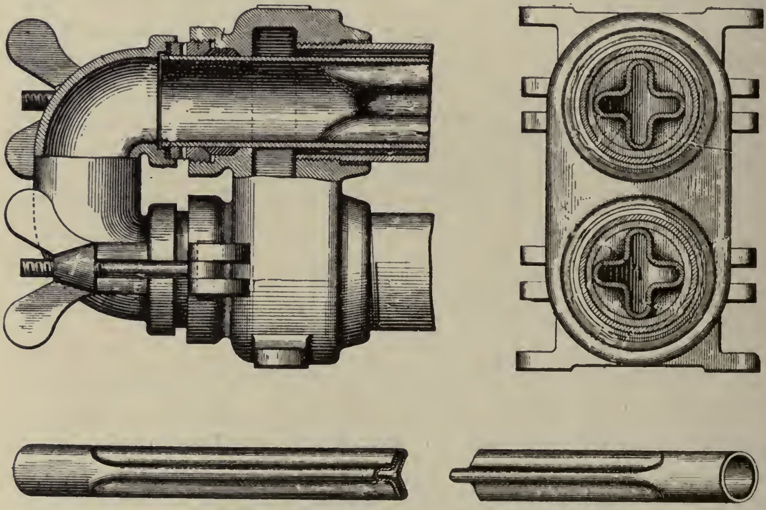


FIG. 166.—SECTIONAL VIEW WITTEMANN'S BEER COOLER.

Coolers that have a sufficient area for the passage of not less than 100 barrels of beer per hour at a pump pressure of 30 pounds, and with a cooling surface of about 75 square feet, are considered the most practical for brewery purposes.

Bronze return bends connect the inner tubes so as to form a continuous beer passage; they are held in position by thumb nuts and are easily detached.

The outer tubes are of extra heavy pipe, secured to the semi-steel ammonia or brine return heads by means of a right- and left-handed thread.

Inlets and outlets are provided by means of bronze T's with an interchangeable round-way cock on one outlet and a capped hose bung, also interchangeable, on the other.

A thermometer with Reaumur and Fahrenheit scale is set into the outlet fitting.

The Joseph Schneible Co.'s cooler (Fig. 167) shows the excellence of construction that is characteristic of all the Schneible apparatus.

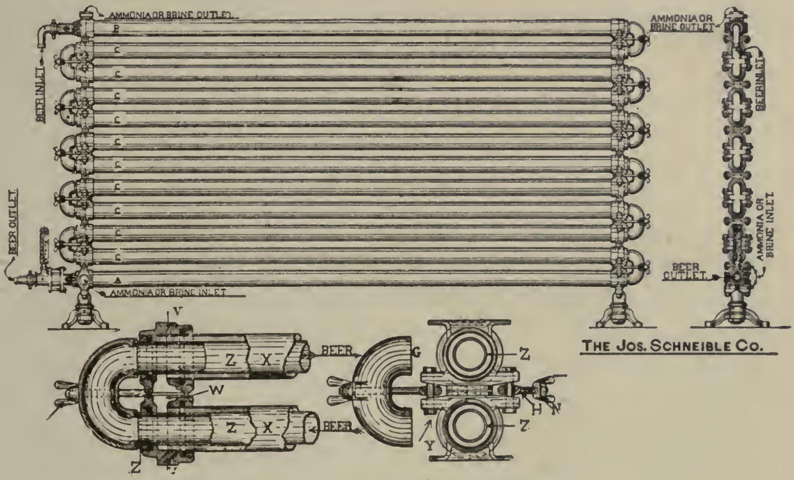


FIG. 167.—SCHNEIBLE'S BEER COOLER.

The principle of cooling is the same as that employed in the Wittemann cooler, and only the details of design, especially the construction of the return heads with their stuffing boxes for the inner tube are different.

The outlet of the cooled beer in this cooler is at the bottom, while the liquid ammonia enters at the bottom and returns through the top pipe header, which is an advantage, inasmuch as it prevents the carrying over to the compressor of unevaporated liquid ammonia.

The Kroeschell Bros. Ice Machine Co., Chicago, has recently constructed a double-pipe cooler which is used in connection with their CO_2 refrigerating system. This cooler consists of 1¼-inch copper tubes and 2½-inch extra heavy iron pipes. The beer passes through the tinned copper tubes, while the CO_2 evaporates in the annular space between the two pipes. The outer pipe is flanged to semi-steel return heads, establishing gas communication, while fire-tinned, bronze return bends form the passage between the copper tubes. These return bends are held in place by means of a simple swinging bracket, which latter carries a bolt with hand-wheel that is used to hold the return bends firmly in place.

The CO_2 cooler is by far the simplest apparatus used for the purpose. Its efficiency is superior to that of any other on account of the greater conductivity of the copper tubes. In connection with the clean, safe and rapid CO_2 refrigeration, it is doubtless the ideal apparatus for breweries.

BEER CARBONATORS.

The last apparatus in the series employed for the re-saturation of the beer with carbonic acid is the carbonator. One of the requirements of its construction is simplicity. It must be so designed that it can be taken apart readily; the parts should be so connected that they can not be entirely detached from the main body, so as to prevent the very annoying loss of plates, bolts, nuts, etc.; the work of opening the carbonator for cleaning must be accomplished in a short time, and when open it must allow of a thorough cleansing.

As has been stated in a former paragraph, it is not intended to saturate the beer fully with carbonic acid, as that would impart to the beer an acidulous character which would be considered as decidedly detrimental by every brewer, inasmuch as the sharp acidulus taste would destroy the flavor as well as the other well-known characteristics of the beverage.

The volume of gas required by the beer is easily absorbed, so that a complicated carbonator, such as is used for carbonating waters, is not required, and it is therefore a comparatively easy task to design a carbonator which will meet the requirements of this beverage.

Before going into the construction of beer carbonators more fully let us recapitulate the advantages of the mechanical process of carbonating over the kraeusen method.

Every brewer agrees that the ordinary process of mixing the beer with new ferments at the end of the first stage of fermentation very often does not provide the beer with the necessary quantity of carbonic acid. Another important defect in this process is the fact that the added ferments frequently do not subside at the desired time, but continue to act after the goods are sent out in barrels or bottles for consumption, which causes the beer to spoil.

The time required for the second fermentation is a very important factor in every modern brewery, and if it should be found that all this time was sacrificed to obtain an inferior product, it is reasonable to suppose that every brewer, as a good business proposition, will look into a method which not only will save that time, but will enable him to finish his product with a full amount of carbonic

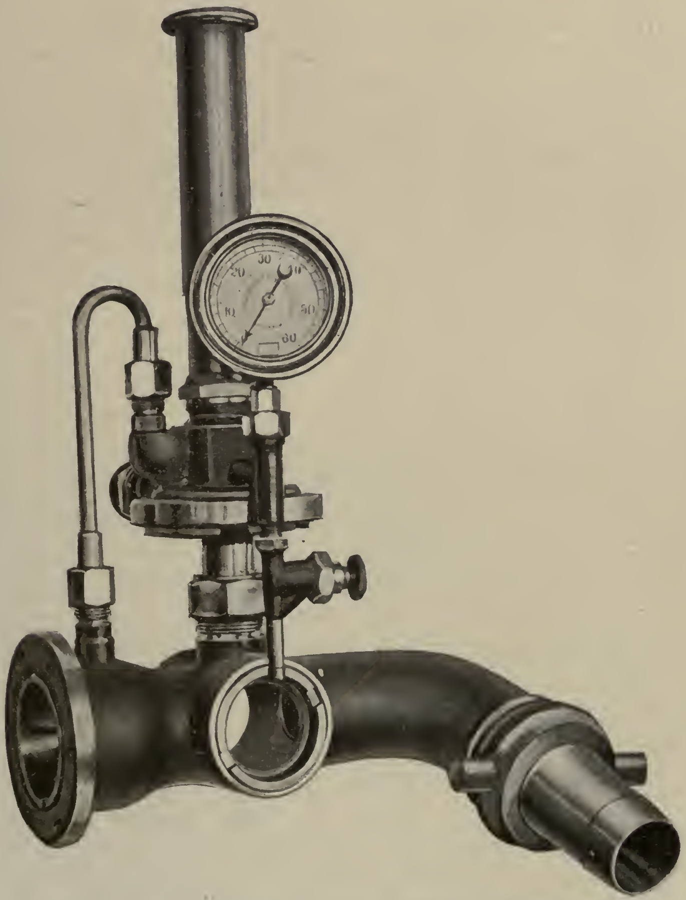


FIG. 168.—SCHNEIBLE'S CARBONATOR AND MOTOR-DRIVEN PUMP.

acid; that will make it superior in foam stability and flavor and which will improve its chances for long preservation.

It is comparatively easy to obtain uniformly good results if the requisite care is taken in the collection of the fermentation gas. If the gas collected today is rich in flavors and sweet in taste, while tomorrow it is comparatively poor in flavors and sharp in taste, it should not be stored separately or used separately; on the contrary, it should be allowed to mix well in the various storage tanks before using for carbonating.

