ELEMENTS OF WATER GAS

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A Practical Treatise on the Manufacture of Water Gas

By

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PREFACE

The object of this work is to briefly outline the development of water gas to its present stage, and enable the reader to grasp the fundamental principles which govern the past and future developments. It will be observed that only such apparatus has been referred to that constitute an important and established development of the process, and the author realizes that the subject is far from being exhausted. The work, however, is intended to provide a stepping stone to a later study, and technicalities have been avoided as far as possible.

To the reader interested in water gas manufacture, it is hoped that a perusal of this work will educate him in a general way into the principles of the process.

To the student who contemplates gas engineering as a profession, it need hardly be said is especially adapted.

To the salesman it will give a brief outline into the principles of modern developments, and enable immediate comparison with his own particular plant.

CHAPTER X.

Construction Developments.

APPENDIX.

ELEMENTS OF WATER GAS

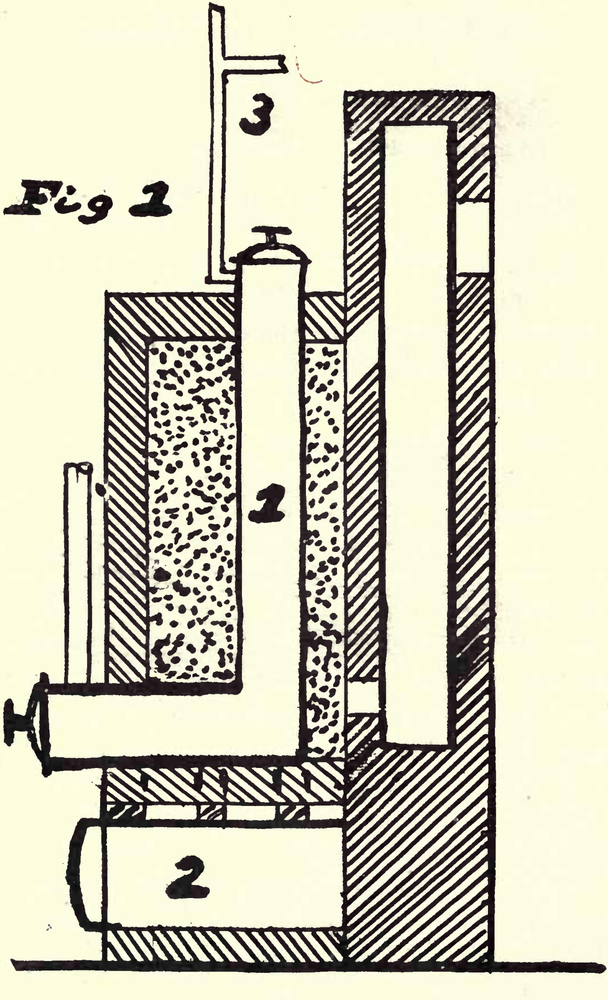
CHAPTER I.

EARLY HISTORY.

The origin of water gas goes back to the year 1780, when Fontana, a French chemist, discovered that by passing steam through incandescent fuel containing carbon, the oxygen of the steam had greater affinity for the carbon than its combining element hydrogen, and thereby the steam was broken up as follows: $C+H_2O=H_2+CO$. It was not, however, until some 50 years later that this reaction was used commercially, when Michael Donavan distributed it for public lighting in Dublin, Ireland. Briefly, this attempt consisted of passing steam through coke heated to redness in contact with vapors of spirits of turpentine, tar, coal naphthalene, or other illuminating agents, but did not, however, meet with much success, and little appears to have been done in further developments until the year 1858, when Dr. J. M. Sanders erected a plant in Philadelphia, to supply gas to a certain Girard House.

In this design of plant a series of (L) shaped retorts 1 (Fig. 1) were set in an ordinary coal gas setting, and filled with charcoal, and heated

Fig 1



externally by furnace 2 while steam and melted rosin were passed downwards by way of pipe 3 through the bed of fuel, the resultant products passing up through the standpipe to an hydraulic main. This process was proven to be about 10 per cent. more expensive than coal gas, and in due course was abandoned.

The next attempt worthy of note was in 1873 by the Allen-Harris system, which consisted of passing superheated steam through anthracite coal in an ordinary coal gas bench, and then passing the water gas into retorts distilling coal gas from bituminous coal. In this process it was claimed that the distillation of coal in an atmosphere of water gas protected some hydrocarbons from decomposition that otherwise broke down into tar, and thereby increased the quantity of gas to about 30 per cent. without any appreciable loss in candle power, and a confirmation of this claim appears to be seen in the fact that the yield of tar was approximately two gallons less per ton of coal than in ordinary coal gas practice. The theoretical principle involved in this process has been the subject of much discussion of recent years, but as yet no design of plant has met with any remarkable success and the advantage claimed can not be accurately confirmed.

The developments following the Allen-Harris system were chiefly for the utilization of naphthas, obtained as a by-product in the petroleum industry, and one of the most interesting consisted of a bench of vertical retorts charged with anthracite coal, through which superheated steam was passed, and a series of horizontal retorts which were divided by a partition which extended nearly to the back of the retort. In the latter retorts oil was sprayed by means of steam, and the water gas from the vertical retorts mixed with it, after which the mixture traversed the bottom section from front to back, and the top section from back to front, and then up the standpipe to an hydraulic main.

The retort processes were continued for some time in a variety of ways, and the last known appears to have been the Slade or Salisbury process, which was finally abandoned in favor of the generator-retort system.

In the development of the generator-retort system the most successful attempts were those of Tessie Du Motay and Wilkinson. In the former apparatus, blue gas was made intermittently in a double generator, and stored in an hydrogen holder, from which it was drawn and passed through a steam heated evaporator, where it took up naphtha vapors. The mixture of gases were then sent through externally heated retorts, the function of which was to fix into permanent gases.

The Wilkinson apparatus, whilst different in construction, was practically the same in principle as the former, and one particularly interesting feature in it is that it was the first apparatus on which the down or reverse run is known to have been used on the generator.

Various modifications of these principles followed, of which the Hanlon-Johnson, Edgerton, Mackensie, and Egner types were the most important.

In the first named, water and oil gas were made and stored in separate holders and mixed cold, whilst in the Edgerton, the oil gas was produced in vertical retorts heated by the producer gases from the generators, and the gases separately stored and mixed cold.

The Mackensie apparatus attempted at a continuous production by carburetting producer gases with oil in coal gas retorts, and in the Egner process blue water gas was made in generators heated by air drawn through the fuel bed, and the water gas carburetted with oil in coal gas retorts. These attempts were proved unsuccessful, and in due course the generator-retort system was finally abandoned with the advent of the internal combustion system, which laid the foundation of modern water gas practice.

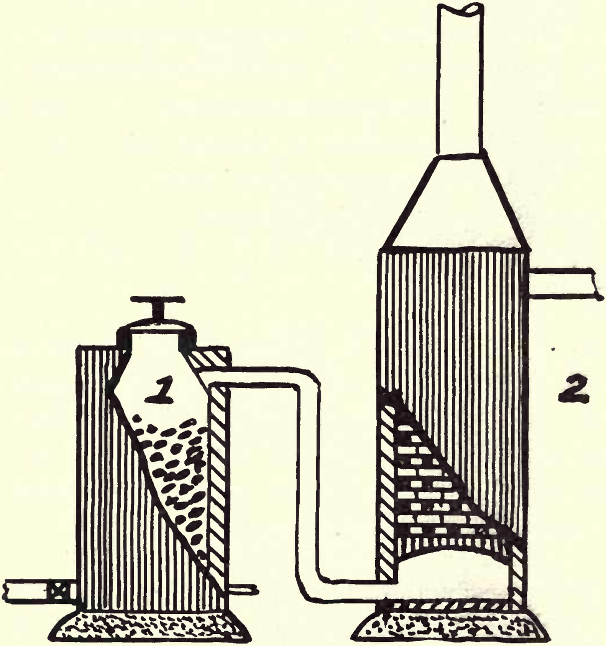


Fig 2

The original apparatus for the generation of enriched water gas by the internal combustion system was invented during the Civil War, in

1874, by Dr. C. S. Lowe, who was then engaged in the manufacture of balloons. The apparatus, which is shown in Fig. 2, comprised a generator 1, and a fixing chamber 2, and was heated by forced blast with secondary combustion in the fixing chamber. In the run of gas, oil was sprayed into the top of the generator, passed through the fixing chamber to a washer, and through a boiler for the production of steam used in the generator. The inventor, in his patent application, laid special importance on the advantages of vaporizing oil in the presence of hydrogen, and also claimed a reduction of fuel consumption by the utilization of wasted gases from the generator by the internal heating of the fixing chamber.

This system was afterwards modified in various ways, the most important of which was that of Granger and Collins, in which the generator was placed so that the top was level with the bottom of the fixing chamber, or superheater, and only a short, straight connection was required. This design met with marked success for several years, and the advantages claimed were:

(1) Convenient means of operation.

(2) Reduction of ground area.

(3) Free access to fire for cleaning.

(4) Minimum amount of heat lost by short connection between generator and superheater.

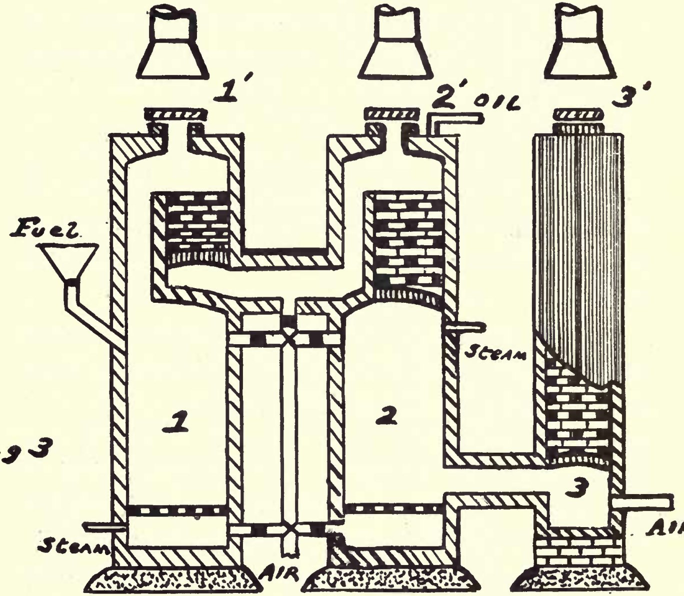
Another modification was the Hanlon-Leadley, which consisted of three generators connected to two steam and two gas superheaters. The generators were blasted in parallel and steam in series, the object of which was to provide a low fuel bed in blasting and thereby minimize the percentage of carbon monoxide, and a deep bed in steaming to minimize the percentage of carbon dioxide in the water gas. The steam used in the generators was first passed through the steam superheaters, and the oil gas and water gas were permanently fixed by passing through the gas superheaters in parallel. It may be interesting to note that this apparatus appears to have been the origin of modern twin-generator practice discussed later in this work.

In the years following these developments it became necessary to use a heavier grade of oil, and the first important development was made by the Lowe apparatus which consisted of adding another superheater and increasing the height of the second superheater to increase the fixing surface of the gases and also provide a draft from the generator when the charging door was opened. The height of the entire machine was also increased to provide a deeper fuel bed, and, in about 1890, means were provided to run the steam in an upward and downward direction, after which the developments consisted of minor and mechanical details.

With the progress of the internal combustion system it was found, however, that only hard coal or coke could be used with advantage, and many attempts have been made to use the cheaper soft or bituminous coals, but up to the present date this practice has not met with any remarkable success, although some interesting plants have been designed for the purpose.

One of the most noteworthy attempts to use soft coal was made by the Rose-Hasting apparatus, which is illustrated in Fig. 3. In this design the generator 1 is charged with soft coal about every 50 minutes, and carries a bed of fuel approximately 8 feet deep, and the regenerator 2 is charged with coke or hard coal. The operation of this plant consists of first blasting 1 and 2 with stack valve 1′ open for a period of 5 minutes, after which the stack valve 2′ was opened and 1′ closed for about 2 minutes, and then the stack valve 3′ opened and 2′ closed, during which time secondary air was admitted to the base of 3 as required until the end of the blasting period. During the run of gas steam was admitted below the grate in generator 1, and the gas passed through the checkerbrick in 1 to the top of the checkers in 2, where it mixed with oil

Fig 3



sprayed into the top of the chamber by steam. The gas then passed through the bed of fuel in 2 and up superheater 3. The object of the regenerator in this apparatus was to improve the quality of the water gas made in the generator by converting the high percentage of carbon dioxide in carbon monoxide, and also to assist in fixing the oil vapors.

Another method tried for some time was the Fehnehjelm apparatus, which consisted of a generator extending into the superheater to form a vertical retort, the purpose of which was to coke the coal before being discharged into the generator. In view of the fact that a modern water gas machine will consume approximately 2,000 pounds of fuel per square foot of grate area in 24 hours, it is evident that the primary object to this plant was that the capacity of the vertical retort was inadequate in producing sufficient fuel for the generator.

The Rew apparatus was another modification of plant designed for the use of soft coal, and was built and operated in pairs. In this plant, Fig. 4, the air blast was admitted beneath the grate in both generators 1 simultaneously, and passed over a bed of fuel in chamber 2, and down regenerator 3. Primary air was also admitted beneath the grate in coking chamber 2 at 4, and secondary air to the top of generator at 5 and regenerator at 6. During the run of gas steam was admitted to the base of one regenerator at 7, and traveled up and down over the bed of soft coal in 2, by which it picked up hydrocarbons, and then passed down through the fire of one generator and up through the fire of the other and over the second bed of coal. The gases then passed to the second regenerator, where they were met by a spray of oil, after which they

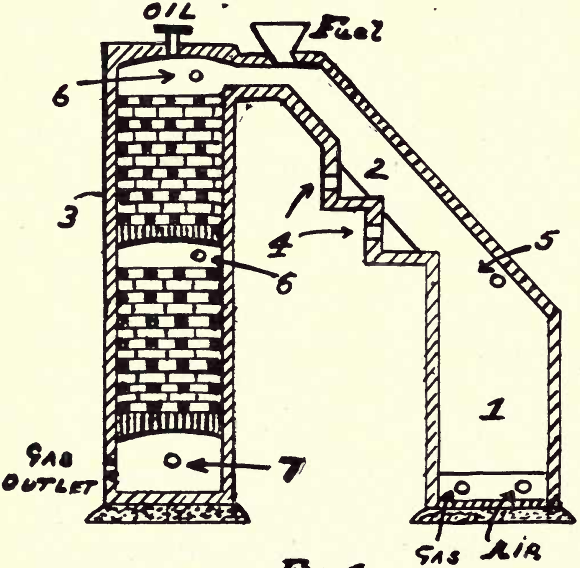


Fig 4

traveled to the base of the lower regenerator and led off to the washing plant. At the end of the run the air blasting was repeated and the direction of flow in the following run reversed. This apparatus can not be claimed to have been a permanent success, and its disadvantages appear to have been in the caking and sticking of coke in the coking chamber, and the comparatively large amount of labor necessary for the operation of the plant.

Various modifications embodying these principles followed, but have either been abandoned or altered for the manufacture of producer gases for power purposes, and in view of the fact that this work is intended to discuss water gas apparatus exclusively, the modifications referred to will not be further dealt with.

CHAPTER II.

Elements of Internal Combustion Process.

The internal combustion process was, as previously stated, originally invented by Dr. S. C. Lowe in 1874, since when many designs of plants have been brought forward, each embodying some new advantage or claim. In general, however, the modern carburetted water gas apparatus consists of a generator for producing water gas according to the reaction $C+H_2O=H_2+CO$, a carburettor for gasifying oil, a superheater to permanently fix the gases produced in the said chambers, an hydraulic seal to remove a certain amount of tarry matter and seal the gases when the machine is opened, and a scrubbing and condensing plant.

The Generator.

The function of the generator is to produce water gas according to the previous reaction, and also to produce carbon monoxide to be burnt in the carburettor and superheater in order to supply the necessary heat for the gasification of the oil. This unit consists of a heavy steel shell 1, Fig. 5, which contains a firebrick lining 2, a set of grate bars 3, air and steam blast inlets 4 and 5, a gas outlet 6, clinker and ash doors 7, and a charging door 8, with sight cock 9.

In the operation of this chamber for the generation of water gas, a blast of live steam is passed through a bed of highly incandescent fuel, containing carbon, which by reason of its greater affinity combines with the oxygen of the steam and liberates free hydrogen, thereby forming the two combustible gases, carbon monoxide and hydrogen. In this part of the reaction heat is absorbed from the fuel and after a certain time the fire has to be revived. This is accomplished by cutting off the steam and admitting a blast of air beneath the grate bars, which combines with the carbon in the lower part of the gene-

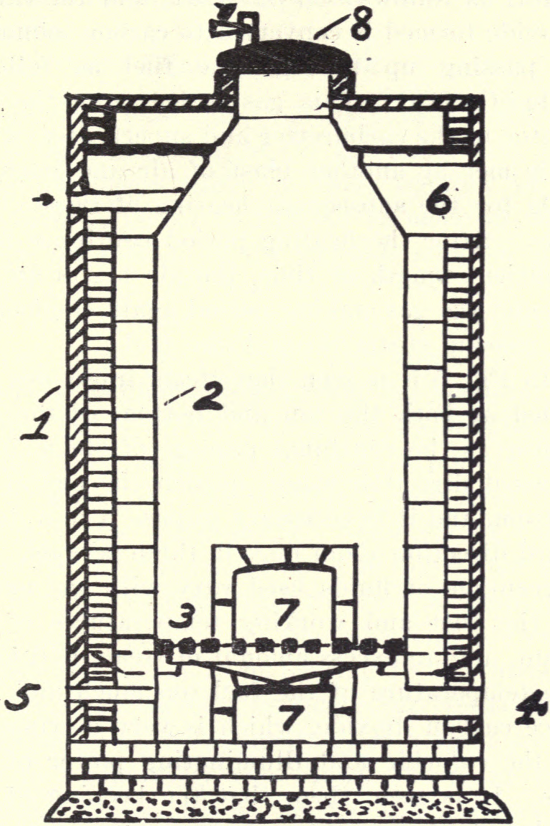


Fig 5

rator, as follows: $C+O_2=CO_2$, and the carbon dioxide formed is converted to carbon monoxide is passing up through the fuel as follows: $CO_2+C=2CO$. This gas is led from the generator to the carburetter and superheater, where it is met by another blast of air and burnt as CO_2 for the subsequent heating of these chambers. After the heating period continues for a sufficient length of time, the air blasts are cut off and the gas-making period again commenced by passing steam through the fuel.

In Fig. 5 it is seen that steam inlets are provided at both the top and bottom of the generator as the continual passage of steam in an upward direction would deaden the fire at the bottom, and it is necessary to pass it in a downward direction about once in three periods. The percentage of fluids used vary with the nature of the fuel and working temperatures of the plant, and an excess amount of steam will lower the temperature of the fuel too much and produce carbon dioxide, which is very detrimental to the calorific and illuminating power of the gas. It is seen, then, that the keeping of the fuel bed at a uniform temperature is a very important factor in keeping down the percentage of CO_2, and the sight cock provided, when used frequently, is of valuable service, as the operator soon becomes expert in judging the correct temperature.

Care of the Fire.

One of the most important factors is gas making is the controlling of the generator fire, and whilst engineers differ in their opinion as to the correct number of runs to be made in each charge, an average of the methods adopted may be taken at six runs when coal is used, and four when coke is used. This should be done after the run of gas, and the operator should always take care to blow the gas from the machine by opening the blast valve for a few seconds before opening the charging door, or an explosion will result when the combustible gases meet the oxygen in the atmosphere. After six or eight hours' continuous operation, it is found that ash and metallic residue from the fuel accumulates in the lower part of the machine, and prevents the air and steam from passing freely through the fire, and thereby seriously interferes with the capacity of the apparatus. It is then necessary to temporarily shut down the plant and remove the clinkers by means of the doors 7, Fig. 5, and in preparation of this the fuel bed is burned well down to allow the removal of clinkers which may adhere to the generator wall.

When the fire is at a suitable depth, the gas is first blown from the machine by the air blast, and then the charging door is opened and the gas lit off before opening the clinkering door. After the clinkers are drawn by means off bars and hooks, the ash pit door is opened for the withdrawal of matter which falls through the grate bars, and on reclosing care should be taken to clean the doors well to ensure a gas tight joint. If the machine is then to be shut down for the night it is charged well up, the depth of fuel made even all round, and the ash pit door slightly cracked to admit a small portion of air to keep the fire alive. If the machine, however, is to be put directly back to gasmaking, the doors are made tight and the air blast put on slightly longer than usual to heat the heavy charge of fresh fuel.

Carburetter and Superheater.

The carburetter B, Fig. 6, comprises the second unit in a carburetted water gas set, and consists of a chamber with a steel shell lined with fire-brick, and is filled with a checkerwork of fire-brick, the purpose of which is to store up heat for the gasification of oil. It is provided with an oil inlet 1, an air blast inlet 2, a steam inlet

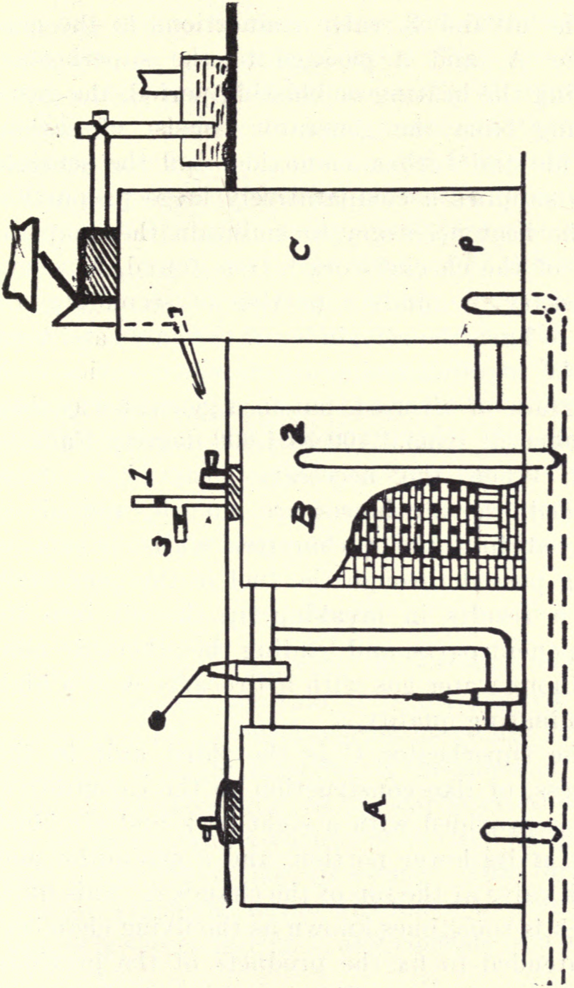


Fig 6

in the oil line 3, valve connections to the generator A, and a passage to the superheater. During the heating or blasting period, the gases coming from the generator consist of carbon dioxide and carbon monoxide, and the sensible heat supplies a comparatively large proportion of the heat necessary to maintain the temperature of the checkerwork. It is found, however, necessary to admit a portion of secondary air at 2 to burn the remainder of the gases and keep up the required temperature, which varies with the grade of oil used, but in a general way may be taken at from 1,400 to 1,600 degrees Fahrenheit. When the necessary heats have been reached, the air blasts are cut off, and oil is sprayed into the carburetter whilst steam is being passed through the fuel in the generator, which results in breaking up the oil into its component parts, and loading the otherwise non-luminous water gas with hydrocarbons of a high illuminating quality.

The superheater C is the third unit in the process, of like construction to the carburetter, and is provided with a sight cock and air blast inlet at its lower portion, and a gas outlet and stack valve at the top of the chamber. This unit, which is sometimes known as the fixing chamber, is intended to fix the products of the previous chamber into permanent gases and complete the work of the generating plant. The air blast inlet, whilst provided in practically all types of apparatus, is scarcely used inasmuch that the sensible heat from the carburetter is usually sufficient to maintain the temperature of this chamber, and it is only necessary to use the valve when starting a set after being shut down for repairs. On leaving the fixing chamber, the blast gases enter into the atmosphere through the stack or through a waste heat boiler for the generation of steam, and the carburetted water gas during the run passes through the off-take to the wash box, which prevents the gas from returning when the stack valve is reopened, and then to the scrubbing and condensing plant.

Oil Spray.

In injecting the oil into the carburetter it is of great importance that it is distributed over the surface of the checkerbrick as evenly as possible, as a straight injection is the cause of dead holes down the center of the carburetter where the oil enters, and a variety of devices have been used to distribute the oil evenly. One form of injector which the writer has found to give good results is shown in Fig. 7, and consists of a spray

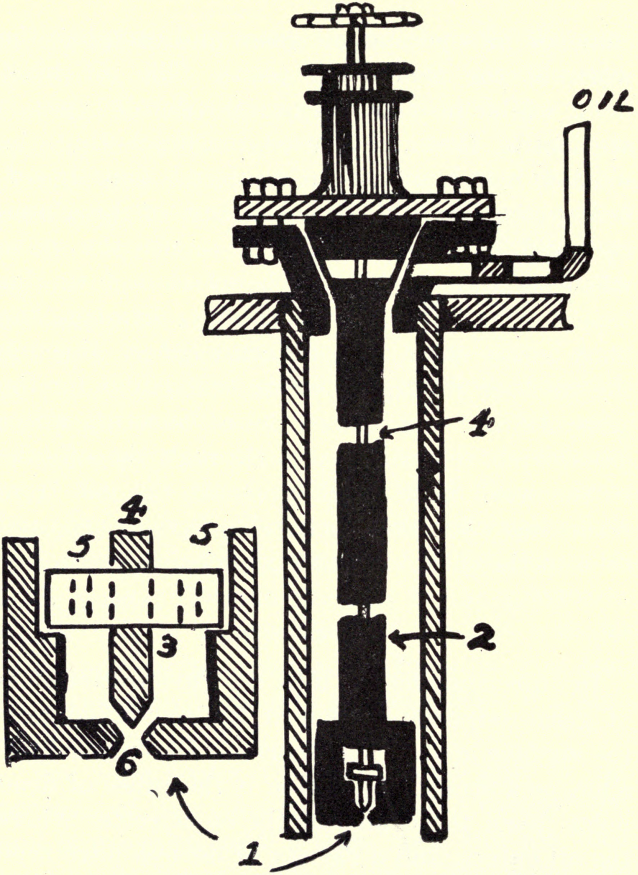


Fig 7

nozzle 1, which threads on a wrought iron pipe 2, and contains a disc 3, through which the valve rod 4 passes. The disc contains a series of small holes 5, and the spray nozzle and valve rod form a tapered joint 6, which produces a very fine injection. A protecting shield which threads in the head of the carburetter is also provided, and the spray can be readily moved for inspection by means of the nuts. These sprays are made in various sizes to atomize a certain number of gallons per minute, and the specified number can be adjusted by means of the hand wheel.

PYROMETERS.

The most commonly used pyrometers in the manufacture of water gas is the thermo-electric type, which depend for their action on the fact than when two metals in contact are heated and the cool end connected by a wire an electric current is generated in proportion to the temperature of the heated contact. The metals employed usually consist of platinum and platinum-rodium, which are fused together at one end and connected at the other end to suitable indicating and recording gauges. These pyrometers are usually placed in the bottom of the carburetter and top of superheater, and are protected by a shield of wrought iron. The indicating gauge is placed on the operating floor to guide the gasmaker in his work, and the recording gauge is

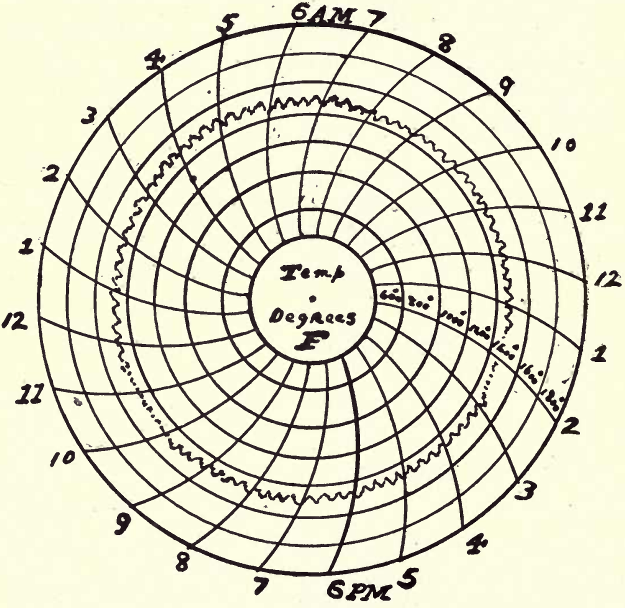


Fig 8

placed in the engineer's or superintendent's office to enable the temperatures of the machine to be ascertained at any time without leaving the office. As previously shown, the heats of the machine alternate with the blasting and gasmaking period, and a recording chart of an efficient gasmaker would appear as illustrated in Fig. 8, in which the high heat represents the beginning of the run, and the low heat the beginning of the blow.

Washing, Scrubbing, and Condensing Plant.

After the carburetted water gas leaves the superheater it passes through the off-take pipe to the wash-box or seal, where a considerable amount of tar is deposited. This vessel usually consists of a cylindrical tank into which a stream of water is constantly passed to maintain a constant level in the box, and thereby prevent the gases from returning when the stack valve is opened. The mixture of tar and water is led from the wash-box at the overflow into a seal pot, from which it flows to a well or tar separator, and the gases pass up a hot scrubber and through a condenser to a relief holder. In Fig. 9 is shown one type of scrubber which is frequently used, and consists of a cylindrical tower filled with coke or layers of wooden trays, which break up the gas into fine streams as it passes upwards, and brings it in contact with hot water constantly passing down, which has the effect of removing more tar and suspended oils. These

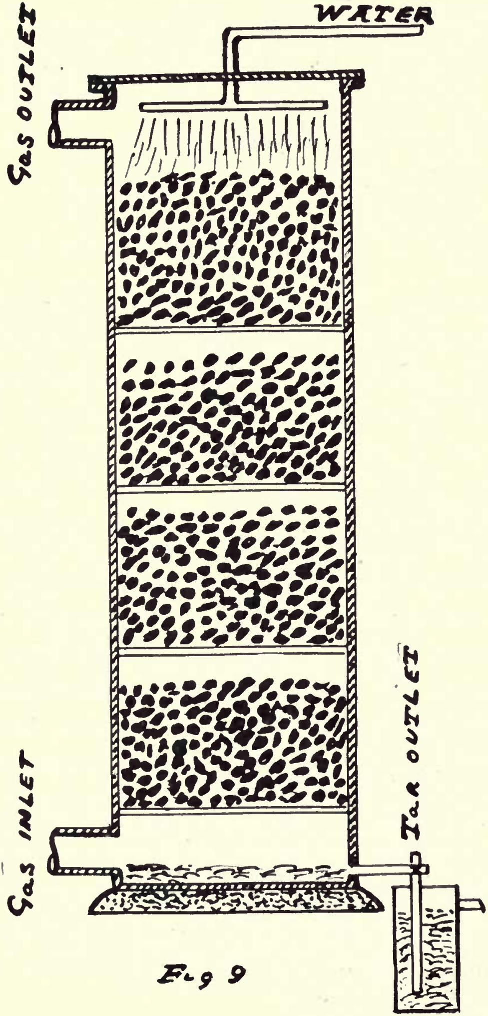


Fig 9

apparatus are provided with separate compartments, each of which are provided with large manholes for easy access whereby the filling of any one compartment may be removed without disturbing the contents of the remaining compartments. On leaving this tower the gas passes to a condenser, which is generally of the multitublar water cooled type, where more tar is dropped, after which the gas passes to a relief holder and treated further in other scrubbing and purifying plant.

Lining and Repairs.

When a water gas apparatus has been run for a certain period, it is necessary to let it down for repairs to generator lining and renewing the checkerbrick in the carburetter and superheater. This period varies according to condition and the engineer's opinion, but in a general way may be taken at 1,000 hours. In letting down the machine, however, the temperature should be allowed to lower gradually to prevent rapid contraction, and it is best to kill the generator fire slowly with steam before drawing it, and allowing cold air to enter a hot machine. When the set has finally cooled off a careful examination should be made of the inner firebrick lining of the generator, particularly around the cleaning doors, where it usually wears out quickly, and the necessary repairs made with a very close joint, using as little fireclay as possible between the bricks. The doors are generally built up with arches and blocks over a cast iron sleeve, and in such a manner as to enable the sleeve to be removed when it burns out and replaced with a new one from the exterior of the machine. Special care should also be given to the brick work around the charging door, as these are liable to be knocked out by bars and shovels when clinkering and charging, and one crevice may let down more bricks and cause the neck casting to be burned or cracked.

It is then necessary to give some attention to the carburetter and superheater, which requires a renewal or cleaning of the checkerbrick. In the injection of oil into the carburetter practically no design of spray reach their maximum efficiency and the brick at the top of the chamber where the oil enters are generally coated with lampblack or splintered by the force of the injection. In any case the brickwork becomes more or less saturated with oil, which burns to carbon and finally does not take up and give out the heat necessary for the economical working of the plant, and all the checkerwork should be removed by way of manhole doors provided and

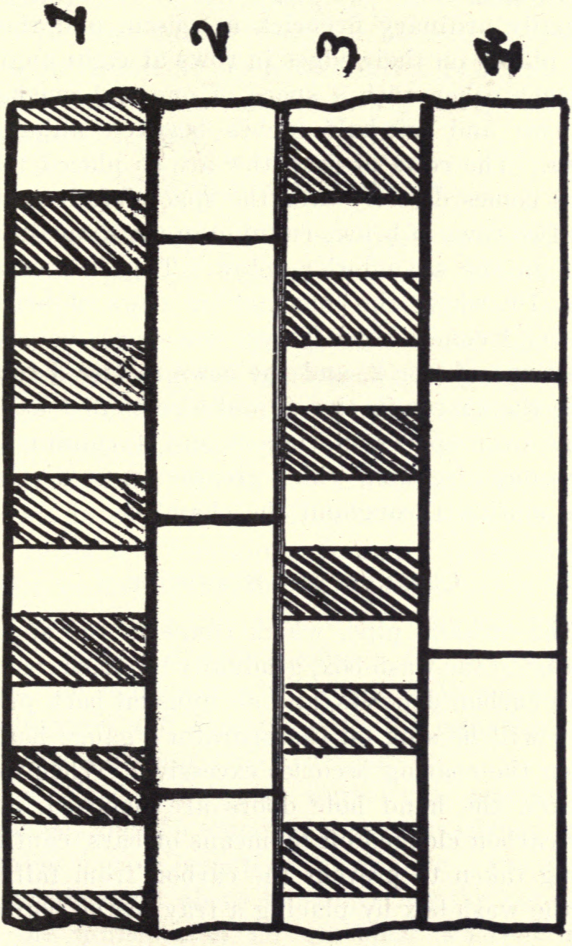


Fig. 10

thoroughly cleaned or replaced with new bricks. Usually ordinary firebrick are used, and these are placed on their edges in rows at right angles to each other with a space of one and one-half to two and one-half inches between adjacent rows. The rows of each tier are so placed that each comes directly over the space left between the two rows of bricks running in the same direction in the second tier below. This is seen in Fig. 10, where the longitudinal rows of bricks in tier 1 comes directly over the spaces between the rows of tier 2, and the rows in tier 3 come over the spaces in tier 4, and also tiers 1 and 2 come over spaces in tiers 3 and 4 running in the same direction, which give the gases a wave-like motion throughout the chamber.

Cleaning the Standpipe.

The off-take pipe, which connects the super-heater to the wash-box, gradually becomes coated with carbon deposits, and an unusual back pressure will be seen on the operator's gauge board when the coating becomes excessive. When this occurs, the hand hole doors are removed, and the carbon cleaned off by means of bars, caution being taken to prevent the carbon from falling in the wash-box by placing a tray in the bottom cleaning door of the standpipe. It is also necessary to clean out the wash-box occasionally, and it is advisable to open the outlet valve at the bottom and wash out the heavy tarry matter about once a week.

Chemical Observations.

Water is composed of two parts of hydrogen and one part of oxygen, and the process of obtaining gases by the decomposition of water vapor or steam is known as the "Water Gas Process" in view of the fact that three-fifths of its weight and three-fourths of its bulk consists of the hydrogen and oxygen which previously constituted water H_2O. It has been repeatedly proven in chemical research that steam can not be broken into its component parts by the direct action of heat alone, but when subjected to high temperatures in the presence of reducing agents which have a stronger affinity for the oxygen than the hydrogen with which it is combined, the oxygen will combine with the reducing element and liberate free hydrogen.

On this theory the water gas process is founded, and the reducing element is carbon containing matter, usually coal or coke. The reaction is brought about by subjecting the hot fuel to the influence of an air blast whereby the oxygen of the air combines with the carbon of the fuel to form carbon monoxide (CO) or carbon dioxide (CO_2) according to the proportion of oxygen available. The combination of the carbon and oxygen may occur in different proportions to form different gases, according to the following conditions.

In the presence of an excess of oxygen burning carbon saturates itself with two atomic proportions of oxygen, and forms the gas CO_2. This reaction is exothermic and completes the combustion of the carbon with the evolution of 14,500 British Thermal Units (B. T. U.) per pound of carbon, taking two and two-third pounds of oxygen and forming three and two-third pounds of carbon dioxide. This reaction being complete is known as the first law of combustion.

In the second law of combustion the supply of oxygen is insufficient to completely saturate the carbon, and the excess carbon will partially satisfy its affinity for oxygen by combining with one atomic proportion or robbing saturated carbon of one of its oxygen atoms, for instance, carbon dioxide passing through heated carbon will be reduced to carbon monoxide, as follows: $CO_2+C=2CO$, with an absorbing of 5,880 B. T. U. per pound of carbon.

If the carbon monoxide is then brought in contact with an excess of oxygen, the third law of combustion takes place to carbon dioxide with an evolution of 10,190 B. T. U. per pound of carbon. In the above it is seen, then, that in the first law of combustion one pound of carbon takes up two and two-third pounds of oxygen, and forms three and two-third pounds of carbon dioxide with an evolution of 14,500 B. T. U. In the second law the CO_2 is reduced by the second pound of carbon with an absorbing of 5,880 B. T. U., resulting in the formation of four and two-third pounds of carbon monoxide with the total evolution of 8,620 B. T. U. In the third law the CO takes up another atomic proportion of oxygen and produces complete combustion with the evolution of 20,380 B. T. U. and the formation of seven and one-third pounds of carbon dioxide, which makes the total heat evolved from two pounds of carbon as 29,000 B. T. U.

In the elementary study of the carburetted water gas process in this chapter, it has been seen that a blast of air is first admitted to the generator when the excess of oxygen combines with carbon and the first law of combustion takes place. The CO_2 gases thus formed then pass up the bed of fuel in an excess of carbon when the gases are reduced to CO, which constitutes the second law, and these are passed to the carburetter to be met by another blast of air when the third law of combustion takes place and completes the heating period of the process. In the decomposition of the steam in the gas-making period there is absorbed 4,340 B. T. U. per pound of carbon, which generates approximately 62 cubic feet of gas with a calorific value of approximately 300 B. T. U. The value of this gas, however, is too low for domestic purposes, and the purpose of the carburetter is, therefore, to generate gas of high illuminating value and thereby enrich the blue water gas. The composition of the oil gases may vary with different conditions and qualities, and a typical analyses before and after enrichment is as follows:

	Blue Water Gas.	Carburetted Water Gas.	
Hydrogen (H)	51.00	30.40	per cent.
Methane (CH_4)	0.50	16.90	"
Hydrocarbons	0.00	7.25	"
Carbon monoxide	40.00	29.00	"
Carbon dioxide	5.50	2.05	"
Oxygen (O)	0.00	0.20	"
Nitrogen (N)	3.00	5.10	"

The consumption of fuel coincident with these figures will be about 35 pounds of coke and 3.33 gallons of oil per 1,000 cubic feet of gas, with a candle power of 20 or heating value of 580 B. T. U.

CHAPTER III.

Standard Double Superheater.

Up and Down Runs.

In the preceding chapter the reader has been led into the elements of the internal combustion or intermittent system, and it will now be to advantage to illustrate a standard type of machine in which modern methods are employed. The following descriptions are not confined to any one particular plant, but embodies the most interesting features of various designs. In the early developments of the intermittent process the steam used in the generator always entered beneath the grate and passed upward through the fuel bed to the carburetter. This, however, resulted in the lower part of the fire being cooled considerably, and a down or reverse run was occasionally adopted to overcome this difficulty. After continued application of the down run it was found that it had several effects on the fuel bed, the foremost of which may be summarized as follows:

(1) It reduced labor in clinkering and in picking out comparatively large proportion of unburnt coke.

(2) It effected a saving in fuel by burning small coke that otherwise fell through the grate bars.

(3) It made it possible to vary the height of the zone of intense combustion, and allow the use of a wider range of fuels.

(4) It enables the temperature at the top of the fire to be better controlled, and consequently a better control in temperatures in the carburetter and superheater.

In the early attempts the down runs were made about once in every six, but this has been increased to one in every three or less, according to the nature of the fuel used. In the up run the gases leave the generator at the top, and in the down run at the bottom, each outlet being controlled by valves which are linked together so that one opens when the other closes. The top valve is generally known as the hot valve, in view of the fact that burning gases pass through it during the air-blasting period, and it was until recent years necessary to water cool it to pre-

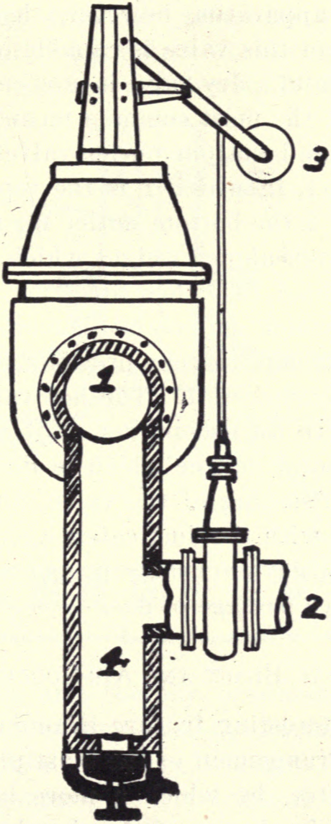


Fig 11

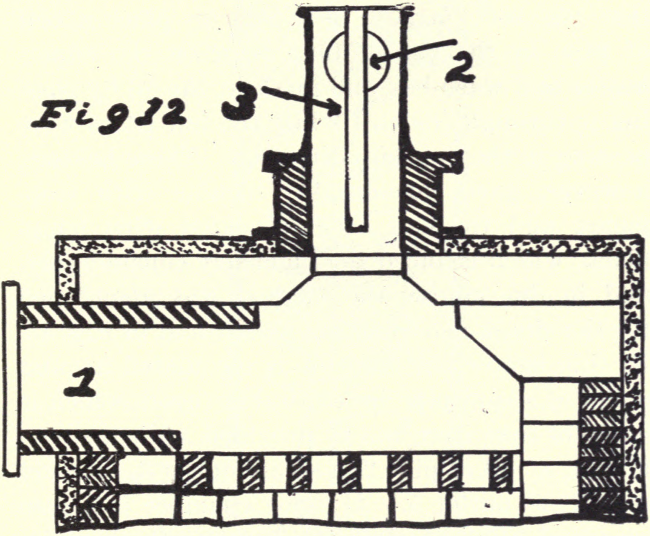
vent overheating and eventual cracking. In modern apparatus, however, the metallic composition of this valve is capable of withstanding the heat and a dry valve is now employed.

One of the most common means of connecting the top and bottom outlet valves is illustrated in Fig. 11, in which 1 is the top outlet for the up runs, 2 the bottom outlet for the down runs, 3 a counterbalance weight which serve to equalize the load in either direction, and 4 a dust catcher which collects solid matter carried over in the gas, and thereby prevents such from entering the carburetter. The hot valve is also provided with an ash pocket (not shown) for collecting solid matter which is liable to interfere with the seating of the valve, and this, in conjunction with the dust catcher, should be cleared every few days to ensure proper seating of valves and a free passage of gas.

Central Blast and Air-Cooled Oil Spray.

An interesting feature in one design of plant is the arrangement of the blast pipe entering the carburetter, by which a more uniform heat is obtained in the top of the chamber, and also has the effect of keeping the oil spray cool during the blasting period when oil is not being passed through it. In this arrangement Fig. 12, the blast gases come from the generator at 1, and the secondary air blast enters the carburetter at 2, which effects combustion directly in the center

Fig 12



of the chamber, and thereby produces a more even distribution of heat over the surface of the checkerbrick. The oil spray 3 is also kept cool by this arrangement, as combustion does not take place until the secondary air meets the blast gases in the top of the carburetter.

Oil Heater.

In certain climates it is advisable to heat the oil before passing it into the machine, and this has been done in various ways. One method that has been largely used was to place a coil of pipe in the gas off-take between the superheater and wash-box and pre-heat the oil by passing it through the coil while the hot gases were passing in the opposite direction. These heaters, however, gave considerable trouble with stoppages, and the coil became coated with lampblack, which reduced the efficiency considerably, and in due course the method was abandoned for the simple modification illustrated in Fig. 13. In this heater the cold oil is circulated around a coil of steam pipe in a suitable vessel, which is made of cast iron and is provided with a steam inlet 1, a coil of pipe 2, a steam outlet 3, oil inlet 4, and oil outlet 5. A vapor chamber 6 is also provided at the top of the heater, which maintains a constant pressure on the hot oil line by minimizing the pulsations of the oil pump. Previous to entering the heater the oil is measured cold by passing through a meter, and the steam condensed by passing through the coil of pipe is led to a steam trap.

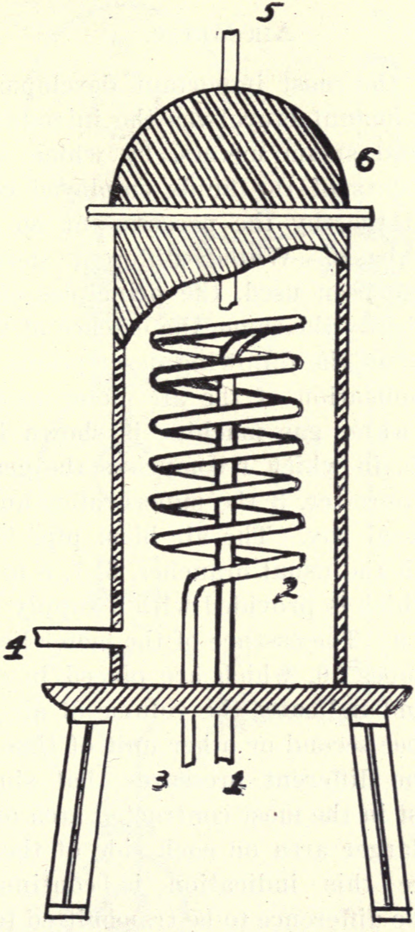


Fig 13

Air Meter.

One of the most important developments in water gas manufacture was the introduction of the air and steam meters, by which accurate measurements of the fluids employed could be made and thereby the process put on a more scientific basis. Whilst different designs of meter have been used, the principles employed are practically the same, the essence of which is illustrated in the following descriptions.

The application of the air meter to the carburetted water gas machine is shown in Figs. 14 and 15, in which 1 comprises the generator, 2 the carburetter, 3 the superheater, and 4 the wash or seal box. The air blast pipe 5 is provided with the usual branches, 6, 7, 8 to 1, 2, 3, each of which is provided with a supply regulating valve 9. The essence of the meter lies in the venturi tubes 10, which are placed in each air supply, and indicates the volume of air passing through per second or other unit of time by reason of the different pressures that simultaneously exist in the most contracted area or throat and the larger area on each side of the throat, and since this indication is continuous, it enables the difference to be transmitted to a suitable indicating gauge. It is now a well estab-

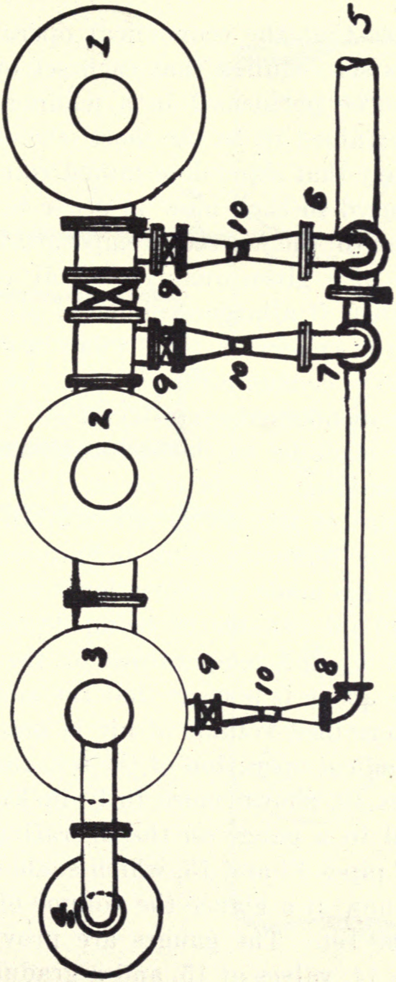


Fig 14

lished fact that the economical operation of a water gas set requires that each set of the process must be performed in a manner that has been ascertained to be the most efficient, and it is necessary that a pre-determined volume of air is introduced in each blow in order to raise the apparatus to the correct temperature for the reception of a given quantity of oil and steam. For instance, if a larger volume of air is passed through the generator than what is needed, an unnecessary consumption of fuel will result, whilst an insufficient quantity of air will fail to raise the machine to the required temperature for gas making. It is evident, then, that the temperature of the set is substantially proportional to the quantity of air introduced, and the volume of gas made is proportional to amount of steam and oil capable of being decomposed or vaporized by the temperature of the machine. From the above it is clear that the admission of a pre-determined volume of air is necessary for the economical operation of the set, and the venturi tubes 10, shown more fully in Fig. 15, are connected to a gauge on the operating floor by means of pipes 12 and 13, which enable the operator to know at a glance the volume of air passing to the set. The gauges are provided with pet cocks 14, valves at 15, and a graduated scale

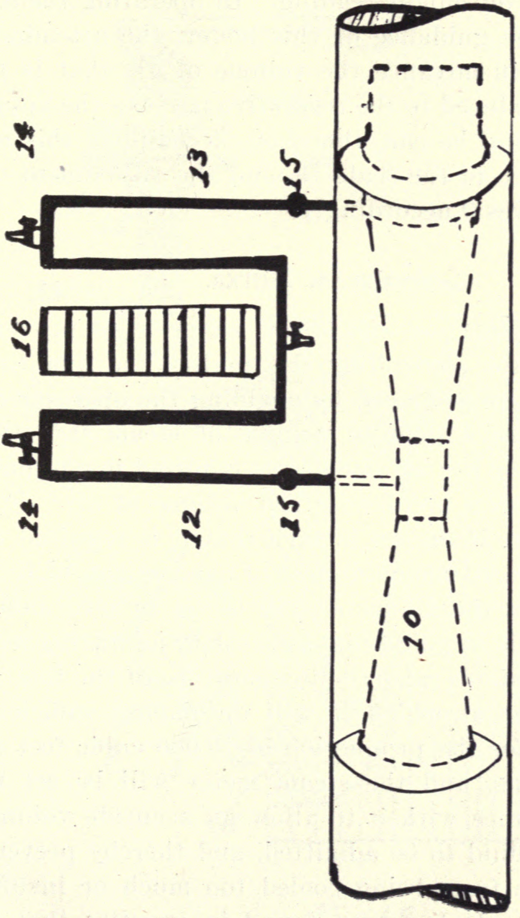


Fig 15

16 for convenient reading. In operating the set with the guidance of this meter, the attendant knows in advance the volume of air that is to be introduced to the respective parts of the apparatus, and he can, therefore, accomplish this by reference to the scale 16, and the adjustment of the valves 9 accordingly.

Steam Meter.