Many brewers have made the mistake of collecting a rich gas from the first stage of fermentation and storing it away in tank No. 1 today; tomorrow a gas is collected which has all the characteristics of emanating from a beer in a more developed stage of fermentation. Let us assume for the sake of argument that this gas is stored in tank No. 2. If gas from tank No. 1 is used for carbonating purposes today, while the contents of tank No. 2 are emptied on the day following, it is clear that the result of the two days' work is a beer sweet and rich in flavor on the first day and decidedly sharp and acidulous in taste on the next.

The collection of the gas simultaneously from a number of fermenters, each containing a beer the fermentation of which is in a state of different advancement is preferable. This gas should be discharged into a battery of storage tanks with all the valves open, the result will be that each tank is filled with a gas uniform throughout in character.

As a direct result of experience with beer carbonators the Joseph Schneible Co. has abandoned its former imposing looking carbonator and has substituted in its place an insignificant appearing one, which is nothing more nor less than a simple inspirator, shown in Fig. 168. But this simple apparatus is perfectly capable of performing its work satisfactorily; at the same time it is sufficiently simple to avoid trouble when taken apart for cleaning.

The Wittemann Co. adheres to its original saturator, a diagram of which is shown in Fig. 169. The beer enters through a regulating valve flanged to the foot of the cylindrical carbonator and is conducted through a hose to the inlet flange, *f*, located on the top cover. A sieve of very fine mesh distributes the beer over the area of the cylinder and collects any solid impurities that may have been carried over, and the spray of beer drops through gas space, *S*, into the lower part of the cylinder. As soon as the beer inside of the cylinder has reached the height of the balancing tank, *B*, it enters the latter through hose connection, *h*, increases the weight of *B*, and the latter descends and closes the valve by means of valve rod *r*. The beer outlet is at *O*, and as soon as sufficient beer is drawn off on the racker, the beer level descends, and the counter-balance weight *w* raises *B* and again opens the valve. The carbonating pump supplies the beer from the vats at a pressure of from 25 to 30 pounds, fermentation gas enters the carbonator under the same pressure at *g* and

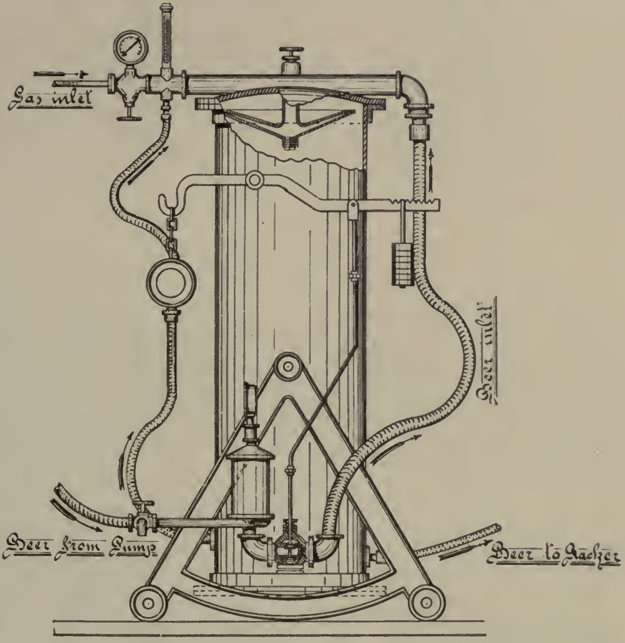


FIG. 169.—WITTEMANN'S BEER SATURATOR.

maintains the amount of gas in space *S*, in the upper part of the cylinder. This carbonator can be used with liquid carbonic acid as well as with fermentation gas.

After using, the cylinder is swung from the vertical into the horizontal position, the heads are removed and it can then be washed and rinsed.

A simple double-pipe carbonator has been used by the author with good results; other simple apparatuses constructed in accordance with the ideas of brewmasters have also given uniform satisfaction.

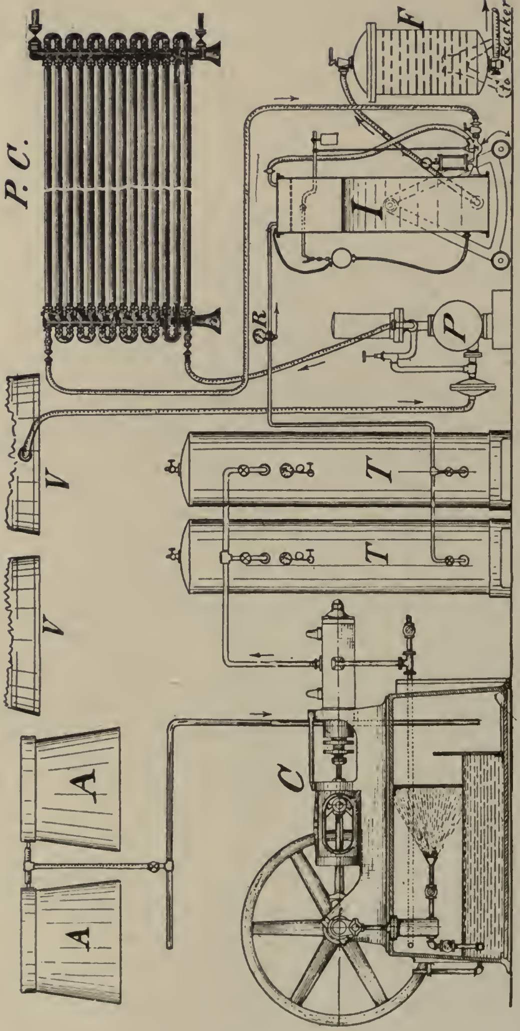


FIG. 170.—DIAGRAM FERMENTATION GAS EQUIPMENT.

The process of carbonating is as follows: The beer is taken from the storage vats by the carbonating pump. As the empty space in the vats increases, it should be refilled, preferably with fermentation gas, under a slight pressure. The pump forces the beer through a double-pipe cooler, reduces its temperature and prepares it for the reception of the gas.

Regulation of the pump pressure is obtained by means of the by-pass valve attached to it; the latter should open at a pressure of 30 pounds.

Before the beer enters the carbonator all atmospheric air should be expelled through the purge valve by allowing fermentation gas to enter under pressure. A pressure of 30 pounds of the gas should be established by manipulating the reducing valves; when once set this valve will replenish the absorbed fermentation gas and maintain a steady pressure automatically. At a temperature of about 34° F. with a beer and gas pressure of 30 pounds a sufficient quantity of gas will be absorbed. Upon leaving the carbonator the beer enters the filter under the same pressure; here the albuminoid matter will be eliminated and the beer passes to the racking apparatus to be filled into the packages.

As in the case of all carbonated beverages it is well to keep the newly filled packages in a state of rest in a cool brewery cellar instead of immediately putting them on to the wagon for distribution among the trade. This period of rest allows the beer time to bind the CO_2 and increases the foam stability. Beer that has not been allowed to rest after carbonating and before dispensing is likely to lose its CO_2 very rapidly when drawn into the glass.

THE FERMENTATION GAS SYSTEM SUMMARIZED.

Having reviewed the complete cycle of fermentation gas production and its uses for carbonating and dispensing purposes, the following diagram of the process, illustrating the various parts and their connections is appended:

Fig. 170 shows the system in diagrammatic form. The gas is drawn from the fermenters *A*, through a 2-inch suction pipe, each fermenter being connected to the suction line by means of a valve and flexible connection, having a proper safety valve to prevent bursting through an excess of pressure. The flexible connection between the fermenter and the suction line is not established until the atmospheric air has been expelled and the gas has attained those characteristics which make it desirable for carbonating. By means of an easy practical test the absence of air is determined, while the other characteristics, *i. e.*, flavor and strength, are easily apparent.

The test of air is made with a small piece of caustic soda or potash and a bottle containing, when filled, about half a tumbler full of water. Before admitting fermentation gas into the bottle it must be filled with a liquid, water or beer, to expel all atmospheric air. Then empty the bottle directly over the surface of the beer into the fermenter. Fermentation gas will then take the space previously occupied by the water and the caustic soda must be manipulated into the bottle. The soda will immediately dissolve in the liquid left in the bottle, forming a lye, and the CO_2 contained in the fermentation gas will be absorbed by the lye. This will necessarily create a vacuum in the bottle, which vacuum can readily be filled under water. The contents of the bottle must then be shaken thoroughly; in so doing more soda dissolves, forming additional lye, which in turn absorbs more carbonic acid. By carefully manipulating the bottle, and after a little practice, this test can be made by anyone. The action of dissolving soda and admitting water to fill up the space previously occupied by the absorbed CO_2, demonstrates within a few minutes, how much air, if any, is contained in the fermentation gas. If the test shows that the gas is entirely free of air, the fermenter must be attached to the suction line and the gas is ready to be drawn off by the compressor. If, however, the test establishes the presence of an appreciable volume of air, then the fermentation stage of the beer is not sufficiently advanced and a corresponding time allowance must be made before the gas can be drawn.

In drawing the gas it is of importance that the natural state of the fermentation should be maintained as near as possible, that is, the fermentation should not take place under a pressure exceeding 1 or 1½ pounds, gauge pressure, nor should the suction of the compressor be allowed to reduce the pressure below that of the atmosphere.

Pressure regulating devices which act upon the difference between the steam pressure on one side and the pressure in the fermenter on the other are attached to the steam inlet of the engine operating the compressor. The regulation of the steam admission obtained by means of that equipment controls the speed of the compressor.

In the case of an electric equipment a simple electro-mechanical speed-controlling device can be used satisfactorily.

It is, however, possible that such controlling apparatus, which is of a more or less sensitive character, will fail to do its work reliably, and it is well for the operating engineer to look at the suction pressure gauge repeatedly so as to be sure that every part of the system is doing its work properly.

The gas compressor *C,* shown in the diagram, is provided with a scrubber for the purpose of washing the gas, depositing impurities that may be carried over, and imparting to the gas sufficient moisture to prevent its heating during compression.

The gas is then pumped into the storage tanks *T* until a pressure of 200 to 250 pounds is reached. It will then be necessary to detach the fermenters from the gas suction line, or better still, to open the gas blow-off valve located near the compressor, so as to allow the balance of the gas, which is still being generated, to escape into the atmosphere.

Before carbonating, all atmospheric air should be expelled from the beer circulation system; beer is then drawn from the larger vats, *V,* by means of the carbonating pump, *P;* this pump forces the beer through a double-pipe cooler, *PC,* into the carbonator, *I.* Fermentation gas is admitted at a pressure of about 30 pounds, which pressure is adjusted and automatically maintained by regulator *R.* The carbonating pump maintains a certain beer level in the carbonator and opens a by-pass attached to it as soon as the carbonator closes its beer inlet valve.

Leaving the carbonator the beer passes through a filter, *F,* to be clarified, and enters the racker to be filled into the packages.

FERMENTATION GAS AS THE REFRIGERATING MEDIUM IN THE BREWERY.

In former years the carbonic acid developed during fermentation was a waste product and a total loss to the brewer. The introduction of the carbonating system, using fermentation gas as the best medium for that purpose, has applied a part of the former waste product to good use; however, this is only a small fraction of the whole quantity produced.

A great step forward in the direction of using more of the gas for the work in a brewery has been accomplished by the introduction of CO_2 refrigerating machinery, the natural CO_2 from the fermentation of beer being used as the refrigerating agent.

Fermentation carbonic acid being a product of the brewery, it is natural that brewers, other things being equal, should favor any machine using this gas as a refrigerating agent. A further advantage to the brewer lies in the fact that it is always on hand, and the only expense connected with its use is the small item for collecting it. In breweries where a fermentation gas-collecting equipment exists this expense is so slight that it can hardly be estimated.

When the first CO_2 refrigerating plant was installed in connection with a gas-collecting outfit, it was found that it was possible to use the same machinery in addition to carbonating and refrigerating for purposes of manufacturing liquid carbonic acid.

The liquid carbonic acid so obtained is not entirely odorless, as it possesses a slight fusel-oil odor; however, it is perfectly adapted for saloon and many other requirements.

If it is desired to use the brewery liquid carbonic acid for commercial purposes, it can be made chemically pure and odorless by an inexpensive method. In this way the whole output of fermentation gas can be used, and as the expense of producing it is almost entirely in the equipment, the gas being a by-product of fermentation, it can readily be seen that it places the artificially prepared CO_2 at a disadvantage.

In spite of these apparent advantages, brewers do not, as a general rule, consider it advisable to divert their attention to this side line; on the contrary, they find it much more profitable to devote their entire energy to the development of the main industry.

Carbonating, CO_2 refrigeration, and CO_2 liquefaction (for saloons controlled by the brewery) is directly in line with that development, however, and has recently been taken up vigorously in many instances.

The principal uses for refrigeration in a brewery are the cooling of the beer wort to the temperature of the fermenting vats, the withdrawal of heat developed by the fermentation, cooling brine or water to supply attemperators in fermenting tubs, and keeping storage rooms and cellars at the required uniform temperature.

For all these purposes CO_2 refrigeration is better adapted than any of the rival systems. It can be used with greater safety in any part of the brewery than either the ammonia or the sulphuric acid system. It is not surpassed by any other medium as regards efficiency, and it is of greater economy in its operation owing to the favorable conditions for its use in the brewery.

When fermentation gas is used as the refrigerating medium, it is only necessary to free it from the traces of moisture contained therein. This is accomplished by drawing the gas through a chloride of calcium dryer, as shown in Fig. 171. Dryer *D* is interposed between storage tanks, *T*, and the carbonating equipment, and when the charge in the refrigerating equipment needs replenishing it is only necessary to close the suction stop-valve on the refrigerating machine, open the charging valve placed in the suction canal of the compressor and draw the gas through the dryer into the system until the required condenser pressure is reached.

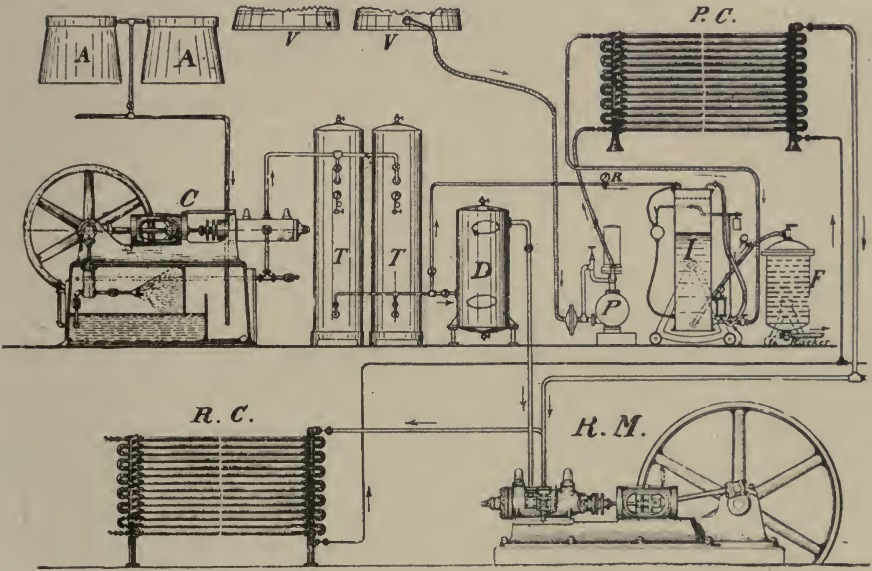


FIG. 171.—DIAGRAM SHOWING CONNECTIONS OF A COMPLETE CARBONATING AND REFRIGERATING EQUIPMENT.

The whole manipulation can be done in a few minutes and does not at all disturb the work of refrigeration in the cellars.

The expense for chloride of calcium is slight, as the gas in the storage tanks is nearly dry; the moisture deposits are therefore so small that this expense does not enter into the calculation of operating expense.

The novelty of the equipment is in the fact that it can be used as a gas-collecting, carbonating, refrigerating and liquid carbonic acid manufacturing plant simultaneously.

No further apparatus is required to make liquid carbonic acid from fermentation gas, and this gas is perfectly adapted for saloon purposes at least.

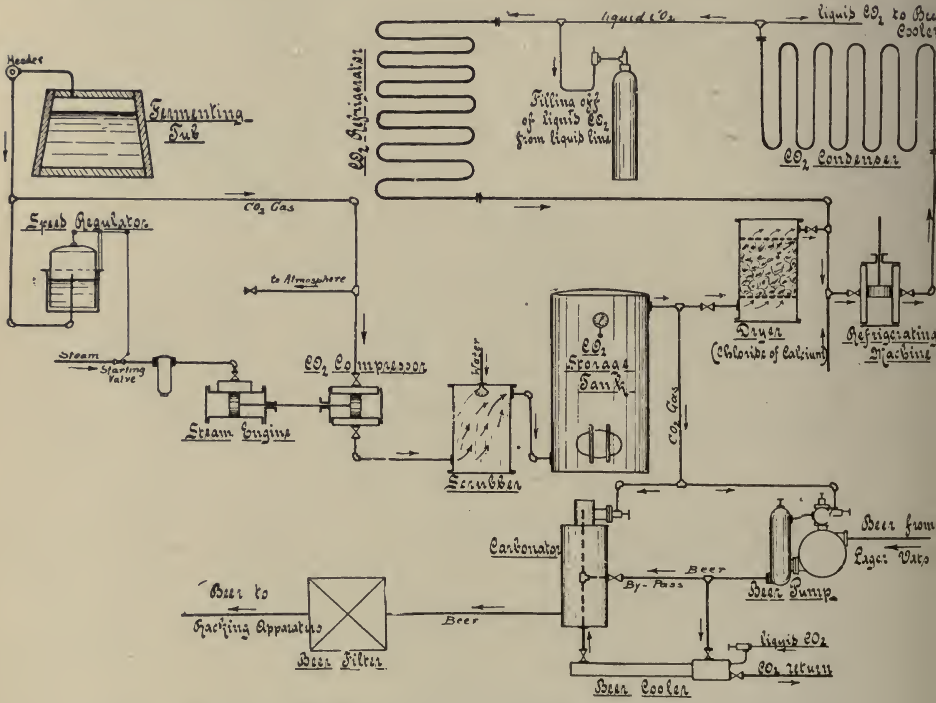


FIG. 172.—DIAGRAM CO_2 FERMENTATION PLANT, COMPRISING GAS COLLECTING, CARBONATING, REFRIGERATING AND LIQUEFYING APPARATUS.