The object of the steam meter is to provide means for controlling the quality and quantity of the gas produced by enabling the operator to introduce a definite volume of steam into the generator per volume of gas required in conjunction with a pre-determined volume of air. For instance, if the set is such that it is required to generate 10,000 cubic feet of gas per run of four minutes, the air meter will be set in accordance with this to guide the operator in admitting sufficient air to raise the temperature of the fuel to a degree at which it will decompose sufficient steam for the production of 10,000 cubic feet of fixed gas, and the steam meter will be set in accordance with it to allow an accurate volume of the fluid to be admitted, and thereby prevent the fire from being cooled too much or insufficiently. It has been found in practice that it

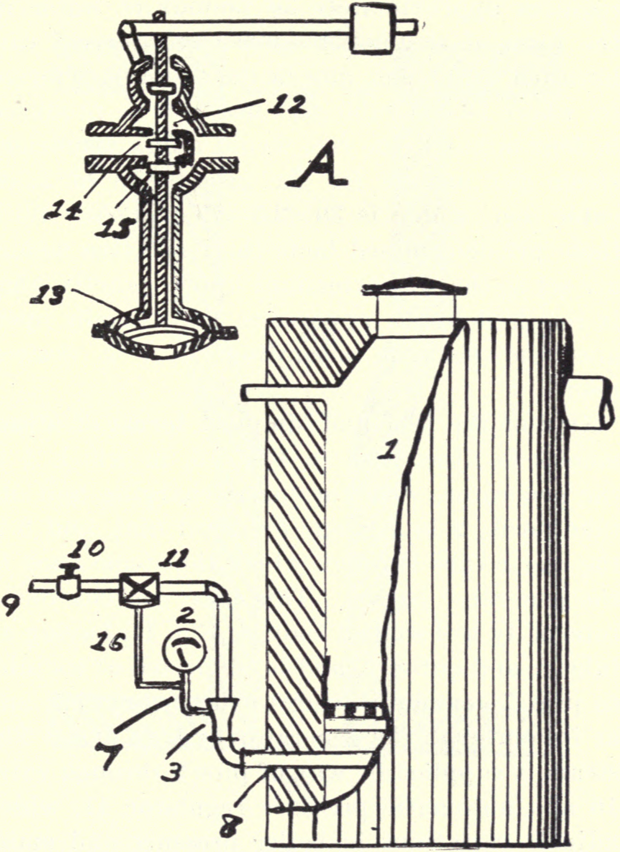


Fig 16

requires approximately 30 pounds of water in the form of steam per 1,000 cubic feet of carburetted water gas, and in the example referred to, where 10,000 cubic feet needs to be produced in four minutes, the fuel would require sufficient steam per minute for the production of 2,500 cubic feet, which is 30×2.5=75 pounds. With these pre-determined facts the respective meters are set so that the attendant knows exactly what is required in the apparatus, and thereby operates the machine accordingly for a desired result.

One of the best and simplest forms of steam meters is illustrated in Fig. 16, in which 1 is the generator, with the usual charging and off-take ports, 2 is a gauge or metal dial, and 3 is the meter tube through which the steam used in the generator passes. This tube consists of an internally bell shaped body, 4, Fig. 17, having an inlet 5, and outlet 6, and is connected at its inlet to pipe 7 communicating to the meter dial, and at its outlet to the generator by way of 8. The steam is supplied by way of pipe 9 through valve 10 and automatic pressure regulator 11, which adjusts variations in boiler pressure and maintains a constant pressure at the meter tube. The regulator may be of various design, and a convenient one as shown at A, Fig. 16, consists of

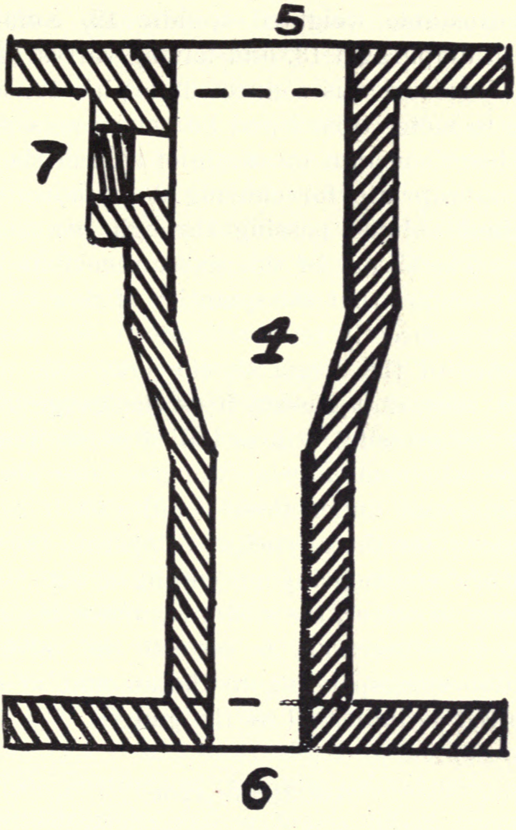


Fig 17

an adjustable weighted spindle 12, connected with a diaphragm 13, and having valves 14 and 15. This device is connected to pipe 16, which leads to meter tube 3 and keeps the pressure of the steam constant on the inlet side of the tube and appropriate for causing 2 to indicate the required volume passing through per unit of time. The theory of this measurement is based upon the fact that the quantity of flow through tube 3 is directly proportionate to the absolute pressure of the steam on the inlet side of the meter tube, and inasmuch as the gauge 2 indicates the pressure, it also indicates the quantity of flow of steam entering the generator per unit of time, and under these conditions it is only necessary for the attendant to operate the valve 10 when commencing or ending a run. Occasionally, however, the steam regulator is omitted when it is necessary to operate the valve to a position corresponding to the amount of steam required as indicated by the gauge.

Air Regulator.

One of the latest developments in the progress of water gas manufacture is the air regulator, the object of which is to automatically increase the quantity of air supplied for the combustion of carbon monoxide to carbon dioxide in the carburetter as the quantity of the former gas increases. In the heating or air blasting period of the apparatus the composition of the gases given off from the generator varies during different portions of the blow whilst the fuel is being raised to its highest state of incandescence, and invariably gives off a greater proportion of combustible gas as the temperature continues to rise and liberates carbon more rapidly. Under the average conditions it has been found that the percentages of carbon monoxide in the producer gases from the generator varies from 5.00 per cent. after 25 seconds of blasting to 20.00 per cent. after 200 seconds of blasting, and in order to effect complete combustion of the gas it is evident that the quantity of air admitted to the carburetter needs to increase in accordance with the increase of combustible matter, whilst, at the same time, an uncalculated increase, such as raising the valve at intervals, is liable to cause an excess of air to be admitted at certain portions of the blow, and thereby cool the checkerbricks and seriously affect the economical operation of the plant.

An interesting and simple device used for the purpose of controlling the necessary quantity of air is illustrated in Fig. 18, in which 1 is the

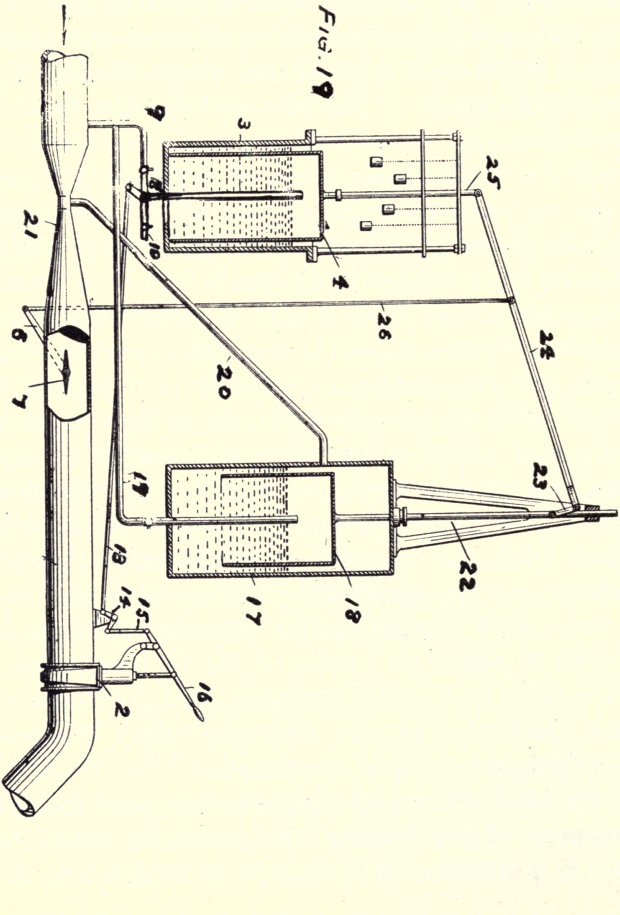


Fig. 19

secondary air line leading to the carburetter, and is provided with valve 2, which is connected by links and levers to operating mechanism on holder 3. The holder is provided with a bell 4, connected by rope 5 to the operating handle 6 of a damper 7, arranged in the air line 1. The interior of the bell is connected by means of a three-way cock 8 to a pipe 9, which leads to the air line or to pipe 10, which leads to the atmosphere, each branch being provided with regulating cocks 11. A counterweight for the damper 7 is provided at 12, and the three-way valve is connected to valve 2 by means of link 13, bell crank 14, link 15, and handle 16, so that the operation of valve 2 will also operate the three-way valve 8. In the run of gas when the gate valve 2 is closed the position of the three-way cock is such that the bell 4 is in communication with the air line 1, which results in the bell being raised to the stops as indicated by dotted lines, and simultaneously causes the counterweight 12 to close the damper 7 by means of the lever 6. At the end of the run of gas the generator air blast is opened, and a few seconds later the carburetter blast valve 2 is opened, which in turn operates the cock 8 so that the bell is put in communication with the atmosphere by way of pipe 10, which causes air to gradually escape and the bell to descend. This movement actuates the damper 7 and automatically increases the supply of air through valve 2 into the carburetter simultaneously with the increase in temperature of the fuel bed in the generator, and subsequent decomposition of the fuel more rapidly. The speed of descent of the bell can be varied by the adjustment of the cock 11 on line 10, and where it is desired, weights are provided which suspend at various heights from the top frame of the holder and rest on the bell throughout a desired portion of its travel and increase the rate of movement accordingly.

A slight modification of this arrangement is illustrated in Fig. 19, in which an additional holder 17 and bell 18 is provided, and has inlet connections 19 to pipe 9 and outlet 20 to the throat of a meter 21 interposed in the blast line. The stem 22 of the holder 18 is connected by a short link 23 with one end of the floating lever 24, which leads to the stem 25 of bell 4 in holder 3, and a link 26 connected with lever 14 is in communication with arm 6 of damper 7. In the operation of this arrangement the bell 4 is in its raised position at the beginning of the blow and the bell 18 in its lowest position, and on opening the blast valve 2 the three-way cock 8 is operated so that the bell 4 descends and opens

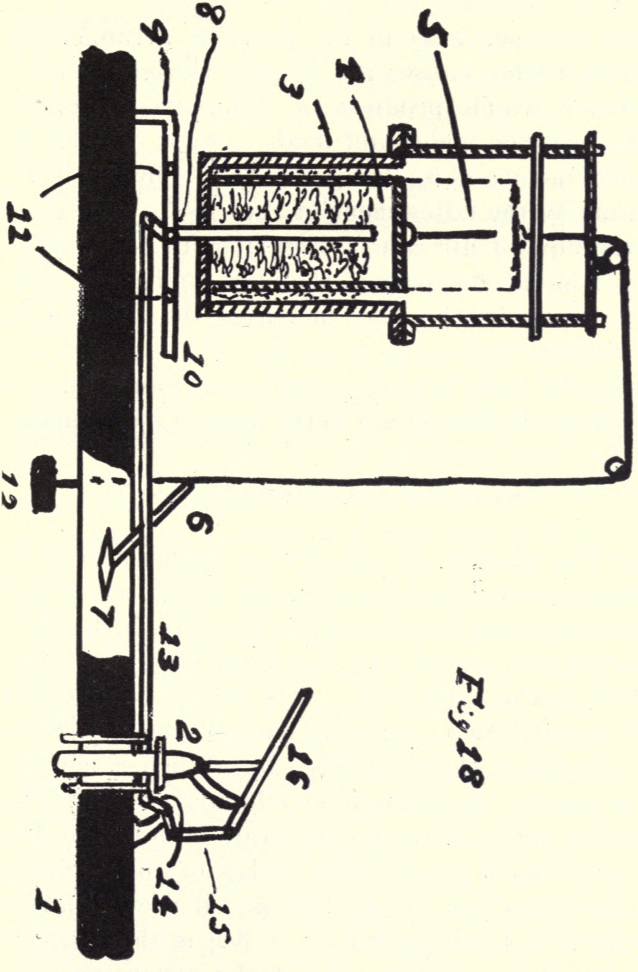


Fig 18

the damper 7 as in the previous arrangement. This action causes air to pass through venturi meter which produces a differential pressure across such meter and tends to raise the bell 18, and in turn close damper 7. It is obvious, then, that by the adjustment of these bells and levers the flow of air can be regulated to any desired portion at any part of the blow, and if the blast pressure in the line increases the differential pressure across the meter will also increase and thereby raise the bell 18 and close damper 7 and reduce the flow of air to the normal requirement.

Starting and Working a Set.

The purpose of the double superheater is to increase the contact surface in fixing the oil, and also to carry the blast gases away from the operating floor and thereby minimize the risk of danger to the attendant. This form of apparatus is erected by a number of makers, and a common example is shown in Fig. 20. When a new set is put in operation it should first be carefully dried out by covering the grate bars of the generator with six or eight inches of coke, adding about one foot of shavings and dry wood and a portion of coal or coke. A fire is then started with the charging door of the generator open until a good body of fire has been obtained, after which the charging door may be closed and the heat allowed to pass through the machine, care being taken to effect a gradual drying by checking the draft at the ash pit doors. If the time is available it is advisable to allow two or three days in drying out a new set, although, if necessary, this period can be reduced to a few hours by careful management without injury to the plant. When the set is being dried gradually the body of fire should be kept at about two feet, and each time fuel is added care must be exercised to light the gases at the charging door before opening wide, or an explosion will result. When the shell of the carburetter is warm the machine may be put under blast, and in preparation of this the fire is charged well up and the clinkering and ash pit doors securely fastened. After the blast has been on for more than ten minutes, the bottom steam valve should be slightly opened to prevent overheating of the brickwork in the lower part of the generator, and when a flame can be seen in the top of the generator through the sight cock, the carburetter blast valve should be opened, care being taken to open only very slightly until a flame appears in the top of the chamber. The carburetter being lit off. it is then advisable to light the gas jet or pilot light at the stack valve on top of the superheater, as this serves as a guide to the attendant by igniting unburnt gases as they issue from the machine, and when a blue flame is seen at the stack valve it is necessary for the attendant to increase the supply of air in the carburetter and effect complete combustion within the machine. When the carburetter has reached a red heat it is time to look for a blue flame in the bottom of the superheater, and when such appears the superheater air blast should be raised and when ignited the carburetter blast should be lowered to allow a portion of combustible gases to be burned in the superheater. A method sometimes adopted in lighting off the superheater is for one man to pass a red hot bar or pipe through the sight cock while another man opens the air supply, but this method is not to be advised in view of the fact that the man holding the pipe is in danger of flying sparks when the gas ignites, and it is certainly not necessary to an experienced gasmaker.

After the superheater has reached a red heat, the air blasts can be cut off and a run of blue gas made by passing steam through the generator, and this should proceed by first closing the superheater air blast, then the carburetter, and finally the generator, after which the steam

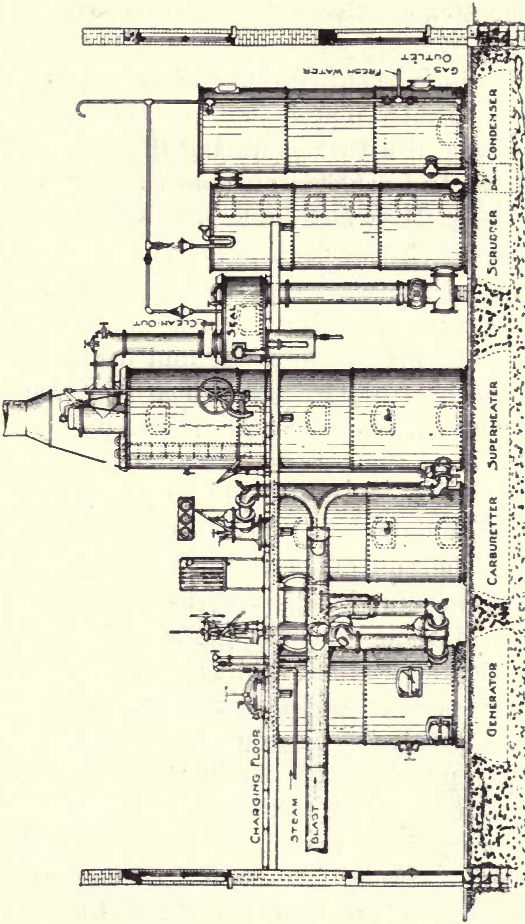

GENERATOR
CARBURETTER
SUPERHEATER
SCRUBBER
CONDENSER
SEAL
CLEAN-OUT
GAS OUTLET
FRESH WATER
CHARGING FLOOR
STEAM
BLAST

FIG. 20

valve is opened slightly, the stack valve closed, and the steam valve adjusted according to the gauge.

It may here be stated that the operator's gauge board is usually placed in a position so that it can be seen at all times during the operation of the plant, and consists of a series of water columns, Fig. 21, which indicate the pressure of the machine in inches at different parts in the order of generator 1, carburetter 2, superheater 3, and seal box 4, the highest pressure being seen on the generator gauge and decreasing in order to the seal box. The board is also provided with steam gauges or meters 5 and 6 for up and down runs, respectively, air meter 7, oil pressure gauge 8, and indicating pyrometer 9, whilst on a stand near the oil meter is placed.

When the run of gas is put on the operator should immediately observe the pressures indicated, and if an unusual pressure is seen, the steam should be immediately cut off until the cause has been ascertained, which generally may be a closed valve or an excess of condensation in the drip pot between the machine and relief holder. It is advisable to see, at this point, that water is passing through the scrubber and condenser, and special care should be taken in seeing that water is passing into the seal box before the run is taken off, or gas will return and escape into the atmosphere when the stack valve is opened. After two or three runs of blue water

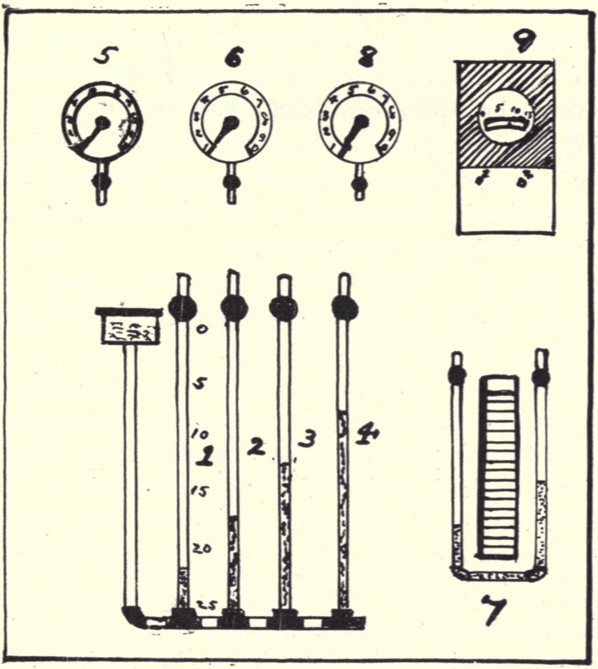


Fig 21

gas have been made the temperature of the carburetter should be high enough to break up the oil to the required extent, and on the third or fourth run the oil is admitted, when a greater pressure will be seen on the water column gauges. About one-half minute before the end of the run the oil is cut off, and the spray wiped out by passing steam through it for a few seconds. When the machine is in full working condition the operator should pay frequent attention to the nature of the overflow at the seal pot for the appearance of lampblack, which is seen when the heats are too high, or for light tars when the heats are too low.

Operating Conditions.

The length of the air blast and runs of gas depend on various conditions, such as the nature of fuel used, power of the blasting plant, quality of gas desired, and quality of fuels used. In the early stages of the internal combustion system it was customary to blast for 20 minutes or more and make runs of gas for 30 minutes, but with the development of the process the tendency has been to reduce the length of the cycle to the present day rate, which may be taken on an average of three minutes' blasting and five minutes' gasmaking, with a blast pressure of 20 inches of water on the gauge. The steam is admitted in accordance with the steam meter, whilst air is admitted to the carburetter in accordance with the differential air meter, and a pressure of about 45 pounds per square inch is kept on the oil line. The temperature of the carburetter and superheater varies, of course, with the grade of oil, and may be taken, on the average, at 1,400° F. in the carburetter, with about 100° F. less in the superheater at the beginning of the run. The gasmaker is provided with printed sheets to record the times of operation of the machine, check the oil meter at the end of each run, record the amount of fuel, and frequently record the temperatures of the carburetter and superheater. In the smaller works he has also frequently to check the reading of the station meter about every hour, and compute the amount of gas per run with the quantity of oil per 1,000 cubic feet.

CHAPTER IV.

The Vertical Apparatus.

A design of apparatus that has met with marked success is the vertical type, the most important of which is the Williamson's. In this plant the carburetter and superheater are arranged in a vertical plane with the generator, the object of which is simplicity of construction and operation, reduction of ground area, and a

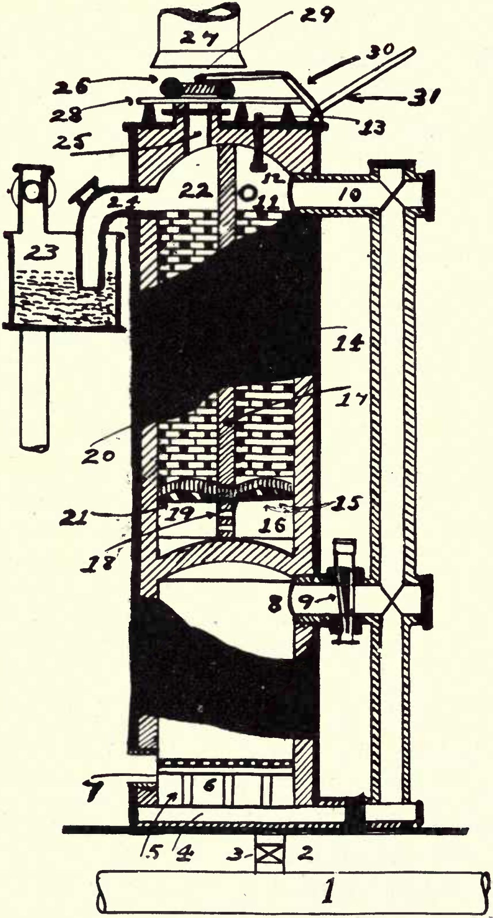

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Fig 22

more thorough uniting of vapors in the carburetter and superheater by passing through a deeper surface of checkerbrick.