Diagram Fig. 172 illustrates the connection as well as the functions of the combined apparatus.

In tracing the gas developed in the fermenting vat, it will be seen that it enters the fermentation gas compressor through a washer, to be forced into the storage tanks, of which there may be as many as desired, according to surrounding conditions. The compressor forces gas into the storage tanks until a pressure of 250 or 300 pounds is reached. At that pressure and density 1 cubic foot of gas weighs

3.3 pounds, so that a storage tank 30 inches in diameter by 9 feet high will contain about 150 pounds of gas, which is sufficient to saturate 7,500 gallons or 238 barrels of beer.

The speed regulator controls the compressor, which forces the latter to dispose of the gas at the same speed at which it is produced in the fermenters. From the storage tanks the gas may be conducted either to the carbonating equipment or to the refrigerating and liquefying plant. Before it enters the suction port of the refrigerating machine it passes through the dryer, where its moisture, and with it most of the odoriferous ingredients, are deposited. The filling stand for drawing liquid carbonic acid into the steel cylinders is connected to a convenient point in the liquid line of the refrigerating system. It is advisable to charge the CO_2 cylinders in a cool place, as it is much easier to get the full weight of liquid into the tubes when the temperature of the latter is lower than that of the liquid CO_2. With water of 60° F. used on the condenser the temperature of the liquid CO_2 will be in the neighborhood of 65° F., and if the CO_2 cylinders are kept in a cool place where the temperature averages 50 to 55° F. the full weight in liquid can be charged into same at pressures not exceeding 65 atmospheres, which is equal to 955 pounds, gauge pressure. The racking room of a brewery would be a good place for this purpose.

LIQUID CARBONIC ACID AS A BY-PRODUCT OF BREWERIES.

Nearly every industry has by-products of one form or another, the utilization of which very often increases the earning capacity considerably. This fact is now recognized to such an extent that technical chemistry has become a very important department in many enterprises.

Soap factories, which formerly paid very little attention to the glycerine, wasting it without further consideration, would not think of wasting so valuable a by-product today.

The packing industry of today does not waste a bone, every particle of the animal body is used for one purpose or another.

During the production of illuminating gas from coal, the by-products (tar, ammonia and coke) are so valuable, that without the proper handling of these, it would be impossible to sell the principle product at the prevailing rates.

The same necessity to economize exists in the brewing industry, and it is therefore logical that the use of the fermentation gas should be seriously considered.

There are numerous valuable uses to which the gas could be put within the brewery. The most prominent of these have been explained. Among others is the employment of the gas during racking and bottling in providing the necessary counter pressure, thus eliminating the use of air, which is objectionable.

Should the brewery find it advantageous to supply the saloons of its clientage with liquid carbonic acid, it could use its regular carbonating gas without further purifying it for that purpose.

The liquid carbonic acid used in the mineral water industry must be chemically pure, and as the fermentation carbonic acid contains a slight fusel-oil odor, which can not be separated by simply washing the gas with water, it requires elaborate purifying apparatus to produce a chemically pure product.

The necessity of such purification increases the manufacturing cost of the brewery gas, so that it can not be produced very much cheaper than the combustion CO_2.

This objection is not of a serious nature, however, and many breweries located in a territory with no or only slight competition in the CO_2 line, would find it profitable to collect all of their gas and prepare it for the market.

Breweries having an annual capacity of 100,000 barrels could produce 500,000 pounds of liquid carbonic acid per year conveniently. The manufacturing cost would probably not reach one cent per pound of chemically pure liquid CO_2; assuming that another cent will take care of the deterioration and interest for the investment, while a third cent will cover the selling expenses, it brings the sum total of the expenses for every pound of liquid CO_2 up to 3 cents, which is a very safe figure. The selling price in localities where no special liquid CO_2 factory exists, is not less than 10 cents per pound, and as a 100,000 barrel brewery can produce 500,000 pounds of liquid CO_2 annually, it would amount to an extra net cash revenue of $35,000 per year, provided all the CO_2 could be sold.

This certainly is a factor which deserves careful consideration and should be looked into in the interests of the stockholders.

A great many of the breweries in the United States are of large proportions; a brewery that produces 100,000 barrels of beer is considered of fair average size. The brewing process is regular and occurs every day, often twice a day. It follows that the production of the gas is of the same regularity. Closing of the fermenters is not objectionable so long as the gas is drawn off in a way that does not disturb the natural process. Many breweries operate with the Pfaudler vacuum system, and in these the fermenters are used without alteration.

THE NATHAN SYSTEM OF BEER TREATMENT.

The Nathan process of beer treatment, which treats and finishes the product in closed receptacles without subjecting it to storage, provides for a fermentation gas-collecting and purifying plant to begin with. The carbonic acid generated during the fermentation is purified after this process, which lasts the short period of three days and a half; the CO_2 is used for the purpose of aerating the beer, which treatment expels the highly volatile flavors of green beer from the fermented fluid.

After thus being aerated, the beer is impregnated with any desired quantity of carbonic acid, at the same time it is being cooled rapidly. This lasts twenty-four hours and at the end of this treatment it contains the same amount of carbonic acid as well kraeusened and long-stored beer, to which it is, at least, equal in foam formation; taste and stability.

The next step is to force the beer by carbonic acid pressure from the apparatus through a filter and into the shipping cask, carbonic caid gas being used throughout, without subjecting the finished beer to air, thus avoiding the danger of introducing germs through the agency of impure air.

PURIFICATION AND LIQUEFACTION OF FERMENTATION GAS.

The wort, which generates the carbonic acid, consists chiefly of saccharine and dextrinous matter dissolved in water, with an addition of hops to produce the aromatic taste desired. It is then pitched with yeast and allowed to ferment, by which process the saccharine constituents of the wort are decomposed into alcohol and carbonic acid.

A chemically pure CO_2 must be free of air, water and odor. The air is discharged from the fermenters during the first stage of fermentation; moisture can be absorbed by means of properly constructed dryers containing an absorbent, and the odors, which ema-

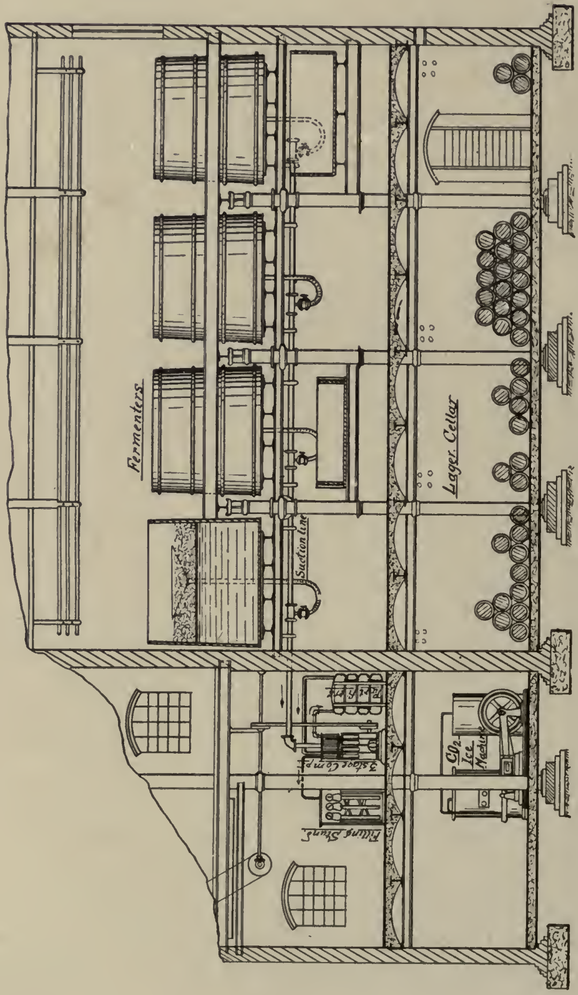


FIG. 173.—J. & E. HALL'S FERMENTATION GAS PURIFYING AND LIQUEFYING SYSTEM.

nate from the above organic matter, must be destroyed by chemicals that have a strongly oxidizing character when dissolved in water. These chemicals destroy the organic, odorous substances, leaving a pure and odorless product.

J. and E. Hall, London, England, have installed several plants on these principles (see Fig. 173). The fermenters are provided with a funnel-shaped gas collector. The gas rises, falls into this collector and is drawn through a suction pipe into the low pressure cylinder of the compressor. The piston of this cylinder discharges the gas into the intermediate cylinder, which in turn pumps it into the high pressure cylinder and the high pressure piston finally compresses it to the pressure of liquefaction. The pressure of the carbonic acid in the low pressure cylinder is 25 pounds per square inch, in the intermediate it is 195 pounds and 950 pounds in the high pressure. The purifiers are placed between the low pressure and intermediate cylinders. A series of eight cylinders containing sulphuric acid, water, permanganate of soda and lastly a calcium chloride dryer are used to expel the air, destroy the organic substances and purify and dry the gas.