In Fig. 22 is shown a sectional elevation of one form of apparatus in which 1 is the air blast line supplying pipe 2, which is provided with a valve 3, which is usually of the ordinary gate type. The pipe 2 leads into header 4, which in turn communicates with the generator by means of a series of partitions 5, each of which are provided with a series of slots for projecting jets of air into the ash box 6 beneath the grate of the generator, which rests on a cross bar 7, supported on the wall. The outlet of the generator is provided at 8 and is controlled by valve 9, which is of special construction, as described later. A connection 10 leads into the mixing chamber at the top of the carburetter, and a port 11 is provided in the said chamber for the admission of secondary air, and there is also an oil spray 12 connected to a pipe 13 through which the oil is passed. The carburetter 14 is filled with checkerbrick as in the usual manner, and has communication at its lower end through passages 15, Fig. 23, into receiving chamber 16, into which the gases descend and commingle before entering the superheater. The dividing wall 17, which separates the carburetter from

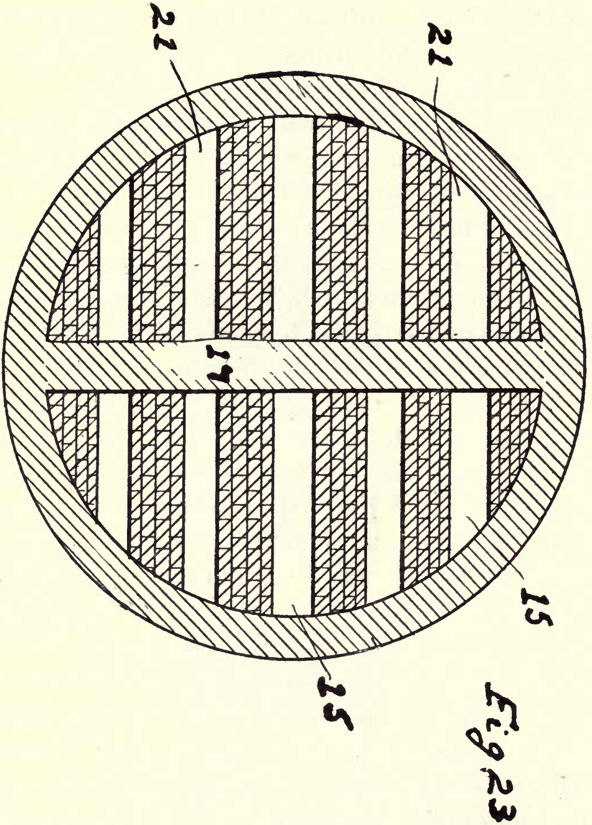


Fig 23

the superheater, extends the whole length of tne chambers, and has openings 18, which furnish communication between the receiving chamber 16 and discharge chamber 19, the latter of which leads into superheater 20 by way of passage 21. The superheater is filled with checkerbrick as in the standard type, and the fixed gases are discharged into chamber 22, which leads to seal box 23 by way of pipe 24. The shell of the carburetter and superheater is of the usual type and is a continuation of the generator shell, and is provided with a lining of firebrick or other refractory material, and is separated from the wall of the generator by means of an arch of special design. The blast gases leave the machine through passage 25 and stack valve 26, and pass into the atmosphere through the stack 27. The stack valve is mounted on wheels and rests on a track 28, supported by swinging links, the lower ends of which are mounted in pivot plates on the top binding plate of the wall of the machine. The stack valve or cap can be moved by means of levers which are connected to a pivot of one of the said links, and is actuated by a chain so that by moving the lever downwards the rails and cap are elevated, and by moving the lever upwards the rails and cap are lowered. In order to move the cap at the end of the blow and run there is provided a draw bar 29, which is pivoted to ears on the cap, and connected by links 30 with a rock shaft mounted in ears, and having connected therewith a lever 31, which is moved

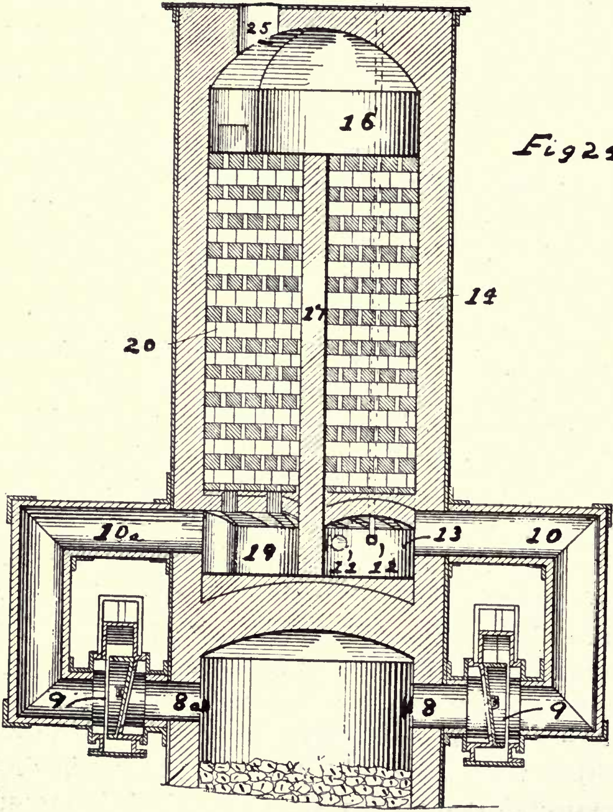


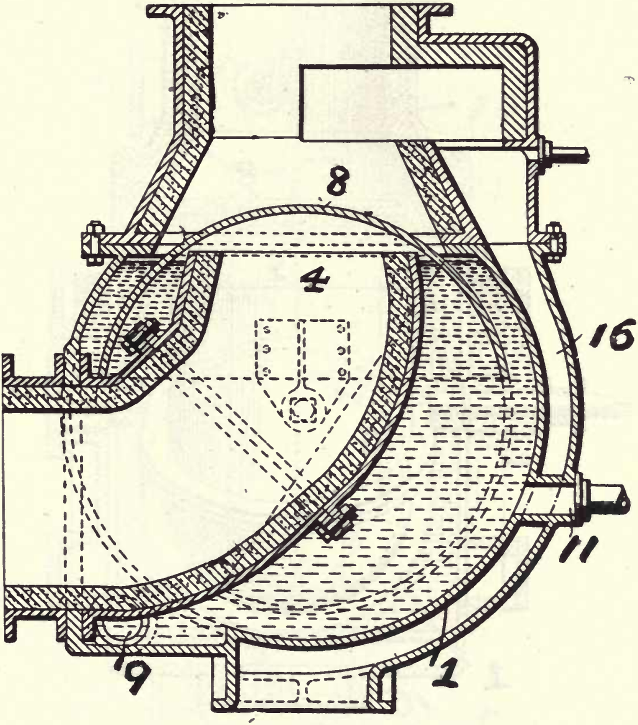
Fig 24

by a chain running over a pulley attached to a girder at the top of the building and another pulley on the operating floor. In some installations of this apparatus the construction of the carburetter and superheater is slightly modified, as illustrated in Fig. 24, where, instead of the blast gases entering the mixing chamber at the top of the carburetter, they are led through outlet pipe 8 on each side of the generator, by way of valves 9, and into chamber 13 on one side of the apparatus and chamber 19 on the other side, the said chambers in this design being separated entirely by a solid wall 17. The chamber 13 constitutes the mixing chamber for the oil and water gas, and leads to carburetter 14 and receiving chamber 16, and down superheater 20, which is in communication with chamber 19, from which the gas passes to a seal box. The operation of this design is the same as in the previous arrangement, but different in the flow of gas in that the carburetted water gas passes up the carburetter and down the superheater, and the blast gases pass up both chambers 14 and 20 through valves 9 simultaneously, and out of the stack by way of 25. At the end of the blasting period the pipe 8a, which leads to 10a, is closed, which causes the water gas to pass off by way of 8 and 10 and up the carburetter and down superheater.

Water Sealed Valve.

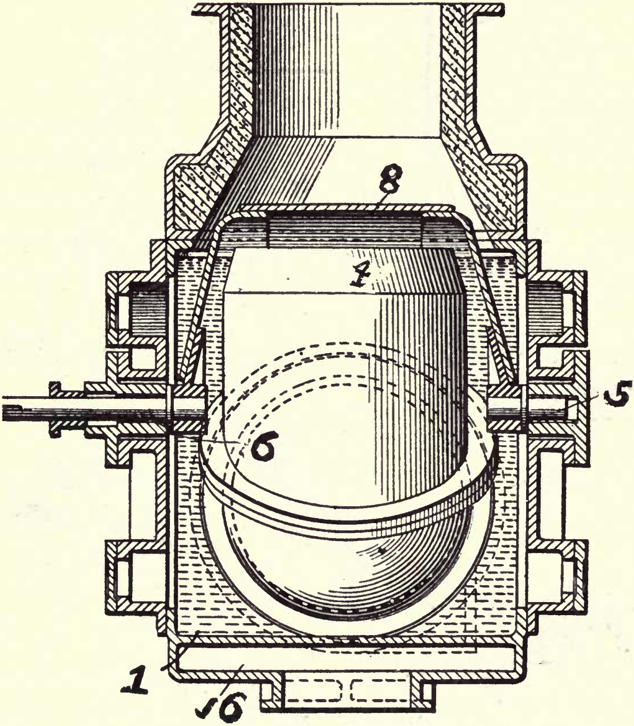
A novel feature in this apparatus is the construction and arrangement of the outlet valve from the generator, which is frequently known as the hot valve, in view of the fact that burning gases pass through it on the way to the carburetter. Briefly, the valve shown in connection with Figs. 22 and 24 consists of an inclined plate and a peripheral rim with a seating face on the solid plate which coacts with a seating face around the pipe, and is located in a casing of ordinary construction, which may be water-cooled if desired. However, in the later developments of this apparatus a specially designed valve has been adopted, which is illustrated in Figs. 25 and 26, in which 1 is the outer casing communicating with the adjacent ends of pipes 2 and 3, Fig. 27, which leads from generator to carburetter. This casing is of spherical shape, and through its wall the nozzle 4 extends upwardly, as shown in Fig. 25. In the opposite walls of the casing and extending inwardly therefrom are stub shafts 5 and 6, the latter of which is connected with a lever 7, Fig. 27, and

Fig. 25



secured to the inner ends of the shafts 5 and 6 is a hood 8 of semi-circular shape in longitudinal cross-section, which is adapted to swing into and out of the position in which it extends over

Fig. 26



the open ends of the nozzle 4. The casing 1 provides a receptacle for water, which enters at 9 and overflows therefrom through a pipe 10, communicating with the casing at 11, and the upper

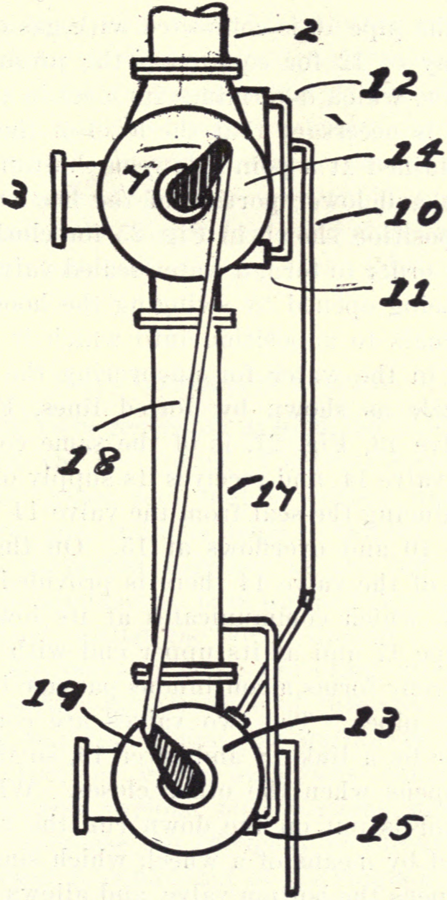


Fig 27

end of the pipe 10 is connected with gas off-take 2 by way of 12 for equalizing the pressure on the water, which determines its level in the casing. It is necessary that the level of the water is maintained at a point between the top of the nozzle 4 and lower portion of the hood 8 when in the position shown in Fig. 25 for closing the valve in order to form a water sealed valve capable of being opened by swinging the hood upon its journals to a position into which it is submerged in the water for uncovering the top of the nozzle as shown by dotted lines, Fig. 25. The valve 13, Fig. 27, is of the same construction as valve 14, and receives its supply of water for producing the seal from the valve 14 by way of pipe 10 and overflows at 15. On the outer surface of the valve 14 there is provided a passage 16, which communicates at its lower end with pipe 17 and at its upper end with pipe 2, and thereby forms a continuous passage between the two pipes. The two valves are connected together by a link 18 and lever 19, so that one valve opens when the other closes. When the generator is put on the down run the valve 14 is closed by means of a wheel, which simultaneously opens the bottom valve, and allows the gas to pass upward to pipe 2 by way of passage 16 into the carburetter. The nozzle 4 of the upper valve is lined with firebrick or other refractory material to prevent rapid deterioration by the burning gases during the blasting period, and it is obvious that the hood or valve proper 8 moves in a water seal and prevents the wearing of metal, which is usually very rapid under the influence of the intense heat, and simultaneously insures a substantially gas tight joint.

CHAPTER V.

Twin Generator Systems.

In the twin-generator system the object is to minimize the percentage of carbon monoxide in the blast gases, and that of carbon dioxide in the water gas, and it is usual to employ two generators connected together at the bottom and allow the air blast to pass upward through them in parallel, whilst the steam during the run is passed up one and down the other alternately. In the earlier installations of this system, however, it was found that the output of gas per square foot of grate area was considerably reduced, and various modifications have been tried to increase the efficiency of the system in this respect to equal that of the single generator system.

CONVERTIBLE APPARATUS.

One design of apparatus possessing a number of advantages over any previous attempts consists of two generators connected by a common bottom, in which the gasmaking steam in proper proportions is passed simultaneously either all upward or downward, or serially in either direction, supplemented by steam for the second generator. The object of this design is to enable the plant to be worked on the single generator system, and simultaneously obtain the advantages of the twin system, according to the will of the operator, and the valve mechanism and link motion is such that the plant can be changed automatically from the single to the twin system by the movement of a single lever.

In Fig. 28 the generators 1 and 2 are connected by a conduit 3, which is provided with an optional gas outlet 4, Fig. 29, controlled by valve 5, in addition to the outlet pipes and valves 6 and 7, and 6′ and 7′. The valves 7 and 7′ are actuated by levers 8 and 8′, Fig. 30, which are connected to shafts 9 and 9′ by arms and links 10 and 10′. These shafts are coupled together and connected to valve 5 by means of yoke 11 and link 12. The lever 8″ is operatively connected by link 13 to clutch 14, whose members

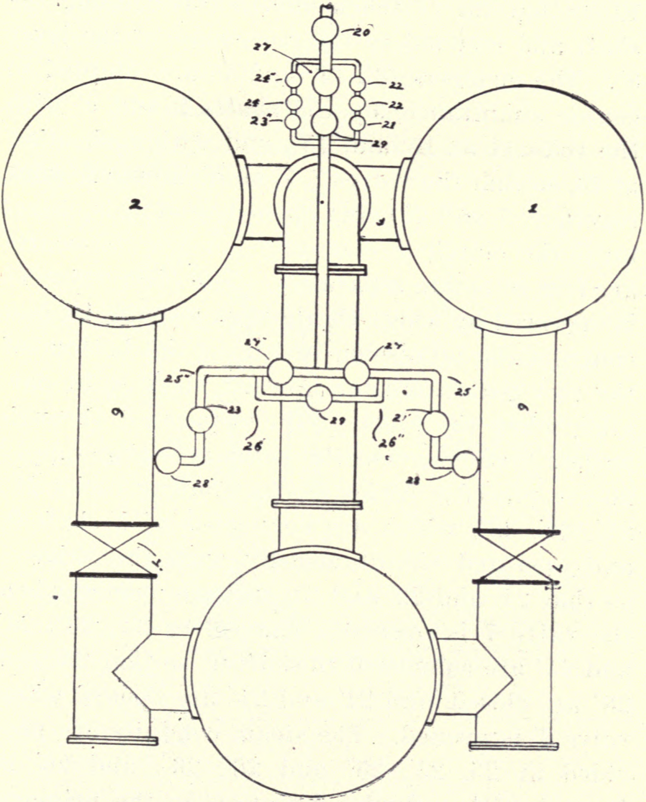
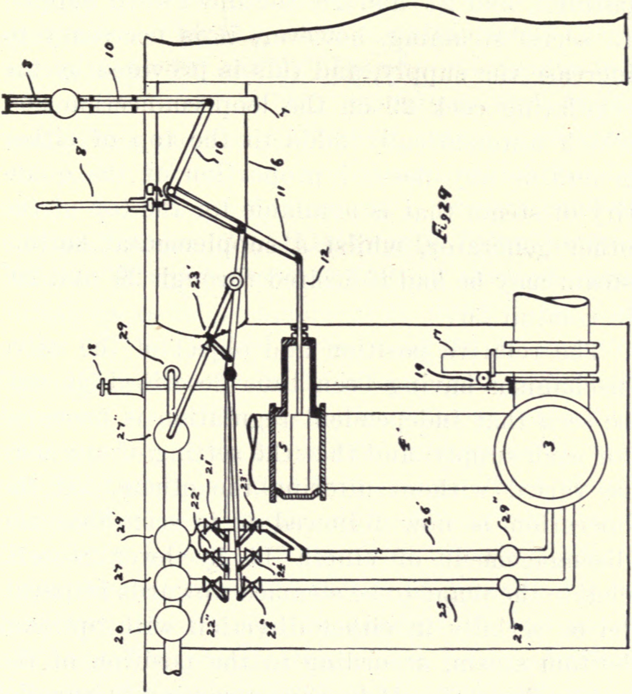


Fig 28

14′, 14″, and 15, are splined on the shafts 9 and 9′ and coupled by snivels to the connecting link 13 so that the clutch members travel along the shaft and respond to the movement of the lever 8″. The members 14′, 14″ and 15 are adapted to couple simultaneously the shafts 9 and 9′ with the yoke 11 at 15′ and 15″, and with each other at 16, so that the valves 7, 7′ and 5 must all work together; 7 and 7′ being opened when 5 is closed until the clutch is disengaged, when the shafts are free to rotate separately. The blast valve 17 is operated by wheel 18, through gearing 19, and controls the admission of air to the bottom of the two generators for upward blasting in parallel, when the blast products pass off through outlets 6 and 6′. On the primary steam supply 20 are placed a series of distributing cocks 21′, 21″, 22′, 22″, which are connected with shaft 9, and operated simultaneously with the valve 7 so that 21′ and 22′ and 21″ 22″ are opened when the valve 7 is opened. The valves 23′, 23″, 24′ and 24″ are connected to shaft 9′, so that 23′ and 23″ are closed, and 24′ and 24″ are opened when valve 7′ is opened. The steam conduits are provided at 25, 25′, 25″ and 26′, 26″, and 26′ is formed with a dual connection to the primary steam supply, and the valves 21″ and 23″ are on one branch of the connection, with 22′ and 24′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27
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25
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Fig 29

on the other. The steam entering the generator is accurately controlled by regulating cocks and meters 27, 27′ and 27″, and 28, 28′ and 28″, of which 27 and 28 control the upward supply in parallel, and 27′ and 28′ the downward supply. In serial steaming, however, it is necessary to increase the supply, and this is provided by the regulating cock 29 on the loop connection 26″, which automatically adds to the top of either generator any desired proportion of the quantity of steam that is available for the top of the other generator, whilst a supplemental bottom steam may be had if desired through 29′ and 29″ in conduit 26′.

The relative position and object of the valve mechanism having been thus described, it will be seen that independent regulation is provided for each supply, and that the setting of any may be varied without altering the others. If the operation is now followed it is seen that the disengagement of clutch 14 by lever 8″ will enable the plant to be steamed upwards in parallel or serially in either direction with optional bottom steam, according to the position of the valves 7 and 7′. If upward steaming in parallel is desired, the valves 7 and 7′ are both open, and steam from the pipe 20 passes through regulating cock 27, steam cocks 22″, 24″, 21″ and 24′, through conduit 25 controlled by them, and meter 28 into conduit 3, and upwards through generators. If it is then desired to steam serially, for instance, down through generator 1 and up generator 2, the valve 7 is closed by the movement of lever 8, which simultaneously closes steam cocks 22″ and 21″, thereby closing conduit 25 to the bottom of both generators, and, at the same time, the closing of these valves is effected, the cocks 21′ and 22′ are opened, which admits steam to the top of generator 1 through conduit 25′ and meter 28′, this supply being supplemented at the bottom, if desired, through regulating cocks 29′, steam cocks 22′ and 24′, the conduit 30, meter 29″, into conduit 3, and up through generator 2. In reversing the direction of serial steam the gas outlet 7 is opened, which closes steam cocks 21′ and 22′, and opens 21″ and 22″, and the gas valve 7′ is closed, which simultaneously opens steam cocks 23′ and 23″, and closes 24′ and 24″. This order allows steam to pass through cock 23′ to top of generator 2 by way of cocks 27″ and 29, conduit 25′ and meter 28″, supplemental bottom steam being admitted through 29′, 21″ and 23″, the conduit 26′, meter 29″, into conduit 3 and up generator 1.

If it is then desired to change the operation of the plant from the alternating series to a pair

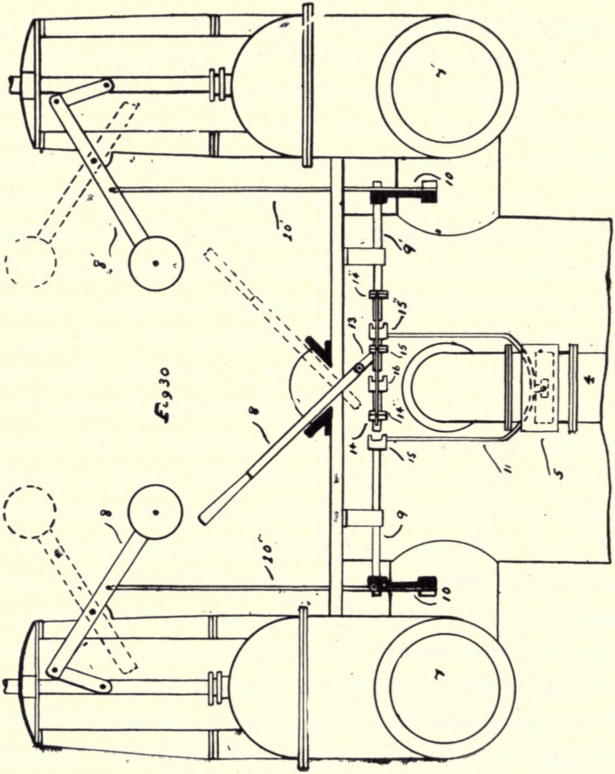


Fig 30

of generators steaming together in either an upward or downward direction, the lever 8″ is moved back to the position shown by dotted lines, which causes the clutch 14 to couple the shafts 9 and 9′ with yoke 11 at 15′ and 15″, and with each other at 16, and simultaneously causes the gas outlet valves 7, 7′ and 5 to work together, 7 and 7′ being opened while 5 is closed.

In this position the up run will proceed as previously described, and on moving one of the levers 8 or 8′ to the dotted position, the gas valves 7 or 7′ will be closed and gas valve 5 will be opened. The steam cocks 21′, 22′, 23′, and 23″ will at the same time be opened and 22″, 24′ and 24″ will be closed, whereby steam will be directed to the tops of both generators for the down run in parallel, when the gas will leave the generators by way of conduit 3 and valve 5. It is seen, then, that the movement of one of the levers 8 or 8′ will alternate the generator from the up and down run in parallel, and the movement of the lever 8″ will automatically change the working of the plant from parallel steaming to serial steaming characteristic to the twin-generator system.

It may here be noted that the valve 5 is of special design so that any excess pressure in the generators will cause the disc to be raised, and thereby act as a relief valve.

The twin system has not been very largely employed, although it may be said to possess certain advantages, and in the writer's opinion a design of plant particularly adapted to meet the requirements will in course of time supersede the single generator system. It has been well said that one of the most important items in the manufacture of carburetted water gas is the control of the generator fire, particularly in keeping it in a healthy condition, and every gas engineer knows that after four or five hours' continuous operation the efficiency of the plant is reduced by the accumulation of ash and clinker, which also interferes with the make per unit of fuel. The removal of this clinker causes the entire plant to be shut down for a period, which may vary from 10 to 150 minutes, according to the condition, and where water gas is made exclusively, as in many districts in the United States, a shut down period of two hours or more at an inconvenient time of the day often causes the holder supply to be considerably reduced, and also interferes with the normal working temperatures of other parts of the apparatus. If, however, a satisfactory design of twin generator was adopted, it would enable the plant to continue working on the single generator system while the condition of the other generator was made healthy, and increase the output of the machine by at least 10 per cent. on the same carburetter and superheater at a comparatively small outlay of capital, and simultaneously combine the advantages of the twin system with those of the single system when both generators are being operated together either serially or in parallel, as illustrated in the previous example.

Continuous Process.

A modification of the twin-system which possesses some very interesting developments is that in which two generators are operated alternately in conjunction with a series of retorts and an oil fixing chamber.

The objects of this apparatus are:

(1) To enable gas to be made continuously.

(2) To allow the use of cheaper grades of soft coal.

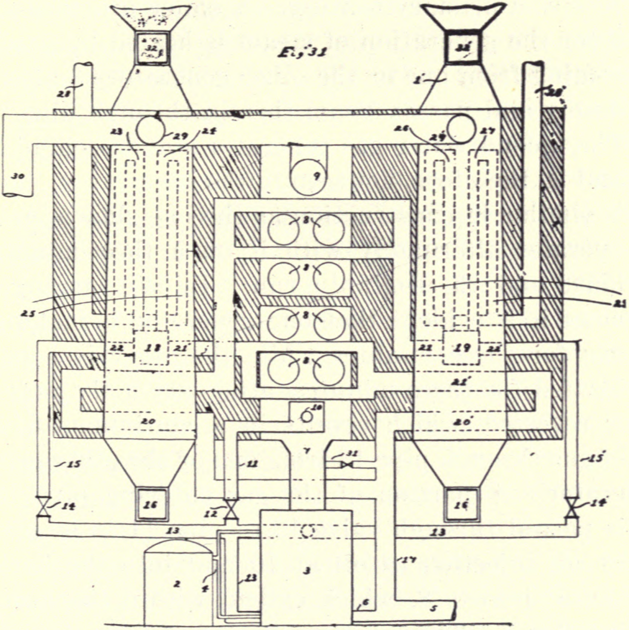
(3) To effect distillation of the coal in an atmosphere of water gas, and thereby take up hydrocarbons that otherwise break down to tar.

(4) To control the temperatures of the distillation chambers by making it possible to use a definite proportion of water gas and air for combustion, under a given pressure and temperature.

(5) To enable a constant temperature in the oil fixing chamber to be obtained.

This system purposes to have several advantages over any previous attempts to carbonize soft coal in conjunction with water gas generators, and its arrangement is such that the water gas generators can be employed with the retorts without the oil fixing chamber and thereby lower the quality of the gas in the event of it being too rich, or the oil chamber can be brought into operation immediately and enrich the gases. It also embodies positive heating of the retorts by employing a definite proportion of gas at definite heating value, and thereby effecting greater uniformity in the working of the plant.

In the diagramatic view, Fig. 31, the principle of the apparatus is shown, and 1 and 1′ are vertical retorts arranged within a firebrick setting and provided with a series of flues as hereafter described. The gas leaves the retorts by way of pipes 29 and 29′ and pass to pipe 30, where they mix with water gas or carburetted



water gas. The retorts are continuously charged at 32 and 32′, and continuously discharged at 16 and 16′ by rotating buckets, and at the lower end of the retorts a series of flues 20, 20′, 21 and 21′ are arranged, through which air is passed to receive a primary heating. A boiler provided at 2 for the generation of steam is heated by gases coming from one or the other generators 3 alternately and passes steam therein through pipe 4. The second water gas generator stands behind 3 and is, therefore, not seen in the illustration, but is similar in construction as the one shown, and operates alternately with it on a three-minute blast and three-minute run. In this arrangement it is evident that one generator is making gas for three minutes while the other is being blasted for three minutes, after which the order is reversed, which results in a continuous flow of gas through pipe 13 from one or the other generator. A portion of the gas entering pipe 13 is passed through valve 12 to pipe 11 to be met by an injection of oil at 10 and into the horizontal retorts 8, which extend within the heating flue 7. These retorts are of various dimensions, according to the location of the plant and consequent nature of enriching agent, and are about 15 to 20 inches in their cross section, where heavy oil is used, or from 8 to 10 inches where light oils are used. The carburetted water gas emerges from the retorts at 9 and is passed into coal gas main 30 or to a relief holder as desired. The heating of the plant is accomplished by admitting air from main 5 through branch 6 into generator 3, which results in the formation of producer gases, which are passed up flue 7 from one or the other generator, and raises the temperature of the retorts to the required degree, which is controlled by the initial pressure of the air blast. The arrangement of this flue is in a vertical plane with the generators, and the resistance of the gases is thereby reduced to its lowest degree, and by employing an high pressure blast and low fuel bed an excess of oxygen is created in the generators which makes it unnecessary to employ secondary air in the carburetter, although means are provided at 31, if desired. The products of the combustion are then passed into chimney 28 or to a waste heat boiler.

In the path of the burning gases are placed a series of flues, 20, 21, 20′ and 21′, through which air passes and receives a secondary heating previous to combustion around the coal gas retorts. The path of the air is up branch 17 from main 5 into flues 20, 20′, 21, 21′, arranged around the lower part of the retorts, and then through the aforesaid flue extensions, which passes through the heating flue 7, and on to the combustion chambers 18 and 19. A portion of the blue water gas fed into main 13 is passed through valves 14 and 14′ into pipes 15 and 15′, and then to the aforesaid combustion chambers, where it meets the heated air, and the products of combustion pass into flues surrounding the vertical retorts; 23 and 24 leading from 18 to downward flues 25, and finally into chimney 28, whilst flues 26 and 27 lead from 19 to downward flues 25′, and finally into chimney 28′.

In following the description of the plant it is evident that the operation of the process is as follows: The generators are caused to produce water gas in the usual manner, part of which is led into combustion chambers for the subsequent heating of vertical retorts, and part of which is passed through a series of smaller retorts in conjunction with oil to be carburetted and fixed, and alternately each generator is caused to produce gases for the purpose of heating the oil retorts and simultaneously giving a secondary heat to air used for combustion around the vertical retorts.

The Fig. 31 is somewhat diagramatical and various modifications employing a similar principle are made; for instance, in one form the air flues 20 and 21 are not passed through heating flue 7 and the producer gases are thereby used entirely for heating the oil fixing retorts, whilst in another modification the combustion flues 1,

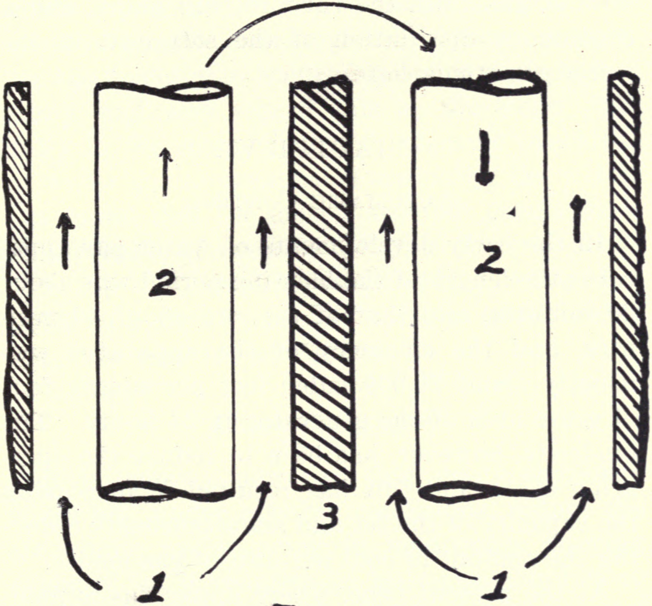


Fig 32

Fig. 32, are divided by a wall 3 and the retorts 2 arranged vertically so that the carburetted water gas passes up one set and down the other, and again the combustion chamber 7, Fig. 31, is divided in the center and filled with a checkerwork of bricks to form fixing chambers as in the intermittent process, and each chamber operated alternately in unison with the alternate operation of the generators so that there is always a flow of gas from the carburetting plant, and a continuous distillation of the soft coal in the water gas atmosphere.

CHAPTER VI.

Automatic Control.

In the early developments of water gas apparatus the length of the blasting period was about 20 minutes, and that of the run about 30 minutes, and the efficiency of the apparatus was usually about 20,000 cubic feet per square foot of grate area of the generator in 24 hours. The tendency, however, has been to reduce the operating cycle, and this has resulted in increasing the capacity of the set and simultaneously reducing the amount of coal per unit of gas made.

At the present time, where apparatus is manually operated the cycle is usually about eight minutes, consisting of a three-minute blow and five-minute run, and occasionally it has been reduced to six minutes, in which a two-minute blow and four-minute run is employed. It has been found that this cycle puts an unusual strain on a gasmaker, who has to be constantly on the alert in an unhealthy atmosphere, and the influence of the poisonous carbon monoxide, combined with the strain of the reduced cycle, has made it practically impossible for a human element to remain consistent to his post and operate the machine to accurately timed periods, and many engineers regard this as the worst difficulty in the economical and scientific operation of water gas apparatus. Personally, the writer has found that the most consistent gasmaker is in the habit of running 10 or 15 seconds above or below the recorded time, and this, when computed in a day's results, is liable to considerably effect the coal and oil figures.

Blast Pressures.

It is evident, however, that many engineers could not, under existing conditions, reduce the six-minute cycle, owing to inadequate blowing capacity, as it requires at least two minutes to get up the heats when the blowing plant is being operated at its maximum capacity, but where the necessary air can be obtained, it has been found that even this cycle can be reduced with advantage to three or four minutes in combination with automatic control.

The capacity of the blowing plant needed depends, of course, on the size of the machine it has to supply, and it is believed that the greater amount of air that can be passed through the fire in a limited time, the more economical will be the results and the greater will be the capacity of the machine. The highest volume of air passed through the fire within the writer's experience is approximately 300 cubic feet per square foot of grate area per minute, and by this it was able to reduce the length of the blow to 75 seconds, and there is every reason to believe that this volume can be increased with advantage and the blasting period still made shorter.

One of the most important advantages of high pressure blasting is that it enables the use of lower grade of fuel, owing to the fact of there being less variation in the temperature of the fuel during the shorter blow. In a fuel containing a high percentage of ash with a low melting point, the ash will fuse into clinker and disturb the efficiency of the fire when a blow of several minutes is adopted owing to there being a wide variation in temperature between the beginning and end of the blow, and if a shorter cycle is adopted the temperature of the fire will not be lowered to the same extent during the run, or need not be heated to the same degree at the bottom of the fire before the commencement of the run.

Temperature Conditions.

With the advent of high pressure blasting it was found advisable to reduce the depth of the fuel bed, and thereby correspondingly reduce the resistance. In existing methods where a three-minute blast is employed it is customary to clinker the fire about every 8 or 12 hours, and in the latter part of this period the depth of the clinker and unburnt fuel is usually one foot or more, which considerably reduces the efficiency of the blowing plant, and also reduces the depth of the live fuel bed. With high pressure blasting, however, and a lower fuel bed the resistance to the air is reduced, which makes it possible to obtain the necessary temperatures in about one minute, and since the difference in the temperature of the fuel at the bottom is not so great, a less proportion of ash is fused and consequently the bottom of the fire is kept more healthy. When the clinker in the generator is one foot or more in thickness, it is a difficult and laborious matter to remove it, and a cleaning period may take anywhere from 30 minutes to three hours, which consequently reduces the capacity of the set per 24 hours. In the high pressure system, however, where the clinker does not fuse to the same extent, it is found that by shaking the fire about every 25 runs or every 100 minutes, the dead or fused matter can be worked through the grate bars in a comparatively short space of time, it being only necessary to pass a light bar over the grate once or twice. In an experimental test in which the writer is acquainted, the average cleaning time for a period of four weeks was slightly over one minute per clean on a system of 25 runs on a four-minute cycle. Under these conditions the fire is kept practically healthy at all times, and the depth of fire can be reduced one foot or more and still be as effective in the decomposition of steam as if the depth was kept seven or eight feet, as in existing conditions. It is also found that in the high blast and low fire system, the excess of air in the presence of less carbon produces a greater percentage of carbon dioxide in the producer gases entering the carburetter, which consumes less fuel per unit of make and produces a larger proportion of sensible heat, which, under the influence of the high pressure, is almost sufficient to heat up the carburetter to the required extent without the use of secondary air. Under these conditions, in which the rate of gasmaking is considerably accelerated, the temperatures of the carburetter and superheater have not such a wide variation and consequently do not require as much heating in each cycle, and whilst it has yet been necessary to use a small portion of secondary air in the carburetter, it is believed that in course of time the secondary air will be dispensed with as the automatic and high pressure system develops still further.

ADVANTAGES.

It is now a well accepted fact that the adoption of a shorter cycle will increase the capacity of the set and improve the oil and fuel results, and in order to reduce the cycle to below six or eight minutes, it is necessary to use high pressures to obtain the heats in the minimum time and to employ automatic operation to obtain the necessary speed. Briefly, the advantages of automatic operation may be summarized as follows:

(1) By accurately timed periods coincident with accurate measurements of air and steam, the operation is placed on a basis at which uniformity must result.

(2) It enables the use of lower grades of fuel containing a higher percentage of ash by reduc-

ing the ranges of temperature between the beginning and end of the blow, and largely preventing fusion of the ash into clinker.

(3) It produces a more constant temperature in the carburetter and superheater, and minimizes excess decomposition at the beginning of the run and the production of tar towards the end of the run.

(4) It enables fuel to be fed at any part of the run or blow, which allows the volatile matter to be driven off at the most suitable time, according to the nature of the fuel.

(5) It keeps the fire at a uniform depth by frequent charging without loss of time, and thereby minimizes the percentage of CO_2 in the water gas, and provides a uniform proportion of CO_2 in the blast gases.

(6) It enables the fire to be kept more healthy at the bottom by preventing fusion of ash into large masses of clinker, and enables the use of a rocking grate which will efficiently remove smaller particles of ash.

(7) It allows the water gas to be driven from the machine at the end of the run by enabling the blast valve to be opened a few seconds in advance of the stack valve.

(8) It increases the capacity of the set by practically 100 per cent., and thereby reduces the outlay of capital per unit of make.

(9) It eliminates the human element and reduces the cost of operation.

(10) It reduces the risk of explosion by avoiding the inconsistency of an attendant.

In looking over these facts, the experienced engineer or gasmaker will no doubt hesitate in accepting the reliability and efficiency of a mechanical or other contrivance which will substantially bring about such radical changes, and the writer intends, in the following pages, to discuss the relative advantages of apparatus at present brought forward.

The first apparatus of which we are aware was designed in England in 1911, but owing to a sudden increase in the rate of oil, the water gas process in that country received a set-back in competition with coal gas, and little interest appears to have been taken in the development of the apparatus for this reason. Other modifications, however, quickly followed, and in the writer's belief the first apparatus successfully operated on a commercial scale was built by the United Gas Improvement Company, Philadelphia, at a subsidiary plant in Pensacola, Florida, in 1914, and it is now a general belief that an automatic and high pressure system will, in the course of a few years, entirely displace the present system. The reliability of this belief undoubtedly depends on the reliability and efficiency of the design of apparatus, and the following chapters have been arranged to bring out the fundamental principles governing the respective designs, and enable the reader to firmly grasp the elements on which successful operation depends.

CHAPTER VII.

Mechanical Operation.

The most reliable means of automatic control is undoubtedly by positive action on the valve mechanism by a substantial application of mechanical means. In this chapter it is intended to outline the generation of blue and carburetted water gas from the automatic standpoint, and to show a combination of apparatus which will serve to illustrate different principles of mechanical control from which a variety of modifications could be made.

Cam and Clutch Mechanism.

The apparatus referred to in figures 33 to 40 is for the generation of straight or blue water gas, which is theoretically a mixture of hydrogen and carbon monoxide only and does not contain any hydrocarbons or other illuminating vapors.

It is obvious, then, that there is no carburetter or superheater in this apparatus, and as there are no combustible gases required for oil carburation, it is usual to employ a higher blast pressure and reduce the percentage of carbon monoxide as far as possible in the producer gases. Until recent years the producer gases given off in this type of apparatus were discharged straight through a chimney in a vertical plane with the generator, it being claimed that the high blast pressures employed produced an excess of oxygen in the generator, and burnt the gases therein direct to carbon dioxide, and consequently the gases were of little heating value after leaving the apparatus. It has, however, been repeatedly proven that under the influence of the high blast pressure and comparatively small area of contact surface, the carbon can not be completely burnt in the generator, and also that the gases already converted to carbon dioxide contain a very large amount of sensible heat when passing up the chimney. In the various tests made, it was found that under average conditions from 30 to 40 per cent. of the total heat was lost in the atmosphere, and by arranging a tubular steam boiler in the path of the burning gases, the heat could be used to substantially generate steam at a most convenient time. This arrangement also claims to have other advantages, the foremost of which are:

(1) It increases the efficiency of the steam boiler by reducing the distance between the boiler and gas generator, and thereby ensures dry steam.

(2) It insures the production of the highest steam pressure at the commencement of the run, when the carbon in the generator is at its most active stage for the decomposition of steam.

(3) It reduces the relative cost of construction, ground area, and centralizes the plant.

(4) It eliminates the necessity of an attendant.

(5) It reduces the amount of fuel per unit of gas by employing gases that were otherwise lost in the atmosphere.

It may be pointed out that blue water gas is not distributed commercially for illuminating or heating, owing to its low calorific value, and such plants are used chiefly for industrial purposes.

Referring now to the automatic apparatus, Fig. 33 is a general view, showing the principal

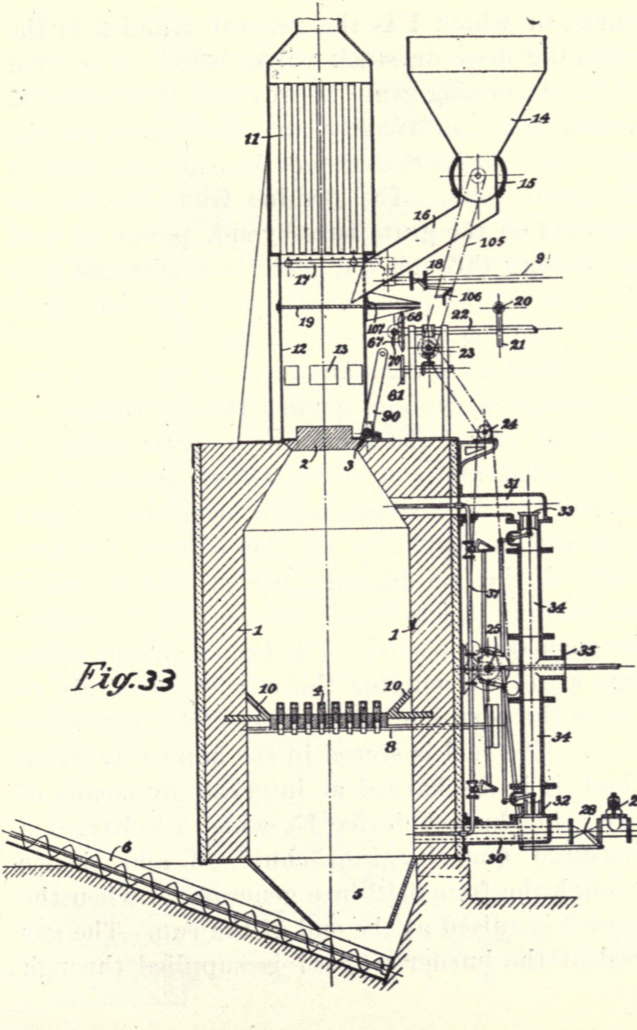

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Fig. 33

parts, of which 1 is the generator and 2 is the charging door or stack valve, which is pivoted at 3. A rocking grate is provided at 4, which is actuated by alternately arranged cams on the revolving shafts 8, arranged beneath the ends of the grate bars. The residue from the fuel is directed on the grate bars by side pieces 10, and on passing through the grate is discharged into the ash pit 5, from which it is carried by a worm 6 to the exterior of the machine. The ash pit is kept at a constant level of water to seal the escape of gas and quench the hot ashes.

At the top of the generator a steam boiler 11 is provided, and connects with gas generator by funnel 12. The steam boiler is of the tubular type and is heated by the gases from the generator during the blasting period, and by water gas burning in jets from a burner ring 17 during the gasmaking period. The funnel 12 has openings at 13 therein for the admission of air to insure the complete combustion of the generator gases. The fuel is stored in the hopper 14, from which it is discharged at intervals by means of a rotating bucket device 15, which discharges a measured quantity into chute 16 and thence through the funnel 12 into generator 1 when the cover 2 is raised at the end of the run. The gas used at the burner ring 17 is supplied through

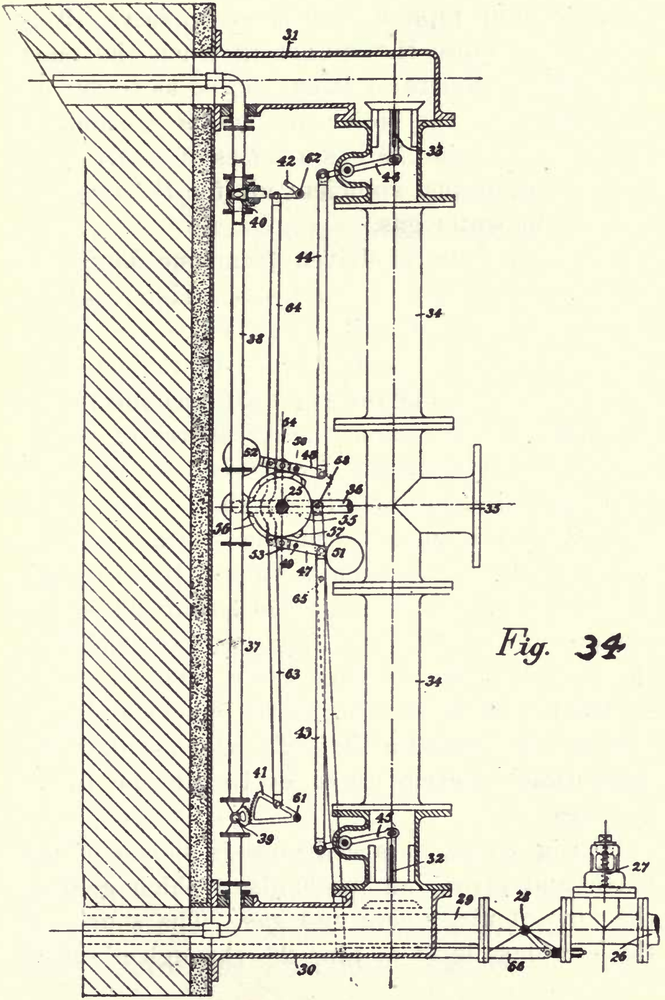
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Fig. 34

cock 18 and pipe 9, and a slide valve 19 is adapted to close the funnel 12 when the blast through the generator is cut off, so as to cut off cold air from the boiler during the gasmaking period. The slide 19 has a series of small openings to admit just sufficient air for the combustion of the water gas.

The apparatus is driven from one source of power by means of shafts, gearing and so forth in order that the various operations are accurately timed to take place in their proper sequences. The driving shaft 20 is connected to an engine or dynamo or other source of power controlled by governor mechanism so that the speed remains practically constant. The shaft 20 drives through a worm and worm wheel 21 a second shaft 22, which in turn drives through another worm and worm wheel a shaft 23, which makes one revolution in four minutes, which is the assumed time of each cycle. The shaft 23 drives a shaft 24 running at the same speed, and this in turn drives a shaft 25, which makes one revolution in every three cycles or one in 12 minutes.

In Fig. 34 an enlarged view is shown of the valve and operating mechanism which control the flow of air, steam and gas. The source of the air blast is from pipe 26, through a safety valve 27, which serves to keep a constant pressure, and through valve 28 and pipe 29 to generator 1. The bottom and top gas outlets are provided at 30 and 31, and are controlled by valves 32 and 33, respectively, which communicate by a connecting pipe 34 to branch pipe 35 leading to a relief holder. The steam admission pipe 36 leads from the steam boiler 11 and branches off into pipes 37 and 38 with cocks 39 and 40 therein, the said pipes being carried through the outlet pipes 30 and 31 into the bottom and top of generator respectively. The cock 40 is shown in section and turned through a right angle to show its construction. The two cocks 39 and 40 are adapted to be operated by toothed sectors 41 and 42, pivoted at 61 and 62, and connected by links 63 and 64, respectively, to rocking levers 48 and 47, which are pivoted at 50 and 49, respectively. The rocking levers 47 and 48 are also connected by links 43 and 44 to rockers 45 and 46, by which the outlet valves 32 and 33 are operated. The said levers are counterweighted at 51 and 52, and have rollers 53 and 54, which work respectively on cams 55 and 56 on the shaft 25. These cams are shown in detail in Figs. 35, 36 and 38, wherein the cams are separated out and also in plan on the shaft 25. A third cam 57, Fig. 37, having three projections is adapted to work against a roller 58 on one end of a lever 59, which is pivoted at 65 and connected by a link 66 to the arm of the air blast valve 28.

The mechanism which raises the cover of the generator is shown more fully in Figs. 39 and 40, in which 67 is a bevel wheel on the shaft 22, Fig. 33, and gears with two bevel wheels 68 and 69, Fig. 40, which are mounted to run loose on the shaft 70 and are held against longitudinal movement by fixed straps or brackets (not shown) engaging in grooves 71 and 72 in the bosses of the bevel wheels. The bevel wheels have ratchet clutch faces 73 and 74 formed on them, opposite to which are ratchet clutch members 75 and 76 revolubly supported on a sliding bracket 77 and working on keyway on the shaft 70. The bracket 77 is adapted to be moved to and fro by means of a toothed sector 78, pivoted at 79 and having a pin 80 at its rear end, which works in a grooved cam 81, driven from the four-minute shaft 23 by means of bevel gearing as shown in Fig. 33. The grooved cam makes one revolution in each cycle of operation, and has two principal projections, 82 and 83, which engage with the pin 80 as the cam rotates in the direction of the arrow. A separate mechanism returns the pin 80 to its mid-position in the

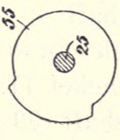

Fig. 35

Fig. 36

Fig. 37

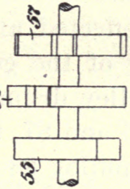

Fig. 38

groove, and behind each of the projections 82 and 83 the cam groove is made wide for a space to allow time for the returning mechanism to operate. The returning of the pin and moving back of the bracket and the disengagement of the clutches therein is effected at the opening and closing of the cover of the generator. On the shaft 70 are two pulley drums 84 and 85, over which pass chains 86 and 87, the chain 86 being carried around the pulley 88 to a staple 89 on the cover of the generator, while the chain 87, which runs in the other direction around its drum 85, is connected to a tail piece 90, projecting rearwardly from the cover 2 and its pivot 3. The cover 2 and the tail piece 90 have projections 91 and 92 respectively upon them, which are adjustable, and which are adapted to knock against and throw over a weighted lever 93, pivoted at 94. This lever is geared through a bevel gear 97 to a shaft 99 carrying a pair of arms 96 and 98, which can strike against a projection 100 on the bracket 77. A stop 95 limits the movements of shaft 99 and its arms 96 and 98. A catch 102 is pivoted on the projection 101 from the support for the member 78, and its forked rear end engages and is moved by the member 78, while its hooked front end coacts with the catch 103 on the cover 2, to hold the

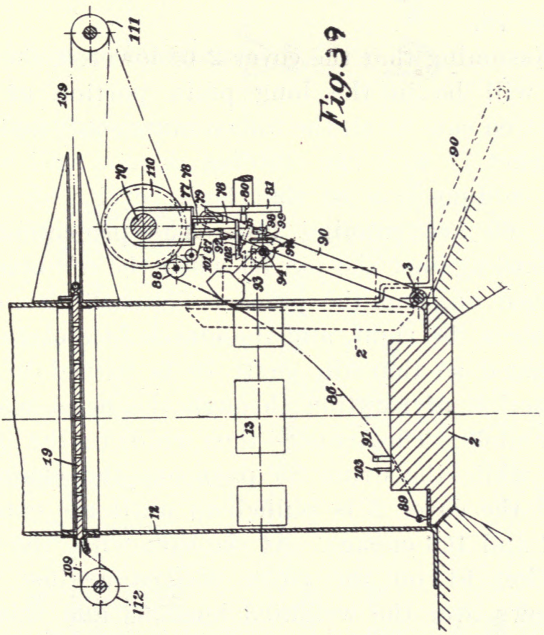

Fig. 39

cover in its raised position. When the toothed sector and lever 78 and the bracket 77 are thrown over into the position for lowering the cover, the catches 102 and 103 are automatically disengaged by the movement imparted to the lever 78.

Assuming that the cover 2 be lowered, the pin 80 will be in the long plain portion of the grooved cam 81 on the four-minute shaft and the bracket 77 with the clutches thereon will be in the mid-position so that both bevel wheels 68 and 69 are running idle. The projection 82 strikes against the pin 80 when the air blast is turned on, and the bracket 77 is thrown over towards the right, and the clutch 74 and 76 are engaged so that the shaft 70 is turned in one direction of rotation through the bevel wheels 67 and 69. The drum 84 then winds up the chain 86, while the drum 85 pays out the chain 87 and the cover 2 is pulled up until the catches 102 and 103 engage. At the same time the projection 91 on the cover strikes against and throws over the weighted lever 93 and this, in falling, operates the fork 98, which throws back the bracket to its mid-position, in which it is held by a spring roller device 104 engages between curved projections 108. The clutches on the bracket are now out of engagement and

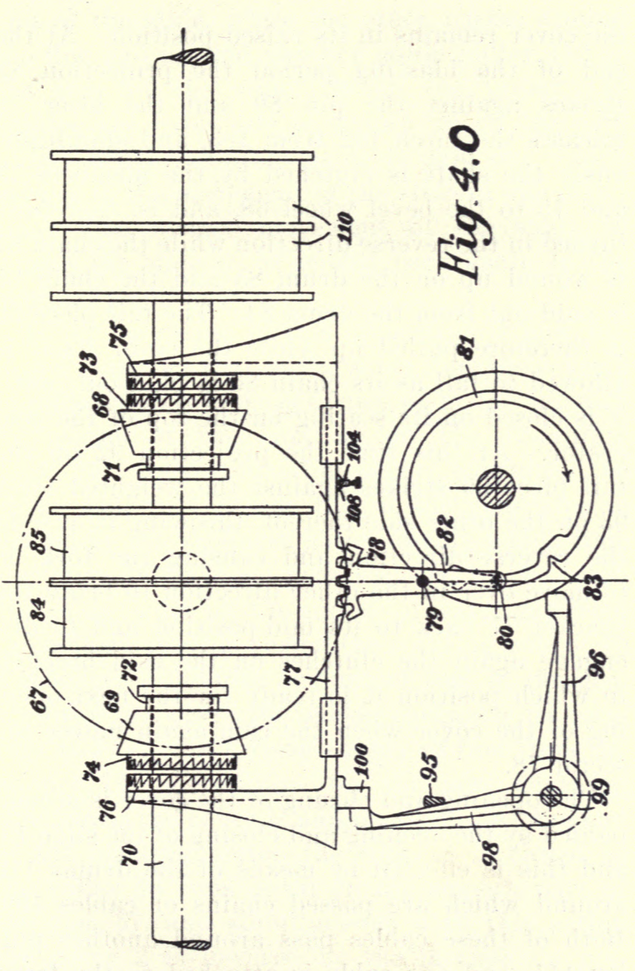
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Fig. 40

the cover remains in its raised position. At the end of the blasting period the projection 83 strikes against the pin 80 and the lever 78 releases the catch 102 from 103, and simultaneously the shaft is clutched by the members 73 and 75 to the bevel wheel 68, and is, therefore, turned in the reverse direction while the chain 87 is wound up on the drum 85 and the chain 86 is paid out from the drum 84. The tail piece 90 is therefore pulled up while the cover itself is allowed to fall as its chain 86 is paid out, until it is closed on its seating on the top of the generator. At this time the projection 92 on the tail piece 90 strikes against the weighted lever 93 on the other side thereof, throwing it over in the reverse direction and causing the fork 98 to move over in the other direction to bring the bracket 77 back to its mid-position and to disengage again the clutches on the said bracket, in which position it is ready for the next opening of the cover when the cam again moves the sector 78.