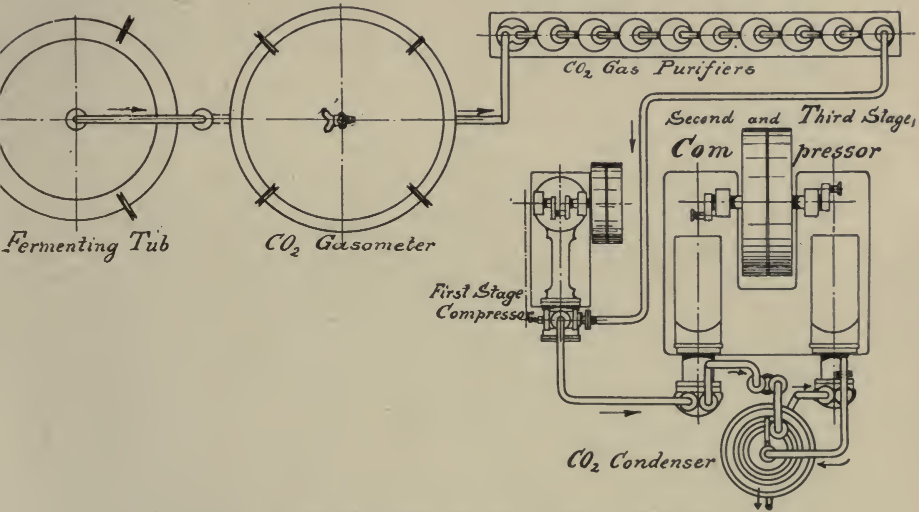


FIG. 174.—SUERTH PROCESS FOR LIQUEFYING AND PURIFYING FERMENTATION GAS.

The "Suerth" process is illustrated by Fig. 174. The gas is collected from the closed fermenters by means of a gasometer. From there it is drawn by a low pressure gas compressor through a battery of purifiers containing such material as is suitable to produce a chemically pure product. The gas is then subjected to a three-stage compression. The first stage compressor discharges the gas under a pressure of 15 pounds into the low-pressure cylinder of the compound compressor, where the pressure is raised to about 150 pounds; the lubricating material is then drained off by means of a separator.

After passing through the intercooler the gas receives its final pressure of 60 to 65 atmospheres in the high-pressure cylinder. A condenser, which in this case is of the submerged type, liquefies the gas and it is then filled into the commercial CO_2 tubes.

Dr. Luhmann's system of purifying fermentation gas is a so-called "dry method," and consists of the following chemical process:

The gaseous carbonic acid is readily absorbed by carbonate of sodium during the presence of water, which may be added to the soda, or it may be mixed with the gas in the form of steam. A revolving apparatus mixes the material thoroughly, converting the mono-carbonate into a bicarbonate of soda; 250 parts of carbonate of sodium are required for 100 parts of carbonic acid. The air does not mix with the soda and can readily be discharged.

One of the best known constructions for this purpose is the Gaskell & Hurter apparatus. A cylinder filled with powdered carbonate of sodium revolves around a hollow axle. A mixture of carbonic acid and steam enters the cylinder at a temperature of about 80° C. When the soda is nearly saturated, additional dry carbonic acid gas enters the absorber to complete the saturation. A number of such cylinders are connected in series, each of which can be disconnected at will, and the mixture of carbonic acid gas and steam is so connected that the cylinder containing the most advanced formation of bicarbonate receives the richest gas.

It is now only necessary to heat the bicarbonate of soda in order to obtain the pure carbonic acid gas contained therein. Several apparatuses have been designed, the simplest of which are retorts, and the required heat can be produced directly by fire or through the indirect medium of steam from the boiler.

Permanganate of potassium is a very energetic germicide; it destroys odors and germs producing putrefaction quickly; it is an excellent disinfectant and is frequently used in connection with a carbonic acid purifying apparatus. If a solution of permanganate

FIG. 175.—SCHNEIBLE'S HOT BEER COOLER, COLD WATER SECTION.

of potassium is used for the purpose of removing odors in the CO_2 it is only necessary to wash and dry the gas after it passes through this solution. The product is absolutely odorless, and if proper attention is paid to the drying apparatus a chemically pure CO_2 can be obtained.

SCHNEIBLE SYSTEM OF BEER TREATMENT.

One of the most perfect gas collecting and carbonating plants—Schneible system—has recently been installed in the Rising Sun Brewery in Elizabeth, N. J. The equipment of the brewery is modern throughout.

A kettle of 280 barrels capacity prepares the wort, which, coming from the hop jack, is received by a hot wort pump and delivered directly into the fermenting tubs through a closed delivery hot wort cooler.

This cooler is of the double-pipe pattern and the cooling medium used to remove the heat of the wort is cold water, wort and water circulating through the cooler in counter-currents, the coldest water meeting the coldest wort and *vice versa.* The cooler is shown in Fig. 175, and its location is in the brewhouse, so as to keep the heat radiated by the hot wort out of the fermenting room. After the wort has been cooled to nearly the temperature of the available water it passes through another cooler of the same type located in the fermenting room. In this cooler mechanical refrigeration, instead of water, reduces the temperature of the wort to that desired for its fermentation. The location in the fermenting room is selected so that any excess of refrigeration radiating from the pipes will not be wasted but will be used to cool the room, and also to enable the men working in the fermenting room to control the temperature of the wort by regulating the intensity of the mechanical cooling process.

Fig. 176 shows the cooling section provided with mechanical refrigeration and its location in the fermenting room. It will be noticed that the beer on its way to the fermenting room remains enclosed and that no unfiltered air comes in contact with it—no open cool-ship and Baudelot cooler being used—thus elminating the danger of introducing germs through contact with the atmosphere.

Before the cooled wort is deposited in the fermenting tub, however, it is necessary to aerate it. This is done by means of a suitable apparatus which supplies it with the required volume of sterilized air on its way to the fermenters.

The fermenting tubs are closed—as shown in diagram, Fig. 177—the wort entering same at the proper temperature for pitching it with yeast, which latter is placed in the tub, and the wort is then pumped on top of it. The fermenting tub is filled to about three-fourths of its height, so as to allow sufficient room for the collection of the gas. Fermentation sets in at once. During the first thirty-six hours the weak gas containing large volumes of air is allowed to escape into the atmosphere. After this period it will be found by testing the gas that it is now free of atmospheric air and that it is filled with all the desirable hop flavors and odors for subsequent re-introduction into the beer, thereby saving all the valuable qualities of the hops, which are always lost when beer is fermented in open tubs.

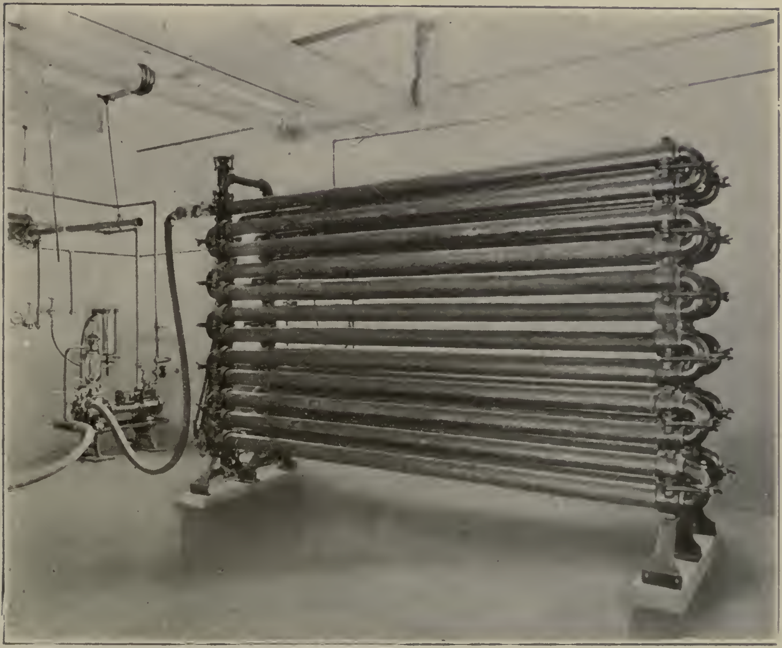


FIG. 176.—SCHNEIBLE'S HOT BEER COOLER, REFRIGERATION SECTION.

Connection is then established by means of special fittings (with which every fermenter is provided) with a 3-inch gas suction line, through which the gas is conveyed to an automatically operated gas compressor.