The opening and closing of the cover is accompanied by the opening and closing of the slide 19, and this is effected by means of the drums 110 around which are passed chains or cables 109. Both of these cables pass around another pulley 111, and one cable is attached to the front end of the slide, while the other passes around the flue and around another guide pulley 112 to the rear of the slide. When the pulley 110 rotates the cable 109 is wound up on the said pulley while the other cable is paid out, which results in the movement of the slide in one direction. The reverse movement of the shaft 70 causes the slide to be moved back again to the original position.

If the operation of this apparatus is now followed it is seen that at the same time the cover 2 is raised the air blast is turned on at the valve 28 by means of the cam 57 on the 12-minute shaft 25. As the blasting period continues the steam boiler 11 at the top of the generator is heated by the producer gases, during which time the valve 18 has been nearly closed by the catch 106 so as to cut off the supply of water gas from the boiler. At this period the rotating bucket 15 discharges a definite amount of fuel in the generator, after which the bucket continues its rotation and takes in a fresh supply of fuel from the hopper 14 in readiness for the next charging time when the cover is again raised. At the end of the blasting period the cock 28 is closed as the roller 58 runs down on the smooth part of the cam 57, and simultaneous with this action the cover 2 is lowered by the mechanism previously referred to. The closing of the cover also effects the closing of the slide 19, and the movement of the latter turns on the gas at the cock 18 by means of the catches 106 and 107, so that the steam generator continues to be heated. At the same time as the blasting period is being ended the cam 56 causes the steam to be turned on at the cock 39, and the outlet valve 33 to be opened. This puts the generator on the up run for 150 seconds, after which the cock 39 and valve 33 are again closed and the blasting period recommenced for a period of 90 seconds. During the next period of four minutes the sequence of operation is repeated for the second up run, and in the third period the steam is turned on at the top through cock 40 and the bottom outlet valve 32 opened, which puts the generator on the down run, after which the shaft 25 has gone through one period of rotation and the whole cycle is again repeated.

Rotary Valves.

The most simplest form of automatic operation is undoubtedly that in which a series of rotary valves are employed to control the inlet and outlet ports. The system has been designed especially to effect simplicity of control, and the

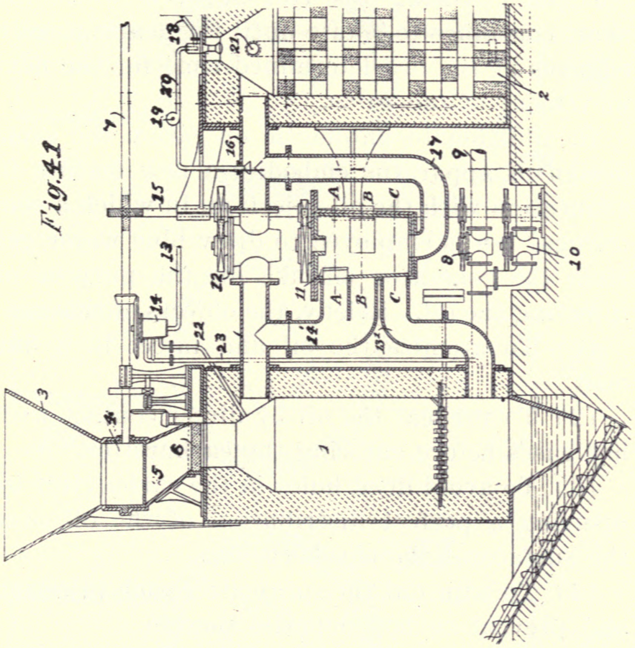


Fig. 41

valves are arranged to rotate continuously in a given period from a constant speed shaft, or are provided with mutilated gearing so that the valves are actuated in a rotary direction at the time period desired, after which they remain stationary during the run or blow while the shaft continues to rotate until the gearing again engages at the pre-determined time for the next movement of the valve.

In addition to automatic operation the same design of apparatus embodies a new feature in connection with the oil injection, in which a centrifugal fan is employed to draw blue water gas from the generator off-take for the purpose of injecting the oil. Briefly, the objects of this are:

(1) To atomize the oil and inject in a fine mist.

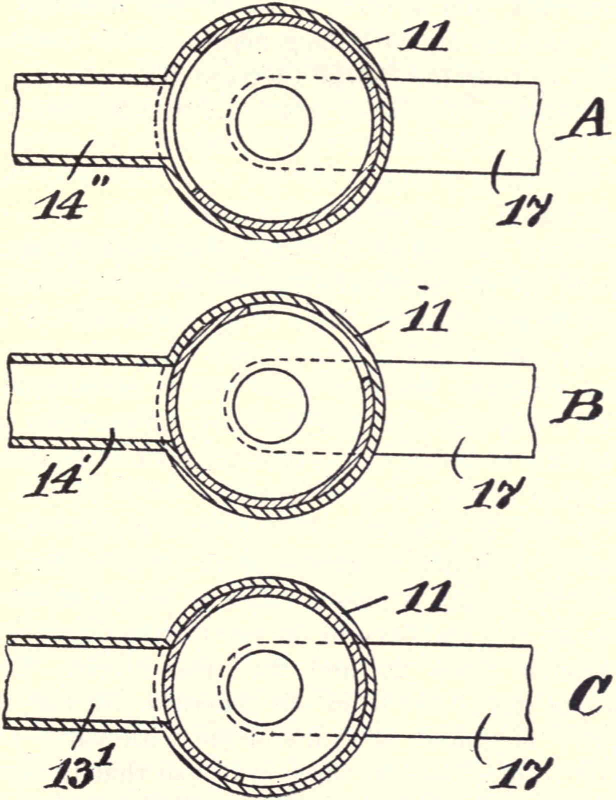
(2) To preheat the oil by direct contact with hot gases before entering the carburetter.

(3) To avoid dead holes in the carburetter by insuring a perfect distribution of the oil over the surface of the checkerbrick.

(4) To wipe out the spray after each injection and prevent carbon deposits therein.

For the purpose of illustration, the constantly rotating valve system will be described, and Fig. 41 shows a vertical section through part of a carburetted water gas apparatus in which 1

Fig. 42



is the generator and 2 the carburetter. The fuel is supplied from the hopper 3 by means of a revolving feed device 4, which delivers a measured charge of fuel into the chamber 5 at fixed intervals, and a valve 6 allows the chamber 5 to communicate with the generator at the desired time to pass the charge therein. The valve 6 is actuated by mutilated gearing from the shaft 7, which rotates once in each cycle.

The valve 8 admits air from the pipe 9 to the generator, and valve 10 admits air to the carburetter by way of inlet 21. The valve 12 connects the generator and carburetter, and rotates synchronously with valve 8, so that when air is admitted to the generator the valve 12 allows the producer gases to pass to the carburetter, and a few seconds later the valve 10 operates so that air is passed to the carburetter for the combustion of the producer gases.

Steam is admitted through the pipe 13 and valve 14, which rotates once in three cycles so that the steam is passed twice to the bottom for the up run and once to the top for the down run through pipes 23 and 22, respectively. The water gas is led from the generator by way of valve 11, which is synchronous with valve 14, and rotates once in three cycles so that the gas leaves the generator twice from the top and once from the bottom in accordance with the admission of steam.

The valves 8, 10, 11, 12 are all operated from one shaft 15. Oil is supplied through pipe 18, and 19 is a centrifugal fan which draws gas from pipe 16 and forces it through 20 for injecting the oil. The oil and stack valves are operated from the shaft 7 in a similar way at the same time as the operation of the steam and outlet valves, and will, therefore, need no illustration.

The sequence of operation is the same as in the previous apparatus, and briefly it may be stated that the process is controlled by two sets of valves which effect the blasting and gasmaking period at the required time, which is controlled by the speed of the shafts 7 and 15.

The valve 11 is similar in construction to valve 14 and is shown in Fig. 42 through the section lines A, B, C, Fig. 41, where it is seen that the valve has three ports which are placed at an angle of 120° to each other, and open the pipes 13′, 14′ and 14″ in order. In the illustration the port 14″ is shown open, while the port 13′ will be opened on the next cycle and 14′ on the third cycle, when the valve will have made one revolution and the order again commences. The valves 8, 10 and 12 operate together, making one revolution in each cycle, and open the ports during the blasting period and close during the gasmaking period.

In this design it is obvious that the operation is of the simplest and most uniform nature and that the plant will require little attention or repair.

CHAPTER VIII.

Electrically Controlled Process.

Carburetted Water Gas.

In this design of apparatus the principle of operation is that of electrically energizing a member mounted on the valve to be operated in accordance with a pre-determined cycle which is controlled by a contact making and breaking device.

The members energized consist of solenoids for the smaller valves, and motors for the larger valves, and by their use the automatic means can be applied to any existing design of apparatus or valve mechanism and ensure a substantial and efficient operation in a speedy or retarded manner as desired.

It is obvious that the scope of electrical control is very broad and could be applied to various combinations of mechanism without departing from the principles hereafter described. However, a description of all the means of application is impossible in a work of this kind, and for the purpose of illustration the most simplest design will be referred to.

In Fig. 43 is shown a form of apparatus of the usual standard type with regards to the generator, carburetter, superheater, and wash-box, and is provided with the usual inlet and off-take ports. The charging of the fuel into generator 1 is effected from the hopper 2 by means of a pair of rotating drums 3 and 4, the upper one of which has a pocket which receives fuel from the hopper each time the pocket comes in the position shown. The drum 4 has also a similar pocket, which is adapted to be turned into a position to receive the fuel from the drum 3 when the latter is inverted, and on further rotation the drum 4 causes the fuel to be discharged into the generator at any period of the run or blow which is found to be the most appropriate, according to the nature of fuel and working conditions. The shafts of the two drums are connected together by chain gearing and rotate in a given period, and since the drum 4 is adapted to discharge into the generator when the drum 3 is being charged from the hopper, the two drums prevent the escape of any gas when charging is taking place, whilst at the same time the

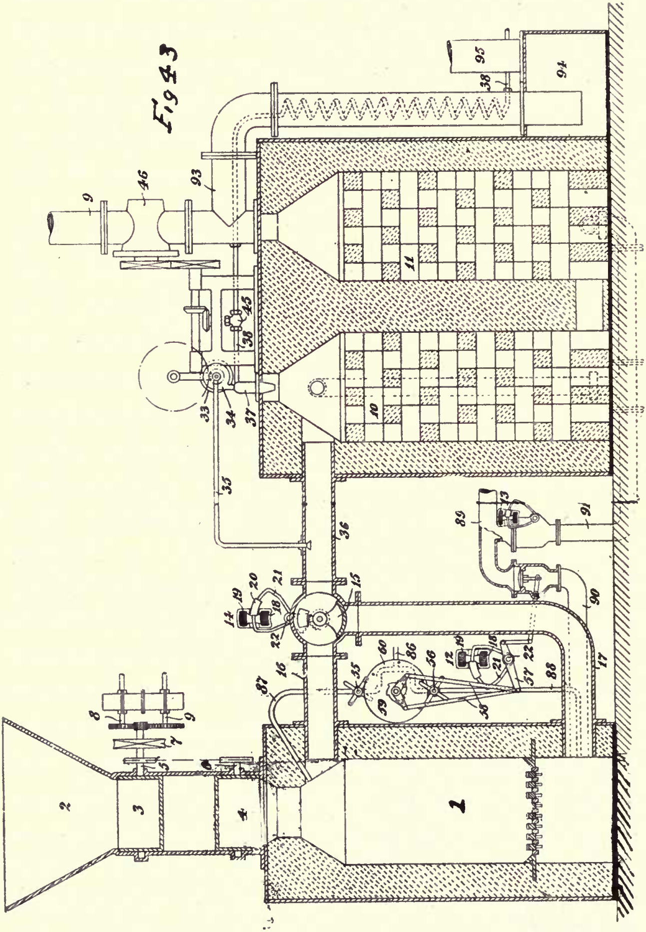


Fig 43

heat of the machine is kept from the upper drum and storage hopper and thereby avoids all risk of the fuel being volatilized before entering the generator. The lower shaft 6 receives its motion from the shaft 5, which in turn receives its motion from an electric motor driven through gearing, the last element of which is a worm wheel 7 on the shaft 5, which also is adapted to give motion to shafts 8 and 9, on which are mounted drums enclosed in a casing, which serve to control the time of operation according to the desired cycle.

The carburetter and fixing chamber 10 and 11 are arranged slightly different from the usual manner, in that the two chambers are enclosed within one shell, the purpose of which is to avoid unnecessary loss of heat, and the admission of air to these chambers is controlled by a valve actuated by solenoid 13.

The solenoids 12, 13 and 14 each comprise a coil 18, partially enclosed in an iron casing 19, fixed in a certain position so that the coil acts when energized upon armatures 20, carried upon frames 21, which are of brass or other non-magnetic material, and is pivoted upon the axis 22. The frames 21 also carries an arm 23, Fig. 44, which is adapted to co-operate with a pair of stationary contacts 24 and 25.

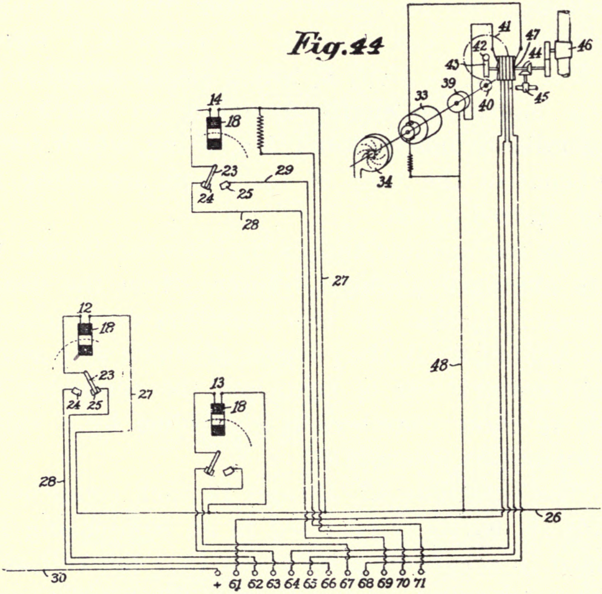


Fig. 44
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One terminal of each of the coils 18 is permanently connected with the negative main 26 by a wire 27, and the contact plates 24 and 25 are connected by wires 28 and 29 with contact members, which, through the intermediary of the controlling drums, are adapted to be put in connection with the positive main 30 for energizing the solenoids. Assuming, then, that the wire connected with the contact plate 25 of the solenoid 12 is put into communication with the positive main, the coil 18 is energized by way of plate 25 and arm 23, and the solenoid attracts the armature and moves it until it takes up a central position relative to the iron casing 19. As it reaches this point the arm 23 moves off the contact plate 25 so that the connection with the positive main is broken, and the solenoid thereby becomes de-energized, at which period the inertia of the armature 20 causes it to swing past its central position and enables it to complete the end of its movement by gravity. In the completion of this movement, the arm 23 is brought in contact with plate 24, so that the circuit is ready for the next energizing of the solenoid for bringing the armature back through the reverse movement to the position shown in Fig. 43. The solenoids 13 and 14 operate in a similar way, but in 14 an additional device is provided, the object of which is to reduce the disadvantageous effects of self-induction of the coil 18. This device consists essentially of a resistance 31,

Fig. 45

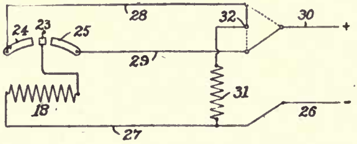
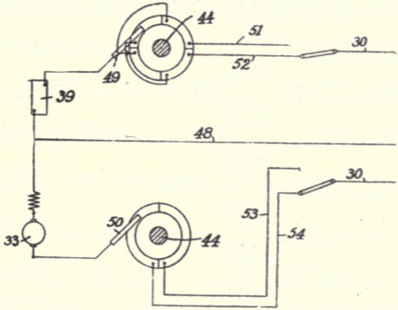


Fig. 45, which is connected with wire 27 and also with terminal 32, and by such connection it is obvious that on the movement of the armature 20 the arm 23 breaks contact with plate 25 and makes contact with plate 24 and closes the circuit through the wire 28, the connection to terminal 32 and resistance 31, instead of breaking it permanently as in the previous example. In order to produce the reverse movement of the solenoid with this additional device, it is necessary to connect the terminal 32 with the wire 29 instead of 28, and to change the connection of the positive main 30 to the wire 28 instead of wire 29 as indicated by dotted lines.

The oil and stack valves on the carburetter and superheater, respectively, are actuated from an electric motor 33, which has permanently connected with its shaft a centrifugal fan 34, which draws water gas through the pipe 35 from the generator off-take 36, and forces the gas through the injector 37 by which it draws oil from pipe 38 and sprays it into the carburetter in a very fine mist. The motor 33 also has on its shaft an electro-magnetic clutch 39, Fig. 44, by which the shaft is adapted to be put into operative connection with a pinion 40 driving a gear wheel 41 on the shaft of which is a worm 42,

Fig. 46



driving a worm wheel 43, on the shaft 44, which actuates the oil valve 45 and stack valve 46. The shaft 44 also carries a controlling drum 47, which is referred to later.

In the operation of the motor 33 and its associated parts, one terminal of the motor, and one terminal of the coil of the clutch 39 are perma-

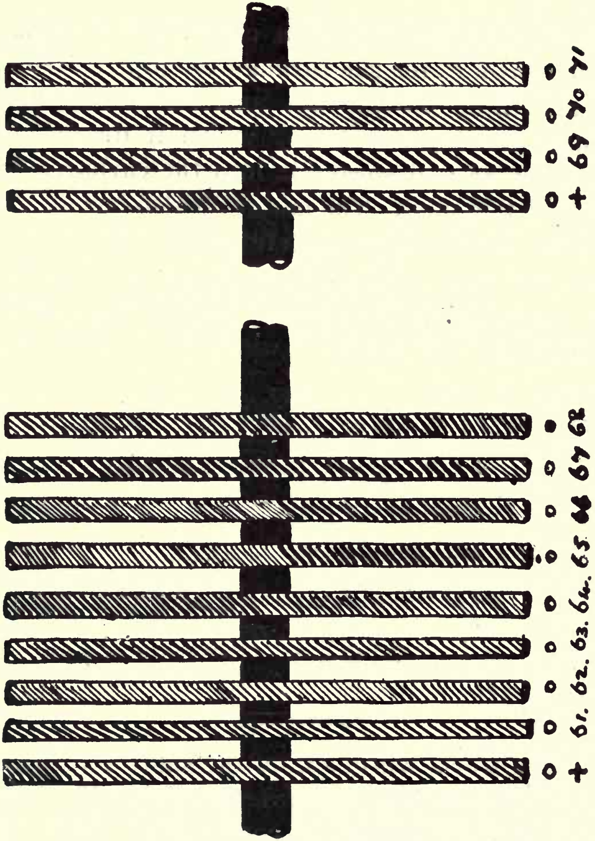


Fig 37

nently connected by the wire 48 with the negative main 26. The connections to the positive main are made through the controlling drum 47 and the contact members shown in the lower part of Fig. 44 coacting with the main controlling drums 8 and 9, Fig. 43.

On opposite sides of drum 47 are mounted a series of curved contact plates insulated from each other, the end views of which are shown in the upper and lower parts of Fig. 46. From the side view of the drum, shown in Fig. 44, it is seen that the plates are mounted on helical surfaces, so that as they rotate, they gradually press the brushes 49 and 50 back, and then permit them to snap on the next contact plate when the end of the first contact plate is reached, which action enables the circuit to be quickly broken. The left-hand end of the drum 47 carries four contact plates connected together in pairs, as seen in the upper part of Fig. 46, and the right-hand end of the drum has two contact plates, as seen in the lower part of the figure. From each end of the drum two connections pass to the contacts of the main controlling drum, which is adapted to put them at appropriate periods into connection with the positive main 30. When the drum 47 is in the position shown in Fig. 46, and the wires 52 and 54 are put in communication with the positive main 30, the motor 33 commences to rotate and at the same time the coil of the clutch 39 is energized, so that, in addition to driving the fan 34, the motor also rotates the shaft 44 and actuates the valves 45 and 46, opening the oil supply and closing the stack valve. When these valves have moved to the required extent, the next contact plate comes under the brush 49 so that the circuit of the coil of the clutch is broken, which causes the shaft 44 to come to rest, while the motor continues to rotate and drive the fan 34. The stoppage of the motor, accompanied by the second operation of the valves 45 and 46 at the end of the run, is brought about by connecting the wire 51 with the positive main 30, and again energizing the clutch 39, and causing the shaft to rotate through another quarter of a revolution, at which the circuit of the coil of the clutch, and the circuit of the motor is broken at the brushes 49 and 50, respectively. In re-starting the motor and energizing the clutch at the end of the blasting period, the wires 53 and 52 are put in communication with wire 30.

The movement of the valves 55 and 56, Fig. 43, for the steam supply to the generator is effected by the rocking of the armature 20 of the solenoid 12, through a lever 57, actuating a pair of connecting rods 58, which rotate the shaft 59 through pawls acting on a ratchet wheel. On this shaft there is mounted a disc 60, having pins projecting from the two sides so as to act upon radial arms on the spindle of the valves 55 and 56. The pins acting on valve 55 project from the rear of the plate, whilst those acting on valve 56 project on the front of the plate, and their disposition is such so as to obtain the correct timing of the opening and closing of the valves, according to the desired cycle. In the illustration it is assumed that the cycle of operation is two up runs and one down run, and four pins are provided at the front of the plate so as to open and close the valve 56 twice in succession, whilst two pins are arranged on the rear of the plate so as to come into action after the four pins referred to, and thereby open and close the valve 55 once for each revolution of the plate. By this means steam is caused to be admitted twice to the lower part of the generator through pipe 88, and once to the top part through pipe 87 in each cycle of three runs.

The main controlling drums 8 and 9 are approximately cylindrical in form, and consist of a series of plates, Fig. 47, which are adapted to strike against the contact fingers indicated by the circles in the lower part of the figure. The plates are all connected together so that a positive current flows through them all, and the surface of the plates are partly of metal and partly of insulating material, according to the work of each, so that when the metal portion strikes the contact finger the current is transmitted through the finger to the valve mechanism to be operated. The surface of the drum is not perfectly cylindrical but has steps form on it in front on the leading edge of each part of the metal portion, so that the spring contact members snap quickly over from the raised part of insulating material on to the next contact plate, and thereby establish the circuit rapidly, and bring about a corresponding rapid action on the valve mechanism with which the respective circuits are associated. The form of the drum is more clearly shown by the section in Fig. 48, where contact plates are

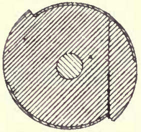


Fig. 48

shown located on the stepped body of insulating material, and the direction of the drum is indicated by the arrow.

It should here be noted that the breaking of the circuit does not occur at the drum, but at contact members carried by movable parts of the apparatus, so that it is not very material at which point the contact plates end, but they have, however, been shown as continued as far as possible over the surface of the drum in the direction of the movement, so that if the members which have control should be accidentally put back in a wrong position, the circuits will be closed and the valve mechanism will move to the position with which they are due to occupy at definite parts of the cycle.

If the sequence of operation is now followed it will be obvious that the proceeding is as follows: Commencing at the beginning of the cycle, the contact 61, Fig. 47, is put into communication with the positive main, and the contact 68 has been previously connected with the positive main and remain so connected at the time.

This causes the shaft 44 to be rotated so as to close the oil valve and open the stack valve, and simultaneous with this action, the contact 62 is connected with the positive main which energizes the solenoid 12 and causes air to be passed into the generator through the pipe 90 by the rocking of lever 57, which actuates the valve. At the same time the movement of the lever imparts an angular displacement of the disc 60, which causes the steam supply to be cut off at one or the other of the valves 55 or 56, according to the previous run. The producer gases pass off by way of pipe 16, valve 15, and pipe 36 to the carburetter 10 and superheater 11, and finally through valve 46 and chimney 92. About 10 seconds after the contact 62 has been put into connection with the positive main, the contact 63 is thus connected, and accordingly the solenoid 13 is energized, which opens the valve on pipe 91 and passes air into the carburetter and superheater, if desired.

The blasting period having been thus established continues for 90 seconds, when contacts 64 and 65 are put into communication with the positive main, which again energizes solenoids 13 and 12 and causes them to cut off the air supplies to the apparatus, and simultaneously open the steam supply. A few seconds after this action, the contacts 66 and 67 are put into communication with the positive main, by which the motor is started, and the clutch 39 energized, so that the shaft 44 is caused to turn and close the stack valve and open the oil valve. The clutch is then de-energized by the drum 47, previously referred to, while the motor continues to run and drive the fan 34 for injecting the oil into the carburetter. The condition has now been established for a run of gas, and this continues for 150 seconds until the fuel needs reviving by the air blast.

The second run constitutes another up run and the proceeding is exactly the same as just described. When the drum has passed through 9½ minutes of its rotation, which is equivalent to the two runs and the third air blast, the contact 71 is put into communication with main 30 and the contacts 69 and 70 are connected together which produces the energizing of the solenoid 14 and the movement of the valve member 15 from the position shown in Fig. 43 to the position in which the pipe 16 is cut off and the pipe 17 opened. This operation synchronizes with the closing of the air valve and opening of the steam valve 55, so that the steam is passed into the top of the generator and the gas passed off at the bottom by way of pipe 17, which constitutes the down run. This condition continues for 150 seconds, when contact 69 is connected with the positive main, and the contacts 70 and 71 are connected together, by which the solenoid 14 is again energized and the valve 15 moved back to the position shown in Fig. 43 when the cycle again commences for another up run.

In large installations where considerable fuel is used, the drum 37 is geared with the shaft 5 at three to one, so that fuel is charged into the generator at each cycle while the drum makes one revolution in every three cycles in order to bring about the up and down runs in the proportion of two to one.