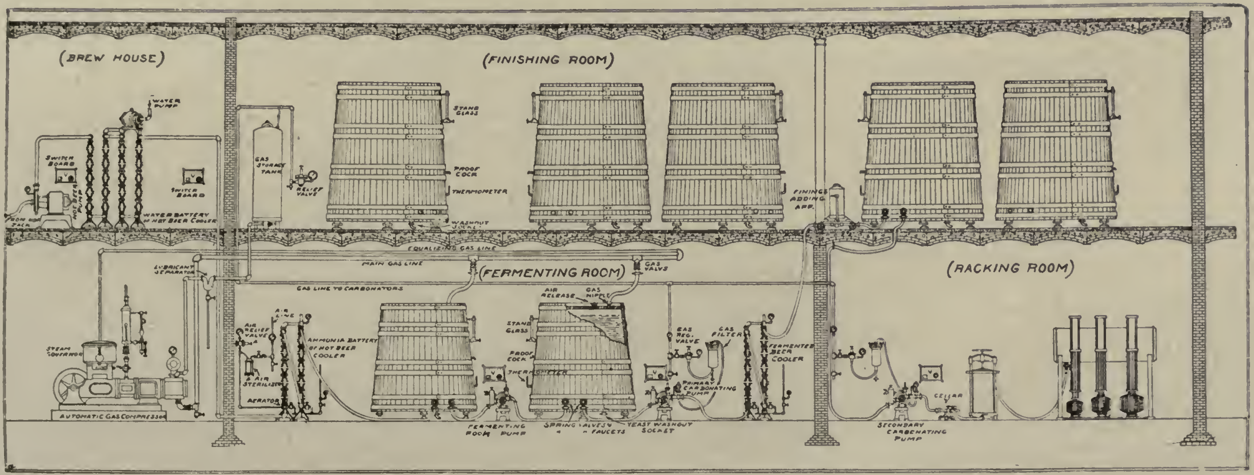


FIG. 177.—DIAGRAM SCHNEIBLE'S SYSTEM OF BEER TREATMENT.

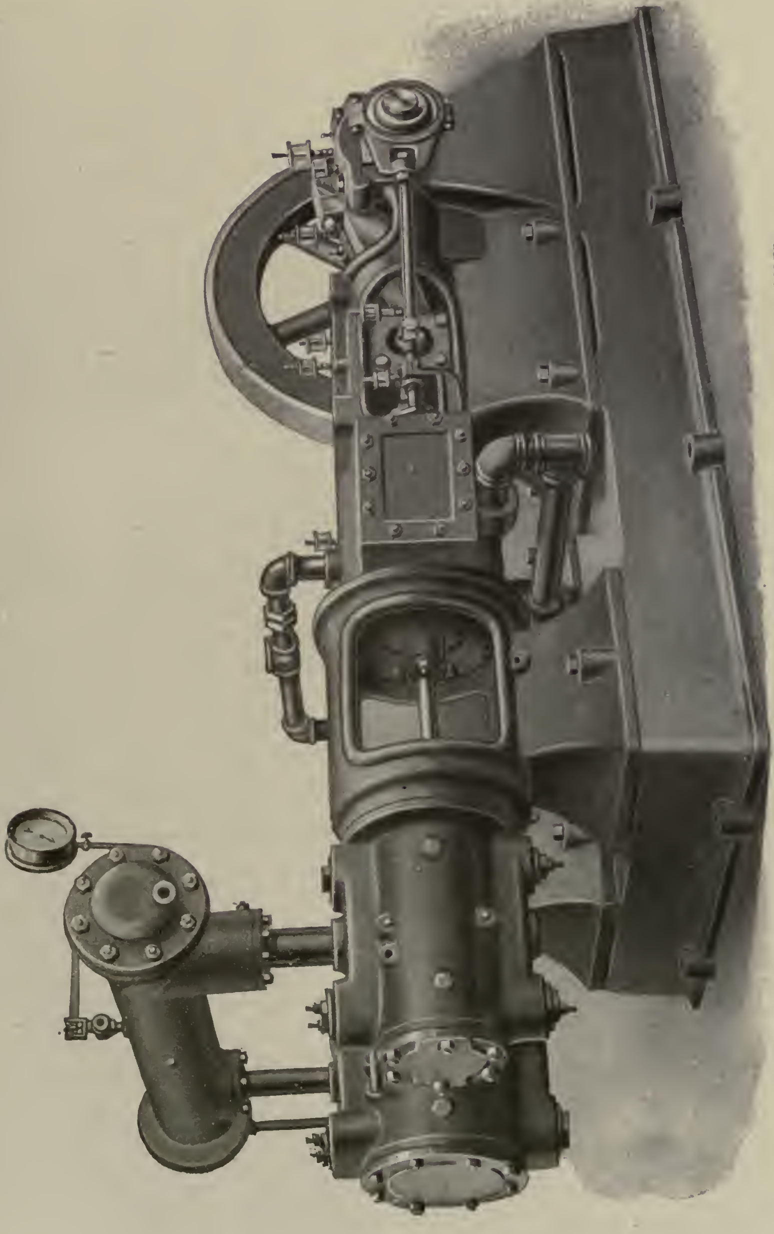


FIG. 178.—CLAYTON DUPLEX FERMENTATION GAS COMPRESSOR WITH INTERCOOLER.

This compressor (Fig. 178) is of the duplex type, having duplex steam cylinders and compound compressor cylinders, the cranks being so set that the machine will operate at the slow speed of twelve revolutions per minute.

A special automatic steam governor and regulator is connected with the gas line on one side, and with the steam admission valve on the other (Fig. 179); the slightest change in the pressure of the gas developed in the fermenter affects this regulator, which immediately acts upon the compressor, increasing or decreasing the speed of the latter.

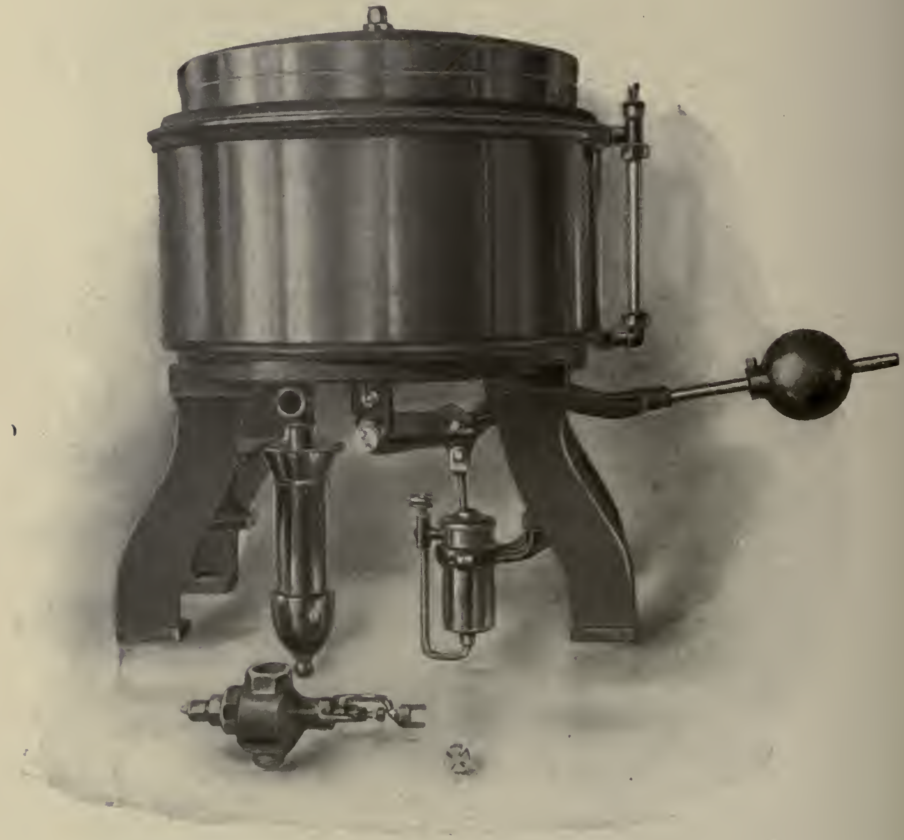


FIG. 179.—SCHNEIBLE'S AUTOMATIC STEAM GOVERNOR AND GAS REGULATOR.

This is done in order to allow the fermentation to take place under the perfectly natural condition of a pressure of one twenty-eighth of a pound, which corresponds exactly with the pressure that exists in an open tub on the wort. Neither pressure nor vacuum can possibly exist in the fermenting tub, as the automatic regulator positively prevents either.

The gas as it is collected is compressed by the low-pressure cylinder of the compressor to the pressure of a few pounds; it then passes through an intercooler, where the heat of compression is removed by running water, into the suction of the high-pressure cylinder—see Fig. 178. This cylinder discharges it into a suitable gas storage tank, which is finally filled with gas under a pressure of about 150 pounds.

The fermenting beer meantime is allowed to rise in temperature as far as it will go, no attemperators being used to check it. At the proper time when all the scum, sediment, wild yeast, etc., have separated from the fermenting beer, the beer containing the good, pure yeast in suspension is pumped into a clean fermenting tub by means of the fermenting room pump. The scum and sediment is then washed from the first tub into the sewer. In the second tub the good yeast settles to the bottom. After a proper period of time the beer is pumped out of this second tub, leaving the good yeast behind. This yeast is then used for the next brew.

The whole fermentation process, from its inception to completion, occupies a period of eight days.

The beer taken from the second fermenting tub is carbonated by means of a primary carbonating pump and is then forced through a double-pipe fermented beer cooler into a finishing cask.

It is not necessary to use an additional cooler for this purpose, as the cooler which previously cooled the wort can be used.

The carbonator which impregnates the beer with the pure fragrant carbonic acid gas from the storage tank is provided with a pressure regulating valve, the gas being drawn into the beer automatically. No chips are added—they are not required, and if admitted will spoil the taste and keeping quality of the beer.

In the finishing cask the beer is clarified. During this period the presence of carbonic acid is especially advantageous, as it prevents absorption of air and destroys the flavors of green beer, aging it, and giving it the character of long-stored beer.

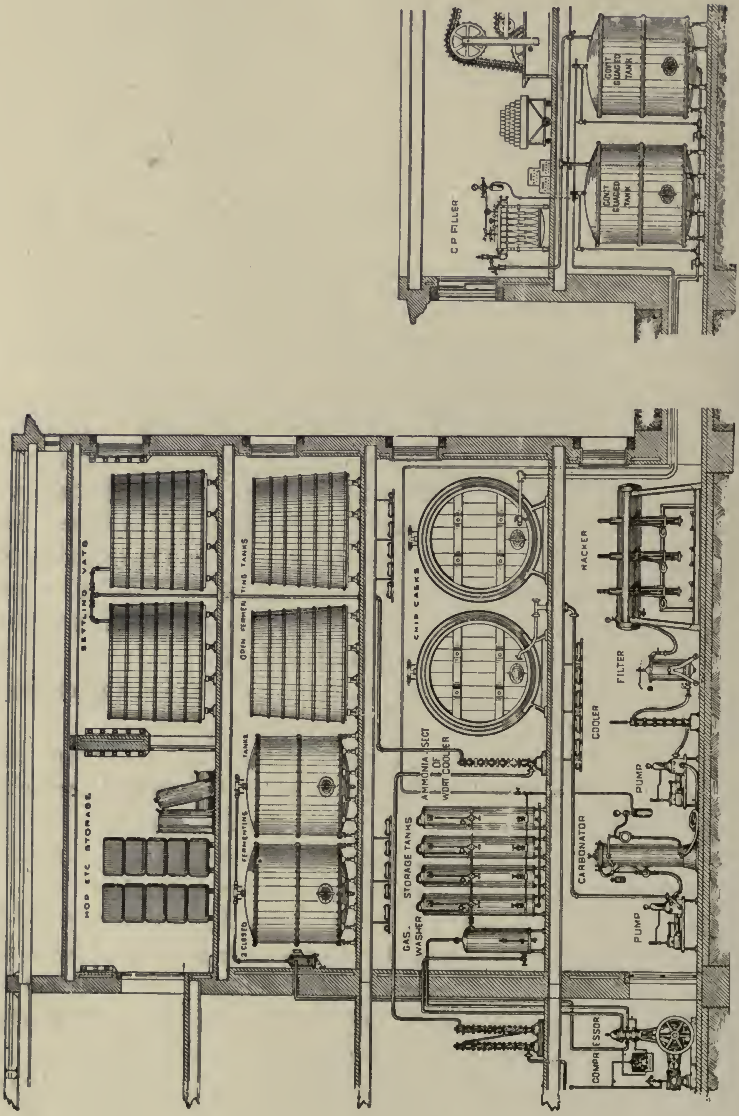


FIG. 180.—DIAGRAM WITTEMANN'S CARBONATING SYSTEM AND GOVERNMENT-GAUGED BOTTLING SYSTEM.

Within fifteen days after the beer enters the finishing cask it is fully matured and clarified and is ready to rack. As it flows to the racker it passes through the secondary carbonating pump and any additional carbonic gas required to give it the necessary refreshing, palatable and foaming quality is added.

The commercial advantages of this method are a factor of great importance inasmuch as it increases the capacity of the brewery at least 30 per cent.

Many brewers would probably hesitate to give the commercial consideration too much weight, if it were not for the fact that the modern method furnishes a product which is at least as good as long-stored beer made from the same material. At the same time it is superior in its keeping quality, foam stability and palatable properties.

WITTEMANN CARBONATING SYSTEM.

The diagram, Fig. 180, represents a complete gas collecting and carbonating equipment upon the Wittemann system. The gas is obtained from two closed fermenting tanks, passes through a foam-trap and enters the compressor, which discharges it through a gas washer into four storage tanks, where it is subjected to a period of rest at the temperature of the storage cellar. A gas line leads to the carbonator, and a second line connects with the Government gauged tanks in the bottling house, for the purpose of emptying these tanks into the bottling machinery by means of gas pressure and without the use of pumps.

Before entering the carbonator the pressure of the gas is reduced to the required carbonating pressure by means of a reducing valve. The beer leaves the chip casks by gravity and a pump forces it through the carbonator at cellar temperature. A second pump—if required—forces the carbonated beer through the cooler and filter into the racking apparatus.

Another modification of this arrangement places the cooler between the pump and the carbonator. Instead of a steam pump, a motor-driven piston pump may be used.

TESTING EFFICIENCY OF CARBONATING APPARATUS.

In order to learn the efficiency of the carbonating apparatus at various temperatures, the following test is recommended by Prof.

Joh. Koehler of Stockholm, Sweden. A diagram of the apparatus and connection for making this test is shown in Fig 181.

The beer to be examined is filled into an ordinary beer bottle, *A*, and is closed with a cork stopper, through which a tube, *b*, containing outlet *a* and b^1, is inserted. A small receptacle, *d*, containing a caustic soda or potash solution connects to outlet b^1, while outlet *a* is placed in communication with bottle, *e*, as shown. This bottle is closed by means of a cork having attached to it a cooler, *l*. The gas outlet from cooler *l* connects to calcium chloride dryer, *k*, and finally to two receptacles, *f* and *g*, containing a caustic potassium lye.

To use the apparatus turn beer bottle, *A*, upside down, allow atmospheric air to enter the bottle through *d*, communication *h* and tube *b*; the air will then force the beer to leave the bottle through *a* into *e*. Heat is applied to *e* and the beer is made to boil. The alcohol contained in the beer as well as the steam condenses in *l*, while the atmospheric air and carbonic acid gas pass on into dryer *k* and finally into *f* and *g*. The atmospheric air escapes into the large end-receptacle *F*, while the CO_2 will be absorbed by the caustic potassium lye in *f* and *g*. The end-weights are then compared with those obtained before starting the test and the balance is the CO_2 originally contained in the beer.

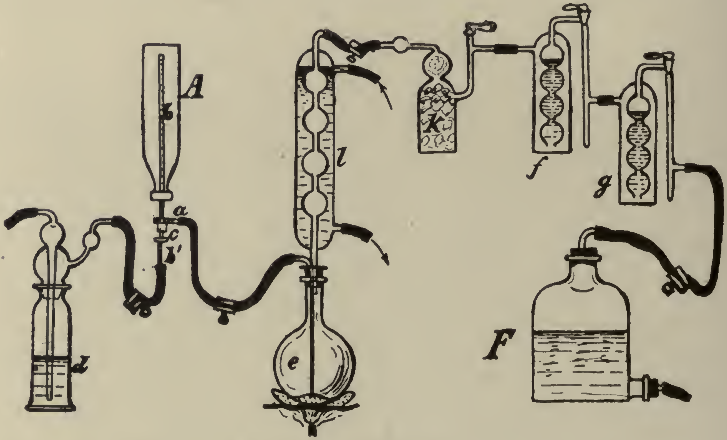


FIG. 181.—TESTING APPARATUS FOR DETERMINING AMOUNT OF CO_2 IN BEER.

Professor Koehler found that the quantity of CO_2 in lager beer averaged 0.32 per cent, while porter contained from 0.38 to as much as 0.65 per cent.

A beer rich in carbonic acid is the only good beer, and the efforts of the brewer should be directed to making a beer which has in the highest possible degree the capacity to absorb and retain carbonic acid.

To attain this end the beer should be of a high fermentation, and the entrance of atmospheric air into it should be carefully avoided.

LIQUID CARBONIC ACID FOR DRAWING BEER.

It is a well-known fact that beer of the same quality and from the same brewery may have an entirely different effect upon the palate when imbibed in different places, and the patron, if at all a judge of beer, will soon make up his mind that in one place the beer receives proper care, while this care is lacking altogether in the other establishment.

When the beer is delivered from the brewery it should be placed in a refrigerator of a temperature between 40 and 45° F., *i. e.,* 40° in summer and 45° in winter. It should be delivered to the faucet by means of carbonic acid gas pressure. When drawn, it should have a temperature of between 40 and 45° F., and the dispenser should do his share toward producing a first-class, palatable and refreshing beverage by adjusting the pressure required for drawing it properly. If this pressure is obtained from a liquid carbonic cylinder, it can easily be maintained at 15 pounds, which is ample in most cases. Should the distance between the faucet and the barrel in the cellar make it necessary that a higher pressure be carried, this fact may readily be determined by observation.

If localities and surrounding conditions permit it, the distance between barrel and faucet should be as short as possible, the gas used should be pure, and, if possible, it should be obtained from the same product that is being dispensed.

The advantages of carbonic acid gas pressure over the air pressure for purposes of dispensing are many. It will easily be understood that there can be no loss of carbonic acid from the beer by diffusion, since the gas which is used for the purpose of raising it to the faucet is the same as is contained in the beverage. Carbonic acid, unlike air, does not assist in the development of microbes, but on the contrary, it retards their development and often exterminates them entirely. A barrel may remain on tap for several days without losing its taste or its natural percentage of carbonic acid.

This applies to and is especially valuable in the case of imported beer, for which there is frequently not sufficient demand to empty a package in one day.

A beer that is comparatively poor in carbonic acid will absorb a part of the gas while under its pressure and will be slightly improved.