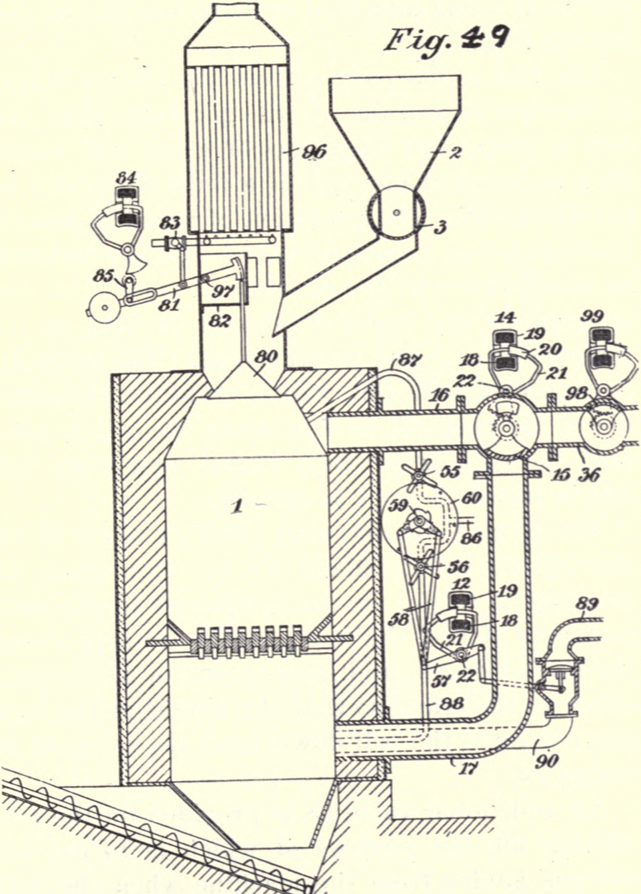
Blue Water Gas.

The automatic operation of blue water gas apparatus by electrical means is practically the same as in the previous example, and the proceeding is only slightly different in accordance with the different construction and purpose of the apparatus.

Referring to Fig. 49, the part 96 is a tubular steam boiler, and is connected with the gas generator with a flue section, which has a series of apertures for the admission of air for completing the combustion of the producer gases. This section is also provided with a gas burner ring controlled by the cock 83, which gives heat to the boiler during the gasmaking period, and is adapted to be almost turned off during the blasting period when the top of the generator is opened at 80 for the flow of producer gases.

The rod of the bell 80 is also connected by links (not shown) to the apertures in the flue section, so that these are partially closed when the generator is closed and opened when the bell is lowered. By this means the air supply is

Fig. 49



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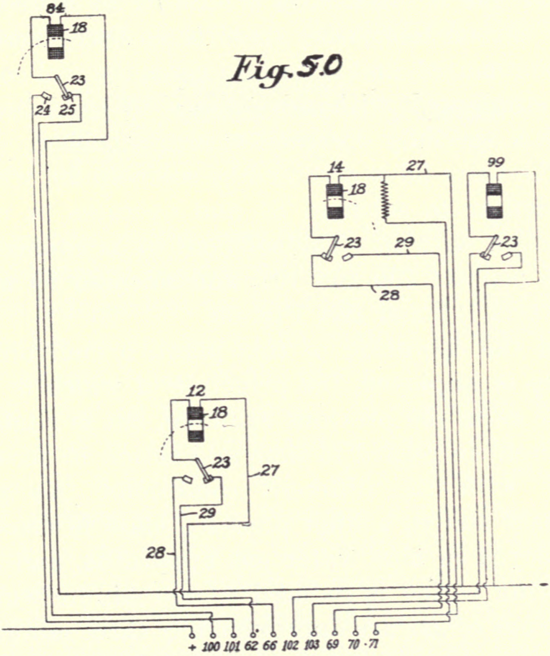
reduced to the boiler during the run of gas, only sufficient being admitted to burn the gas at the burner ring.

The fuel is discharged from the bucket 3 and to the bell 80 and then to the generator, and the bell is suspended by means of a rod and chain on a segment of one end of a lever 81, which is pivoted at 97. The provision of a rod as one of the connecting members insures that the bell can be forced down by the pressure of one end of the segment on the rod if it should be held up by the pressure of gas or otherwise. The lever 81 is connected by a link with a crank on the spindle of the cock 83, so that when the bell is lowered the cock is partially closed, and when the bell is raised the cock is opened.

The lever 81 is actuated through solenoid 84 through the intermediary of a pin on a crank 85 working in a slot in the lever, and in the two positions of rest the line of pressure acts along the line of crank, and thereby exerts no turning effect on the crank so that the weight of the fuel can not force the bell down until the solenoid is energized.

An additional valve 98 is provided on the gas off-take 36, the purpose of which is to cut off the gas holder from the machine when the bell is lowered, and thereby prevent gas from return-

Fig. 50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ing. It will be obvious that this valve has the same purpose as the water seal in carburetted water gas apparatus, but inasmuch as blue water gas is essentially a mixture of hydrogen and carbon monoxide, there is no tarry matter to be removed, and in certain cases the seal could be eliminated with advantages or substituted with a specially designed washer-scrubber.

The valve 98 is actuated by solenoid 99, which is similar to solenoid 84 and operates in conjunction with it. The solenoid 84 is connected with contact 100 and 101, and solenoid 99 with contacts 102 and 103, Fig. 50.

In the operation of this plant, a controlling drum is employed, the principle of which is the same as in the previous example, but is slightly different in regard to time and action in accordance with the different conditions. As previously stated, a high pressure blast is usually employed in blue water gas apparatus, and the blasting period is reduced to one minute whilst the runs of gas are approximately three minutes, which makes the cycle at four minutes, or one complete cycle of three runs at 12 minutes. The controlling drum, which is shown diagramatically in Fig. 51, is driven on the same shaft as the charging apparatus, and makes one revolution to three of the latter, and, as seen from the diagram, the solenoids all come into operation practically at the same time, by which it is possible to simplify the connection by allowing solenoids 12, 84 and 99 to be operated from the same contact members. The diagram, however,

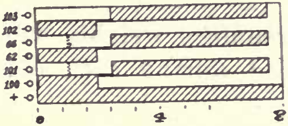

Fig. 51

is prepared on the assumption that it is desirable for electrical consideration to maintain the circuits independent so that they are not connected together except when the contact members are on the metal part of the drum.

In view of the sequence of operation being described in the carburetted water gas apparatus, it is believed that a detail description is not necessary in the blue gas apparatus, inasmuch as the action of the controlling drums on the solenoids and valves is practically the same. Briefly, the process is that of heating the bed of fuel to incandescence by a powerful air blast for a period of one minute, during which time the steam boiler is being heated by the complete combustion of the producer gases, after which the air blast is cut off and steam admitted instead for a period of three minutes, during which time gas is generated and carried off to the holder, and the steam boiler is heated by water gas from a burner ring as herebefore described.

It may here be pointed out that pivotal parts connected with the valves and solenoids are provided with counterbalance weights which serve to equalize the load during each of the two strokes, and the valves have also the lever attachment, each of which are connected by link mechanism to a lever at a centralized point so that in the case of an electrical breakdown the valves can be operated by hand, and by centralizing the operation one or more valves can be operated simultaneously and thereby effect a rapid changing action on the apparatus.

CHAPTER IX.

Hydraulic and Air Systems.

Hydraulic Control.

A recently adopted system 'of automatic control is that of acting on the valve mechanism by hydraulic power by means of a cam or tappet arrangement which controls the source of power. The object of this system is to provide means by which the power can be turned on in a rapid

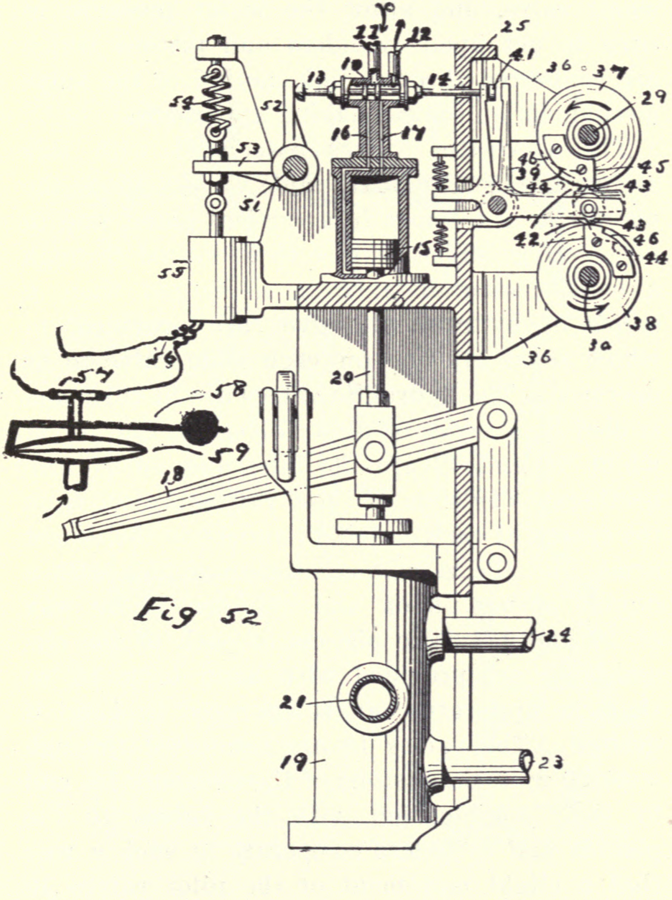
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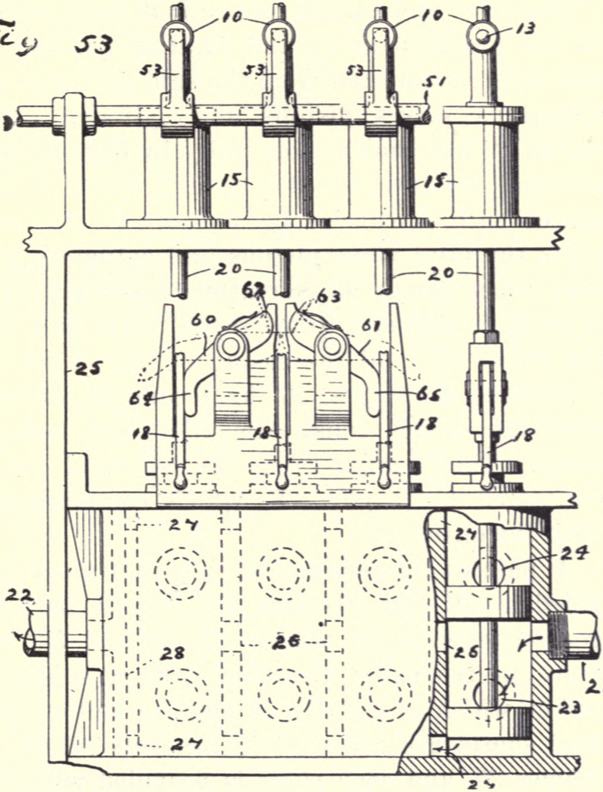
Fig 52

manner by the movement of a comparatively small valve, and allow the water pressure in turn to act upon cylinders and pistons which are connected through link motion to the valve mechanism on the gasmaking apparatus.

The apparatus valves associated with this system are usually of the slide variety where the pistons need to move in a vertical plane, and in large valves which require to be moved through a considerable distance in a limited time, a series of hydraulical valves are provided, of which there are one for each slide valve to be operated. The hydraulic valves are in turn controlled by a series of pilot valves 10, Fig. 52, of which 11 and 12 are the inlet and outlet connections. The stem of these valves project from the casing at each end at 13 and 14 to the tappet arms, and the valve body communicates with a double acting piston and cylinder 15 by way of 16 and 17. The pistons of each of the elements 15 are provided with hand lever 18, so that the apparatus can be operated by hand if desired. The valves 19 are connected through stem 20 with the pistons of the elements 15, and by their combination with the valves 10 the pistons and cylinders co-operate in such a way that a slight movement of the pilot valves 10 opens up large fluid ways to the valves 19 and

Fig 53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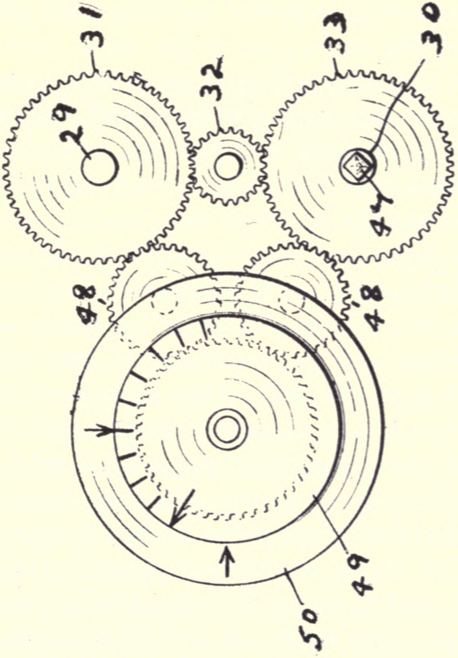
causes the slide valve on the gasmaking apparatus to move quickly through a comparatively long distance.

The inlet and outlet connections from valves 19 are provided at 21 and 22, Fig. 53, and 23 and 24 are connected from the said valves to the apparatus valves pistons and cylinders. The valves 19 are shown more fully in Fig. 53, and are enclosed in a suitable casing, which is connected with or carried by a frame 25 that supports the pilot valve pistons and cylinders, and also other parts as hereafter described. The inlet 21 is common to all these valves and also the outlet 22, and the casing of the valves are connected at 26 and 27 by means of suitable openings which constitute inlet and exhaust ports. The opening 27 at the left-hand end is connected by a port 28, which communicates with the outlet 22.

A pair of interconnected cam shafts are provided at 29 and 30, Figs. 52 and 54, and are geared together by wheels 31, 32 and 33, and move in the same direction from a source of power which is usually an electric motor. The said shafts are mounted in brackets 36 on the frames 25, and each shaft is provided with tappet or other projecting devices 37 and 38, of which there is a pair for each pilot valve. The

Fig 54



tappets of each pair operate upon one of a pair of spring retracted followers or tappet arms 39 and 40, which in turn operates respectively upon opposite faces of a head 41 on the pilot valve spindle. At the other ends of these arms a roller 42 is provided, which has a knife edge 43, and ordinarily runs on the rim of the cam, keeping the knife edge clear of it. When the tappet arm, however, is about to drop into the lower part of the cam, the roller first runs into a groove 44 in the cam, and permits the knife edge to ride on the wear plate 45, and finally allows it to drop into the low part 46. This results in the tappet arm being quickly moved for the subsequent operation of the apparatus valves. It should here be noted that the function of the two shafts with their respective cams and tappets is to operate the pilot valves in opposite directions, and the position of the tappets is such that at the end of the movement the pilot valves are left in a position relative to the operation of the gasmaking apparatus valves. The regulation of the shafts and their cams can be made by disengaging the wheel 32 and turning the shaft 30 by applying a crank to the square end 47, and meshing the wheel 32 to the desired position. The shafts 29 and 30 drive through a pair of gear wheels 48, two concentric dials 49 and 50, which serve to indicate the relative angular position of the said shafts.

A shaft 51, which is revolvably supported in the frame 25, is provided with tappet arms 52, Fig. 52, so that when the shaft 51 is turned from its normal position, its arms 52 push the pilot valves into a position which correspond to one of rest and safety of the valves on the gasmaking apparatus. On the shaft 51 there is also an arm 53, which is subjected to the pull of a spring 54, and also the pull of an electro-magnet 55.

When the circuit 56 is connected with a live wire, the spring and electro-magnet balance each other, and the parts associated therewith are in the position shown, but on the failure of current in the circuit the power of the spring predominates and turns the arm 53 into a position for bringing the arm 52 into action on the pilot valves. A circuit breaker 57 is provided in the live circuit, and is connected to a weighted arm 58 that is held up by a diaphragm 59, which is exposed to the fluid pressure system, which operates on the various apparatus valves. By this means a safety device is obtained, in that if the power in the fluid system fails, the circuit is interrupted and the safety mechanism controlled by the electro-magnet comes into operation. An extra precaution is also provided in the form of a pair of centrally pivoted dogs 60 and 61, Fig. 53, which are normally held in their position (dotted lines) by springs, in such a way that their inner ends 62 and 63 block the line of travel of one of the handles 18, which is linked to the stack valve and prevents the valve from being closed and thereby leaves the apparatus in a safe position. The handles 18 adjacent to the stack valve handle constitute the generator and carburetter air blast, and operate the tail of the dogs 64 and 65 when pulled down and turn the dogs into the position shown by full lines in which their inner ends does not block the stack valve handle. In this arrangement it is obvious that the stack valve handle can not be pulled down until the generator and carburetter blasts have been pulled down, and when all the valves are in the up position, it is evident that the air blast must be cut off first before the stack valve can be closed.

The operation of the process according to this system may be briefly described as follows: The speed of the shafts 29 and 30 is adjusted so that each makes one revolution in each cycle of operation of the gasmaking apparatus. The cams 38 on the shaft 30 are set in respect to each other that they cause the mechanism with which they coact to move the valves at the end of the run and commencement of the blast, and the cams 37 on the shaft 29 are set in their respective order to move the valves at the end of the blast and commencement of the run.

This condition continues while the mechanism is in working order, and in the event of a failing of power on the shafts, the safety device comes into operation and leaves the apparatus in a safe position, whereafter the machine can be operated manually by levers 18 until the automatic mechanism is repaired.

Air Control.

A modification of the latter apparatus is that in which hydraulic pistons are employed to actuate the apparatus valves, while the control is affected by means of air pressures acting on the fluids in the hydraulic cylinders.

The air control is a development of the former apparatus, and its object is to produce greater activity in turning on or off the source of power and thereby speed up the movement of valves passing through a long distance of travel, as in the case of large gate valves which are usually employed in connection with these systems.

The air controlling valves, Fig. 55, are actuated from a constant speed shaft, which carries a series of cams, of which there is one for each valve to be operated. Each of the valves on the gasmaking apparatus are self-closing, with the exception of the stack valve, in the sense that the operating levers 1, Fig. 56, are provided

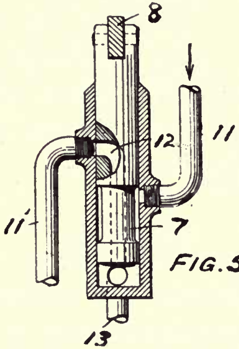
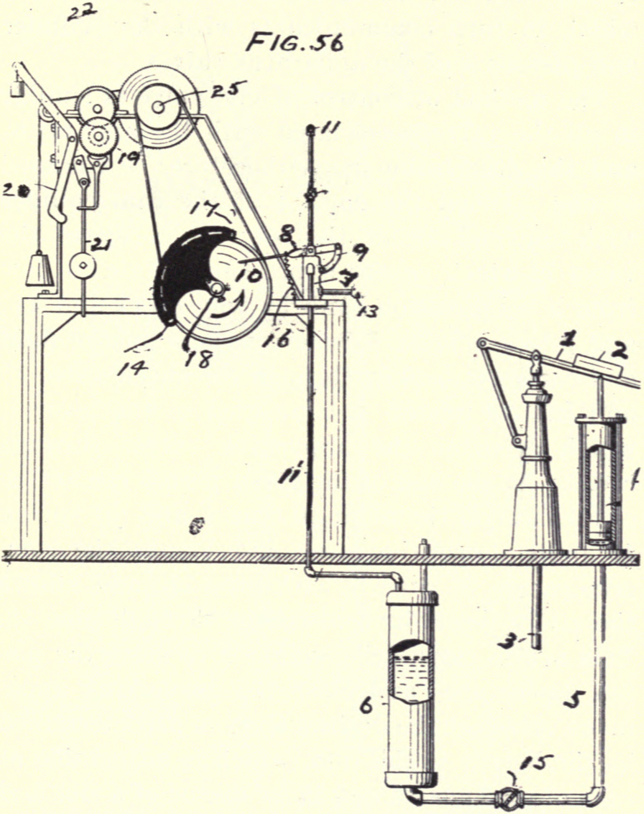


FIG. 55

with weights 2, which force down the rods 3 when the upward pressure is released. Attached to each lever there is fluid cylinder and piston 4 connected by a pipe 5 to a reservoir 6. These pipes have interposed in them a valve 7, the stem of which is connected with levers 8, pivoted at 9, and have their ends 10 in range of the cams. When the valves 7 are in the position shown in Fig. 55, they correspond to the position of the lever 8, shown in Fig. 56, so that the pipe 11′ is in communication by means of port 12 with the exhaust pipe 13, but when the end of the

FIG. 56



lever is raised the pipe 11 is put into communication with 11′, which leads to the reservoir 6, which in turn communicates with the cylinder and pistons 4 of the apparatus valves.

The method of control of one valve is similar in all the valves associated with the apparatus, and the description may, therefore, be confined to one. When the end 14 of the cam collides with the end 10 of the lever 8, it opens the valve 7, which causes a pressure of air to flow from a compression tank by way of 11 and 11′, and into reservoir 6, where it acts on the fluid and causes it to flow through the check valve 15 and lift the piston 4, connected to the lever 1, which actuates the apparatus valves through rod 3. At the end of the given period the action of the cam on the point 10 ceases, and the spring 16 pulls down the lever and breaks the communication of valve 7 with pipe 11′, and allows the air in reservoir 6 to escape through pipe 13. This action causes the weight 2 to move the piston downwards and close the gasmaking apparatus valves at the desired time as predetermined by the length of the cam, which is adjustable at each of the ends 14 and 17 by means of a slot and pin connection.

The shaft 18 controls the operation on a cycle, according to its speed of rotation, and is driven

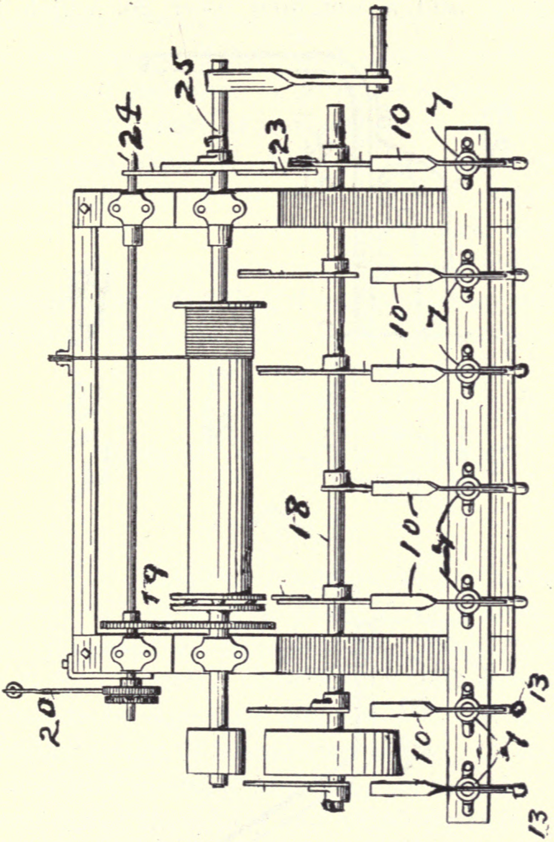


FIG. 57

by a clockwork arrangement. This consists of a gear 19, Figs. 56 and 57, connected with the clockwork, and a weighted lever 20, which is

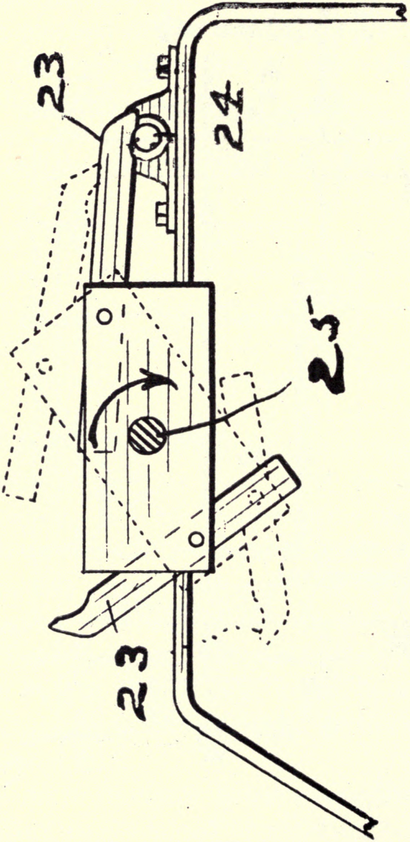


FIG. 58

adapted when released to arrest the pendulum 21 out of the plumb and stop the clockwork, and also when restrained by the cord, it is adapted to free the pendulum and consequently let it swing and oscillate. A governor is also provided to keep the shaft at normal speed, and consists of pivotal arms 23, Fig. 58, which at normal speed clears the projections 24, as illustrated by dotted lines, but which, at an increase in speed, strikes the projection and arrests the clockwork. The arms constituting the governor are adjustable by winding the shaft 25 of the clockwork.

CHAPTER X.

Construction Developments.

Valve Mechanism.

In the previous descriptions of automatic operation it is obvious that the apparatus illustrated constitute three distinct principles of control, from which a variety of modifications may arise, to be especially adaptable to any one particular design of apparatus valves. In the electrical and mechanical arrangements, the valves used are of the rotary and angle types, inasmuch as these valves move through the smallest distance of travel in opening and closing, and thereby effect a most rapid opening and closing of the connections associated therewith, whilst at the same time the valves are equally balanced for movement in either direction. In the hydraulic and air system of control it is evident that the action is especially adaptable to valves of the slide variety, in view of the fact that the primary object is to effect a rapid action on valves passing through a long distance of travel by the movement of an air or hydraulic valve, which is comparatively smaller, and thereby only need move through a short distance in order to apply the power to the apparatus valves.

It has been claimed, however, that the air and hydraulic systems are more adaptable to machines already in operation by manual labor, inasmuch as the slide valve is almost universally adopted in these plants, and that by applying the automatic operation to apparatus without the substitution of a different type of valve, a less outlay of capital will be needed. Whilst this claim may carry some weight with those unskilled in the art, it is clear to the technical man that the efficiency of the mechanical or electrical operation on the valves illustrated is much greater than the hydraulic or air systems on the slide valve, and would more than compensate the outlay of capital in substituting types of valves especially suitable to automatic operation. It is clear, however, that the mechanical means is equally adaptable to valves of the slide variety, in view of the fact that the power can be made to act in either a vertical or horizontal plane, whilst positive action is assured at all times. A convenient and substantial mechanical arrangement applicable to valves of the slide variety would be to provide a shaft running at constant speed in accordance with the cycle, and connected to the rack of the slide valve by means of gear wheels, which are put into communication at the required time by sliding pinions actuated by a lever or grooved cam. In this way a rapid action would be obtained on the valves, and such could be opened at any desired speed, according to the speed of the shaft and size of the pinions. In the writer's opinion, however, the slide valve is not to be recommended for automatic operation, in view of the unequal weight in its up and down movement, and comparatively long distance of travel, and it is believed that the valves illustrated in the mechanical and electrical methods possess a much greater efficiency.