The objections to the method of using air pressure are largely of a hygienic character, principal among which is the location of the pumps, which is often such that stagnant and foul air mixed with smoke from cigars, etc., is drawn into the pumps and forced into the barrel. Such air is saturated with bacteria and microbes, all of which become very productive and mischief-making as soon as introduced into the barrel. When air is used, a part of the CO_2 contained in the beer diffuses into the air; in its place air will be absorbed by the beverage, and as the barrel is gradually emptied, this exchange decidedly impairs the quality of the beer and robs it of much CO_2, so that it is almost without life and foam when drawn into the glass. Beer that has been under the pressure of air over night has lost its palata-

FIG. 182.—DRAWING BEER UNDER LIQUID CARBONIC ACID PRESSURE.

bleness almost entirely, as it has lost most of its carbonic gas by diffusion and exchange, and with it, its palate-fulness and foam stability. The cost of using liquid carbonic acid is slight, as it requires only between one and one-and-a-half pounds of liquid carbonic acid to dispense the contents of one barrel of beer.

A very commendable way of connecting the liquid carbonic acid cylinder with the beer barrel and the latter with the bar faucets is shown in Fig. 182.

The barrels are placed in the refrigerator below the bar. Connection between the liquid carbonic acid cylinder and the barrels is made so that the pressure regulating valve, which is interposed in the line, can be observed and adjusted when required by the bartender. A pressure of about 15 pounds will be sufficient in this case.

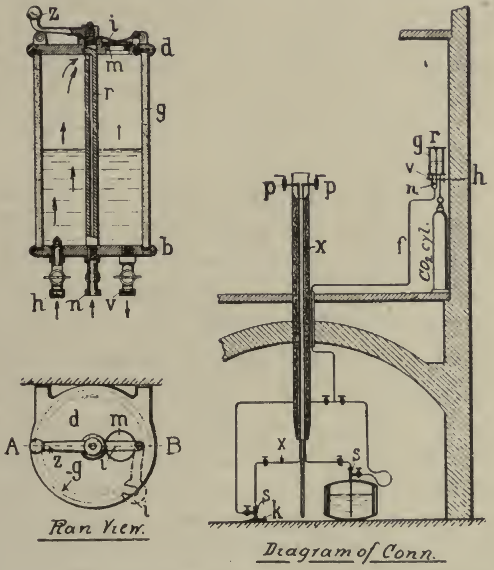


FIG. 183.—TESTING AND CLEANING APPARATUS FOR BEER AND GAS CONNECTIONS.

TESTING AND CLEANING OF BEER DRAWING APPARATUS.

The pipe connection through which the carbonic acid gas is conducted to the beer barrel in the cooler for the purpose of raising the beer to the faucet is liable to develop a leak, causing loss of gas and annoyance before it can be detected. It is also necessary to clean the beer connection between the barrel and the bar from time to time.

For this work an apparatus has been invented which is permanently installed and can be used successively as a detector of leaks and for the purpose of cleaning the pipe line.

The principal part of the equipment consists of glass cylinder *g* —Fig. 183—which is fitted into metallic top and bottom plates, *d* and *b,* having a corresponding rubber-packed groove. These three parts are held together by means of crank *z*. Opening, *m,* is used to fill the testing or purifying liquid into the cylinder when required.

The bottom plate, *b,* is provided with three valved connections, *h, n* and *v;* a check valve is fitted in *h*.

In the ordinary operation the gas connection with the liquid CO_2 cylinder is established at *h*. A pressure reducing valve located between the drum and *h* maintains the desired pressure. The gas enters the cylinder, passes through the liquid, consisting of clear water, then through tube *r* into the barrel, forcing the beer through *x,* upward to the bar faucet *p*.

If the water in *g* shows slight gas bubbles at a time when no beer is being drawn, it is evident that the gas line has a leak.

When the apparatus is to be used for cleaning purposes, it is necessary to change the gas connection from *h* to *v*. The barrel, which is connected to the line at *k,* must be removed and a direct communication between *s* and *x* must be established. It is then necessary to fill glass cylinder *g* with a cleansing liquid, such as permanganate of potassium, etc., and as soon as the gas pressure is turned on the gas enters through *n* and tube *r,* forcing the liquid out at *v* into the gas as well as the beer line and up to the faucet *p*. The air can be drawn off at this faucet. As soon as that has been done it must be again closed before the liquid used as the purifying agent runs out.

It is well to keep the lye, or whatever is used as the purifier, in the line a short time, when it is drawn off through *p*. After removing the lye the pipe line must be thoroughly rinsed with sweet water in the same way as above.

To re-establish the original connection it is only necessary to change *n* back to *h,* place a filled barrel in position *k* and the apparatus is again ready for dispensing beer.

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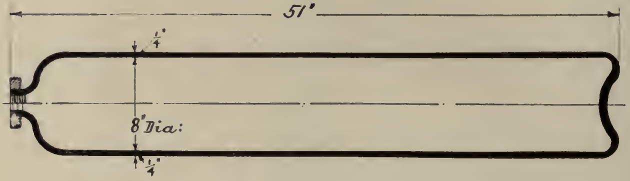
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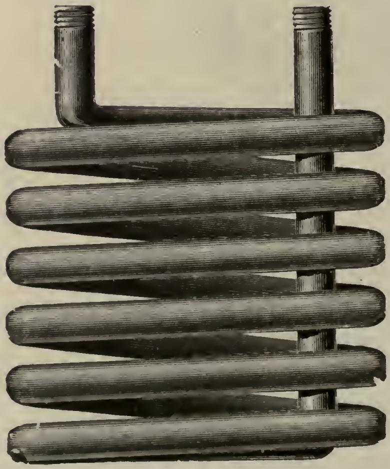


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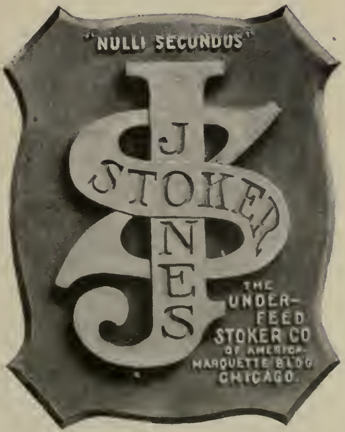
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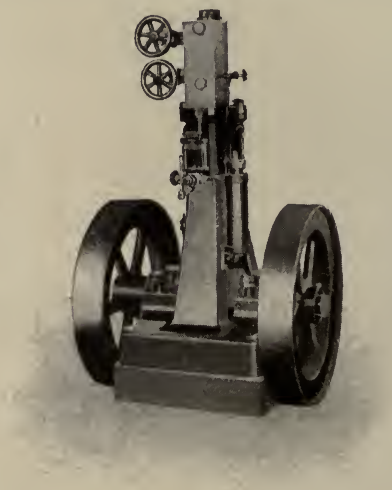

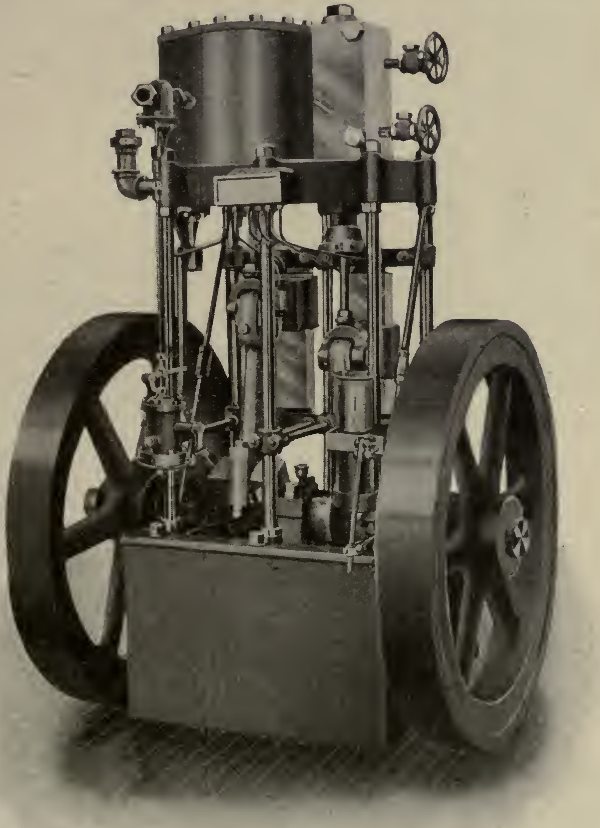

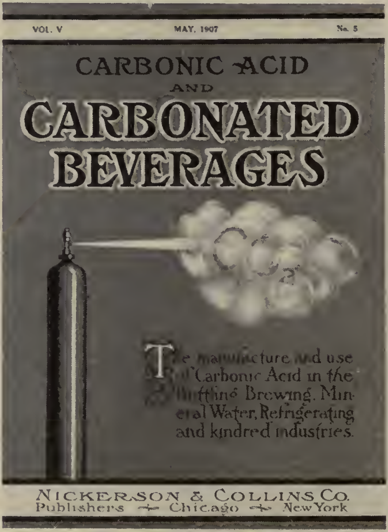
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