AUTOMATIC CLINKERING.

It has been shown that the importance of keeping the fire in a healthy condition comes second to none in the economical operation of water gas apparatus, and various attempts have been made to remove the ashes and clinker automatically. It is well known that in the direct fired furnaces as used in the generation of steam, there are many designs of moving grates which have met with a fair degree of success, but in water gas apparatus, however, the conditions are more difficult, in view of the higher and variable temperatures brought about by the alternation of the run and blow, and also amount of fuel used per square foot of grate area per unit of time. In the methods that have been tried it is found that the larger masses of clinker could not be successfully removed, whilst the movement of the smaller ash was accompanied by the removal of a comparatively large amount of small fuel, and was, therefore, not economical. It was also found that the grate bars suffer rapid deterioration by the heat brought down upon them during the down run.

A modification of the rocking grate which may claim to have a fair degree of efficiency is that which is only moved occasionally at the most suitable time. In this grate the bars are of ordinary construction, and are adapted to be moved at intervals of about 30 minutes for one or two oscillations only. The period of oscillation takes place immediately after the down run, and breaks up the thin layer of clinker so that it falls through the grate bars into a pit from which it is carried away by a worm discharge working in a water seal. The object of moving the bars after the down run is that the clinker formed during the next three blasting periods provide a protection for the bars when they are subjected to the heat under the pressure of the down run, and in small installations where the clinker formed would not be sufficient to form a layer the design of the bars are such that they turn over at each oscillation period and the surface previously exposed to the fire is exposed to the cooling action of the steam during the next period of three cycles, so that the same surface of the bars are only exposed to the influence of the down run but once without being cooled by the steam which enters beneath the grate during the up run.

From the previous description of automatic operation it will be clear that the bars can be actuated at the required time in a variety of ways, and this will need no further description.

In view of the fact, however, that the movement of the bars is only required at certain times, it may, in certain cases, be more economical to move them manually by means of a lever which may be connected to a source of power, or by a wheel suitably geared down to the actuating shaft.

Carburetting Zone.

In injecting the oil into the carburetter it is found that the top courses of brick suffer more rapid deterioration than the rest of the apparatus, which is partly due to the force of the injection, and partly to the greater variation of temperature at the beginning and end of the run. During the air blasting period these top courses of brick receive the greater percentage of sensible heat from the generator, and are consequently heated to a higher degree during the air blast than the rest of the machine. When the oil is injected these bricks are subjected to the pressure of the injection and are splintered at the result. It is to be noted, however, that the temperature of the carburetter needs to be higher at this point than the rest of the machine, in order to supply an extra heat equivalent to the "latent heat of vaporization" of the oil, and the object of the carburetting zone is to provide means by which the top of the carburetter can be raised to a temperature which is comparatively higher than the rest of the fixing apparatus, and thereby supply sufficient heat for the vaporization of the oil at one centralized point and enable the temperature of the fixing chamber to remain more constant and consequently lengthen the life of the brickwork contained therein. Assuming that the pyrometer at the bottom of the carburetter records 1,400° F., it may generally be taken that the top of the carburetter is about 100° F. higher while the top of the superheater is 100° F. lower, the gradual fall in temperature being due to the vaporization and breaking up of the oil as it passes through the apparatus. If, then, the vaporization of the oil could be centralized, a portion of the carburetter and superheater would remain at a more constant temperature throughout, whilst the centralized point or carburetting zone could be filled with special constructed brickwork adapted to withstand the higher temperature. In order to raise this zone to a temperature which is comparatively higher than the rest of the apparatus, it is suggested that the walls of the zone be built oval so that the blast gases are given a circular motion, and instead of passing direct through the apparatus, they repeatedly react on the brickwork contained in the zone and thereby give up a greater percentage of heat within it. If the oil is then injected in a fine mist by means of a fan or otherwise, and led into the zone in a circular manner, the latent heat of vaporization of the oil will be counteracted under the higher temperature and repeated contact, and the rest of the apparatus will remain at a more constant temperature and break up the oil vapor to the required degree, instead of subjecting the oil vapors to the variable temperature and evitably producing excess decomposition to a certain amount of the lighter hydrocarbons.

Self Sealing Cap.

At the stack valve or cap it is usual to provide a pilot light to burn up gases which are liable to leak through the valve, as these gases, when passed into the atmosphere unburnt, produce complaints from neighboring residents. It is well known that this valve frequently becomes coated with lampblack and tar, and occasionally during working periods the waste of gas is comparatively large. It is obvious that this condition could be easily and inexpensively remedied by providing a cap with an outer rim adapted to dip into a water seal when the cap is closed. The escape of gas could then be passed off through a pipe in the seal basin to the wash box, or to a small holder of about 10 cubic feet capacity, where it provides a good mixture for an indicating photometer or for analytical purposes. The seal and rim could be provided with an opening extending to within one inch of the cap seating for the usual pilot light to ignite unburnt gases during the blasting period.

NOTES ON CONSTRUCTION.

The engineer who is contemplating the erection of water gas apparatus will find it to advantage to compute the cost of constructional developments associated with the apparatus before deciding upon a contractor's estimate. Of course, local rates can usually be obtained for excavation, concrete work, bricklaying and carpentry, but in the face of this the essential data for obtaining such prices will generally be of service.

EXCAVATION.

It will be in order to first consider the item of excavation of a trench, say, five feet deep, which included the leveling of the bottom and fixing or removing planking. Assuming that the ground is of ordinary description, the amount of soil capable of being thrown out per man per day of nine hours may be taken at nine cubic yards, at a cost of approximately $1.50, or 16.66 cents per cubic yard, to which may be added one-tenth for the laying and removing of planks, which makes the cost at about 18.30 cents per cubic yard, and it will also be well to provide one-tenth for supervision, making the total cost at approximately 20 cents.

Concrete.

The concrete floor of the generator house should then be considered, and a mixture of one part of cement to five parts of a mixture of gravel and sand will, under ordinary conditions, be found suitable. In view of the fact that the sand and cement diminishes in volume when mixed with water, the approximate quantities per cubic yard may be taken as:

.75 cubic yards of gravel.
.50 " " " sand.
.25 " " " cement.
25 gallons of water.

The cost of these materials varies considerably, according to the location, and on the average may be taken at $2.10, to which 20 cents per cubic yard should be allowed for laying and 10 per cent. for superintendence, making the total cost at approximately $2.50 per cubic yard. Assuming that the floor is to be laid at a thickness of nine inches, one cubic yard will be equal to four square yards of floor surface, which makes the cost per square yard at $0.625.

Brickwork.

In computing the cost of brickwork it is well to first consider the lime mortar, which may be computed of one part lime to three parts of sand, and 40 gallons of water per cubic yard. The cost of these materials also vary greatly according to location, and may be taken at $3.25 per cubic yard, with an addition of 45 cents for labor or $3.70 per cubic yard. Assuming the brickwork to be one and one-half bricks in thickness, the material desired per rod will be approximately:

4,500 bricks at $10 per 1,000	$45.00
500 gallons of water	.10
Bricklayers' time (four days at $5)	20.00
Laborers' time (four days at $1.50)	6.00
Scaffolding	1.50

Two cubic yards of mortar...............	7.40
	$80.00
Ten per cent. superintendence.........	8.00
	$88.00

This does not include pointing the building, and if same is desired a 1 per cent. allowance should be made.

Columns and Girders.

On the roof and floor of a generator house it is necessary to eliminate wood of any description and provide steel girders and columns, as the temperature of the room and liability of explosion would be an incentive to fire in the presence of timber. The main girders are usually about eight inches, and are built in the wall, and extend the length and breadth of the building with supporting columns or angle irons at about every ten feet. It is necessary to provide for four-inch girders which are bolted at right angles to the main girders at about every three or four feet to receive the floor plates, which are usually of cast iron.

The roofing is provided by extending six-inch girders over the breadth of the building at distances of about 15 feet, upon which are placed smaller girders at distances which vary according to the roofing material. This may be of tiles, slates, or corrugated iron, and the cost will vary accordingly. With this data the amount of girder and roofing material can be computed, and this in combination with the cost of material per ton will give the approximate cost per unit, to which must be added a labor and superintendence allowance.

Carpentry.

The item of carpentry and glaziers with reference to windows is subject to wide variation, according to the location of the building and the number of open sides, and also the supply of material is purely a local proposition and in general it will be more economical to obtain estimates locally for frames and windows complete.

APPENDIX

TEMPERATURE AND BAROMETRIC FACTORS.

	Barometer.									
Temp.	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.0	29.3	29.4
105.	.820	.823	.827	.830	.833	.836	.839	.842	.845	.848
104.	.823	.827	.830	.833	.836	.839	.842	.845	.848	.851
103.	.827	.830	.834	.837	.840	.843	.847	.849	.852	.855
102.	.830	.834	.837	.840	.843	.847	.850	.853	.856	.859
101.	.834	.837	.840	.843	.846	.850	.853	.856	.859	.862
100.	.837	.840	.843	.846	.849	.853	.856	.859	.862	.865
99.	.840	.844	.846	.850	.853	.857	.860	.863	.866	.869
98.	.844	.847	.850	.853	.856	.860	.863	.866	.869	.872
97.	.847	.850	.853	.856	.859	.863	.866	.870	.873	.876
96.	.850	.854	.857	.860	.863	.867	.870	.873	.876	.879
95.	.854	.857	.860	.863	.866	.870	.873	.876	.879	.882
94.	.857	.860	.863	.866	.869	.873	.876	.879	.882	.885
93.	.860	.863	.866	.869	.872	.876	.879	.883	.886	.889
92.	.863	.866	.869	.872	.875	.879	.882	.885	.889	.892
91.	.866	.869	.872	.875	.879	.882	.885	.889	.892	.895
90.	.869	.872	.875	.878	.881	.885	.888	.892	.895	.898
89.	.871	.875	.878	.882	.885	.889	.892	.895	.898	.901
88.	.875	.878	.881	.885	.888	.892	.895	.898	.901	.904
87.	.878	.881	.884	.888	.891	.895	.898	.901	.904	.907
86.	.881	.884	.887	.890	.894	.898	.901	.904	.907	.910
85.	.884	.887	.890	.893	.896	.900	.903	.906	.909	.913
84.	.887	.889	.893	.896	.899	.903	.906	.909	.912	.915
83.	.889	.892	.895	.899	.902	.906	.909	.912	.915	.918
82.	.892	.895	.898	.901	.905	.908	.911	.914	.918	.921
81.	.895	.898	.901	.905	.908	.911	.914	.917	.921	.924
80.	.898	.901	.904	.907	.910	.914	.917	.920	.923	.927
79.	.901	.904	.907	.910	.914	.917	.920	.923	.926	.930
78.	.904	.906	.909	.913	.916	.919	.923	.926	.929	.932
77.	.906	.909	.912	.915	.919	.922	.925	.928	.931	.935
76.	.909	.911	.915	.918	.921	.925	.928	.931	.935	.938
75.	.911	.914	.917	.921	.924	.928	.931	.934	.937	.940
74.	.914	.917	.920	.924	.927	.930	.933	.937	.940	.943
73.	.917	.920	.923	.926	.930	.933	.936	.940	.943	.946
72.	.920	.923	.925	.929	.932	.935	.939	.942	.945	.949
71.	.922	.925	.928	.931	.935	.938	.941	.944	.948	.951
70.	.925	.927	.931	.934	.937	.941	.944	.947	.950	.954
69.	.927	.930	.938	.937	.940	.944	.947	.950	.953	.957
68.	.930	.932	.936	.939	.942	.946	.949	.952	.956	.959

TEMPERATURE AND BAROMETER FACTORS.

Barometer.—(Continued.)

Temp.	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.0	29.3	29.4
67.	.932	.935	.938	.942	.945	.949	.952	.955	.959	.962
66.	.935	.938	.941	.944	.948	.951	.954	.958	.961	.964
65.	.938	.941	.944	.947	.950	.954	.957	.960	.963	.967
64.	.941	.943	.946	.949	.952	.956	.959	.963	.966	.969
63.	.943	.945	.949	.952	.955	.959	.962	.965	.969	.972
62.	.945	.947	.951	.954	.958	.961	.964	.968	.971	.975
61.	.947	.950	.954	.957	.961	.964	.967	.971	.974	.977
60.	.950	.952	.956	.959	.963	.966	.969	.973	.976	.980
59.	.952	.955	.959	.962	.966	.969	.972	.976	.979	.983
58.	.955	.957	.961	.964	.968	.971	.975	.978	.981	.985
57.	.957	.960	.963	.967	.970	.974	.977	.980	.984	.988
56.	.960	.962	.966	.969	.973	.976	.979	.982	.986	.990
55.	.962	.965	.968	.972	.975	.979	.982	.985	.989	.993
54.	.965	.967	.970	.974	.977	.981	.984	.988	.991	.995
53.	.967	.969	.973	.976	.980	.983	.986	.990	.993	.997
52.	.969	.971	.975	.978	.982	.985	.989	.992	.996	.999
51.	.971	.974	.977	.981	.984	.988	.991	.995	.998	1.002
50.	.974	.976	.980	.983	.987	.990	.994	.997	1.001	1.004
49.	.976	.979	.982	.986	.989	.993	.996	1.000	1.003	1.007
48.	.979	.981	.985	.988	.992	.995	.999	1.002	1.006	1.009
47.	.981	.984	.987	.991	.994	.998	1.001	1.005	1.008	1.012
46.	.984	.986	.990	.993	.997	1.000	1.004	1.007	1.011	1.014
45.	.986	.989	.992	.996	.999	1.003	1.006	1.010	1.013	1.017
44.	.989	.991	.994	.996	1.001	1.005	1.008	1.012	1.015	1.019
43.	.991	.993	.996	1.000	1.004	1.008	1.011	1.015	1.018	1.022
42.	.993	.995	.999	1.003	1.006	1.010	1.013	1.017	1.020	1.024
41.	.995	.998	1.001	1.005	1.009	1.012	1.016	1.019	1.022	1.026
40.	.998	1.000	1.003	1.007	1.011	1.015	1.018	1.022	1.025	1.028
39.	1.000	1.003	1.006	1.010	1.013	1.017	1.020	1.024	1.027	1.031
38.	1.003	1.005	1.009	1.012	1.016	1.020	1.023	1.027	1.030	1.034
37.	1.005	1.007	1.011	1.015	1.018	1.022	1.025	1.029	1.032	1.036
36.	1.007	1.009	1.013	1.017	1.020	1.024	1.027	1.031	1.035	1.038
35.	1.009	1.012	1.015	1.019	1.023	1.026	1.030	1.033	1.037	1.040
34.	1.012	1.014	1.018	1.022	1.025	1.029	1.032	1.036	1.040	1.043
33.	1.014	1.016	1.020	1.024	1.027	1.031	1.034	1.038	1.042	1.046
32.	1.016	1.019	1.023	1.027	1.030	1.034	1.037	1.041	1.044	1.048
31.	1.019	1.021	1.025	1.029	1.032	1.036	1.039	1.043	1.047	1.050
30.	1.021	1.023	1.027	1.031	1.034	1.038	1.042	1.045	1.049	1.053
29.	1.023	1.026	1.030	1.033	1.037	1.040	1.044	1.048	1.051	1.055
28.	1.026	1.028	1.032	1.036	1.039	1.043	1.047	1.050	1.054	1.058

TEMPERATURE AND BAROMETER FACTORS.

Barometer.—(Continued.)

Temp.	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.0	29.3	29.4
27.	1.028	1.030	1.034	1.038	1.041	1.045	1.049	1.053	1.056	1.060
26.	1.030	1.033	1.037	1.041	1.044	1.048	1.051	1.055	1.059	1.062
25.	1.033	1.035	1.039	1.043	1.046	1.050	1.054	1.057	1.061	1.065
24.	1.035	1.037	1.041	1.045	1.048	1.052	1.056	1.060	1.064	1.067
23.	1.037	1.040	1.044	1.048	1.051	1.055	1.058	1.062	1.066	1.069
22.	1.040	1.042	1.046	1.050	1.053	1.057	1.061	1.065	1.068	1.072
21.	1.042	1.044	1.048	1.052	1.055	1.059	1.063	1.067	1.071	1.074
20.	1.044	1.047	1.051	1.055	1.058	1.062	1.065	1.069	1.072	1.076
19.	1.047	1.050	1.054	1.058	1.061	1.065	1.068	1.072	1.076	1.079
18.	1.050	1.052	1.056	1.060	1.063	1.067	1.070	1.074	1.078	1.082
17.	1.052	1.055	1.059	1.062	1.066	1.069	1.073	1.076	1.080	1.084
16.	1.055	1.057	1.061	1.064	1.068	1.071	1.075	1.079	1.083	1.086
15.	1.057	1.059	1.063	1.066	1.070	1.074	1.077	1.081	1.085	1.088
14.	1.059	1.062	1.066	1.069	1.073	1.076	1.080	1.084	1.087	1.091
13.	1.062	1.064	1.068	1.071	1.075	1.078	1.082	1.086	1.090	1.094
12.	1.064	1.066	1.070	1.073	1.077	1.080	1.084	1.088	1.092	1.096
11.	1.066	1.069	1.073	1.076	1.080	1.083	1.087	1.091	1.095	1.098
10.	1.069	1.071	1.075	1.078	1.082	1.086	1.090	1.093	1.097	1.101
9.	1.071	1.073	1.077	1.081	1.084	1.088	1.092	1.095	1.099	1.103
8.	1.073	1.076	1.079	1.083	1.087	1.090	1.094	1.098	1.102	1.105
7.	1.076	1.078	1.082	1.085	1.089	1.093	1.096	1.100	1.104	1.108
6.	1.078	1.080	1.084	1.088	1.091	1.095	1.099	1.103	1.107	1.111
5.	1.080	1.083	1.087	1.090	1.094	1.098	1.102	1.105	1.109	1.113
4.	1.083	1.085	1.089	1.092	1.096	1.100	1.104	1.108	1.111	1.115
3.	1.085	1.088	1.092	1.095	1.099	1.103	1.107	1.111	1.114	1.118
2.	1.088	1.090	1.094	1.098	1.101	1.105	1.109	1.113	1.117	1.121
1.	1.090	1.093	1.097	1.100	1.104	1.108	1.111	1.115	1.119	1.123
0.	1.093	1.095	1.099	1.103	1.107	1.111	1.114	1.118	1.122	1.126

BAROMETER.

Temp.	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5
105.	.851	.855	.858	.861	.864	.867	.871	.874	.878	.881	.884
104.	.854	.858	.861	.864	.867	.871	.874	.878	.881	.884	.887
103.	.858	.862	.865	.868	.871	.874	.878	.881	.885	.888	.891
102.	.862	.865	.868	.871	.874	.878	.881	.885	.888	.891	.894
101.	.865	.868	.872	.875	.878	.882	.885	.888	.891	.895	.898
100.	.868	.872	.875	.878	.881	.885	.888	.891	.895	.898	.901
99.	.872	.876	.879	.882	.885	.889	.892	.895	.898	.902	.905
98.	.875	.879	.882	.885	.888	.892	.895	.898	.902	.905	.908
97.	.879	.882	.885	.888	.891	.894	.898	.901	.905	.908	.911
96.	.882	.886	.889	.892	.895	.898	.901	.904	.908	.911	.914
95.	.885	.889	.892	.895	.898	.901	.904	.907	.911	.914	.918
94.	.888	.892	.895	.898	.901	.904	.907	.911	.914	.918	.921
93.	.891	.895	.898	.901	.904	.907	.910	.914	.918	.921	.924
92.	.894	.898	.902	.904	.907	.910	.914	.917	.921	.924	.928
91.	.898	.902	.905	.908	.911	.914	.917	.921	.924	.928	.931
90.	.901	.905	.908	.911	.914	.917	.920	.924	.927	.931	.934
89.	.904	.907	.910	.914	.917	.920	.923	.927	.931	.934	.937
88.	.907	.910	.913	.917	.920	.923	.926	.930	.934	.937	.940
87.	.910	.913	.916	.920	.923	.926	.929	.933	.937	.940	.943
86.	.913	.916	.919	.923	.926	.929	.932	.936	.940	.943	.946
85.	.916	.919	.922	.926	.929	.932	.936	.939	.943	.946	.949
84.	.919	.922	.925	.928	.932	.935	.939	.942	.946	.949	.952
83.	.921	.924	.928	.931	.935	.938	.942	.945	.949	.952	.955
82.	.924	.927	.931	.934	.937	.941	.945	.948	.951	.954	.958
81.	.927	.930	.934	.937	.940	.944	.948	.951	.954	.957	.960
80.	.930	.933	.937	.940	.943	.946	.950	.954	.957	.960	.963
79.	.933	.936	.939	.943	.946	.949	.953	.956	.960	.963	.967
78.	.936	.939	.942	.946	.949	.952	.956	.959	.962	.966	.969
77.	.938	.942	.945	.948	.951	.955	.958	.962	.965	.968	.972
76.	.941	.944	.948	.951	.954	.958	.961	.964	.968	.971	.975
75.	.943	.947	.950	.954	.957	.960	.963	.967	.971	.974	.978
74.	.947	.950	.953	.957	.960	.963	.966	.970	.973	.977	.980
73.	.949	.953	.956	.960	.963	.966	.969	.972	.976	.980	.983
72.	.952	.955	.959	.962	.965	.968	.972	.975	.979	.982	.986
71.	.954	.958	.961	.965	.968	.971	.975	.978	.981	.985	.989
70.	.957	.960	.964	.967	.970	.974	.977	.980	.984	.988	.991
69.	.960	.963	.967	.970	.973	.977	.980	.983	.987	.990	.994
68.	.962	.966	.969	.972	.976	.979	.983	.986	.989	.993	.997
67.	.965	.968	.972	.975	.979	.982	.985	.989	.992	.996	1.000
66.	.968	.971	.974	.978	.981	.985	.988	.992	.995	.998	1.002
65.	.970	.973	.977	.980	.984	.987	.991	.994	.997	1.001	1.005

BAROMETER.—(Continued.)

Temp.	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5
64.	.973	.976	.980	.983	.986	.990	.994	.997	1.000	1.004	1.008
63.	.975	.979	.982	.985	.989	.993	.996	1.000	1.003	1.006	1.010
62.	.978	.981	.985	.988	.991	.995	.999	1.002	1.006	1.009	1.013
61.	.981	.984	.987	.991	.994	.998	1.001	1.004	1.008	1.011	1.015
60.	.983	.986	.990	.993	.997	1.000	1.004	1.007	1.010	1.014	1.017
59.	.986	.989	.992	.995	.999	1.003	1.006	1.010	1.013	1.016	1.020
58.	.988	.992	.995	.998	1.002	1.005	1.009	1.012	1.016	1.019	1.023
57.	.991	.994	.997	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025
56.	.993	.996	1.000	1.003	1.007	1.010	1.014	1.017	1.021	1.024	1.028
55.	.996	.999	1.002	1.006	1.009	1.013	1.016	1.020	1.023	1.027	1.030
54.	.998	1.001	1.005	1.008	1.012	1.015	1.019	1.022	1.026	1.029	1.033
53.	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025	1.028	1.031	1.035
52.	1.003	1.006	1.010	1.013	1.017	1.020	1.024	1.027	1.031	1.034	1.038
51.	1.005	1.009	1.012	1.016	1.019	1.023	1.026	1.030	1.033	1.037	1.040
50.	1.008	1.011	1.015	1.018	1.022	1.025	1.029	1.032	1.036	1.039	1.043
49.	1.010	1.014	1.017	1.021	1.024	1.028	1.031	1.035	1.038	1.042	1.045
48.	1.013	1.016	1.020	1.023	1.027	1.030	1.034	1.037	1.041	1.044	1.048
47.	1.015	1.019	1.022	1.026	1.029	1.032	1.036	1.040	1.045	1.047	1.050
46.	1.018	1.021	1.025	1.028	1.032	1.035	1.039	1.042	1.046	1.049	1.053
45.	1.020	1.024	1.027	1.031	1.034	1.038	1.041	1.045	1.048	1.052	1.056
44.	1.022	1.026	1.029	1.033	1.036	1.040	1.043	1.047	1.050	1.054	1.058
43.	1.025	1.029	1.032	1.036	1.039	1.043	1.046	1.050	1.053	1.057	1.060
42.	1.027	1.031	1.034	1.038	1.041	1.045	1.048	1.052	1.055	1.059	1.063
41.	1.030	1.032	1.037	1.041	1.044	1.048	1.051	1.055	1.058	1.062	1.065
40.	1.032	1.036	1.039	1.043	1.046	1.050	1.054	1.057	1.060	1.064	1.068
39.	1.035	1.039	1.042	1.045	1.049	1.053	1.056	1.059	1.063	1.066	1.070
38.	1.037	1.041	1.044	1.048	1.051	1.055	1.058	1.062	1.065	1.069	1.073
37.	1.039	1.043	1.046	1.050	1.053	1.057	1.060	1.064	1.068	1.072	1.076
36.	1.042	1.045	1.049	1.052	1.056	1.060	1.063	1.067	1.071	1.074	1.078
35.	1.044	1.048	1.051	1.055	1.058	1.062	1.065	1.069	1.073	1.076	1.081
34.	1.047	1.050	1.054	1.057	1.061	1.064	1.068	1.072	1.075	1.079	1.083
33.	1.049	1.053	1.056	1.060	1.063	1.067	1.070	1.074	1.078	1.082	1.086
32.	1.051	1.055	1.058	1.062	1.066	1.069	1.073	1.077	1.081	1.085	1.089
31.	1.054	1.057	1.061	1.064	1.068	1.072	1.075	1.079	1.083	1.087	1.091
30.	1.056	1.060	1.063	1.067	1.071	1.074	1.078	1.082	1.086	1.090	1.094
29.	1.058	1.062	1.065	1.069	1.073	1.076	1.080	1.084	1.088	1.092	1.096
28.	1.061	1.065	1.068	1.072	1.075	1.079	1.083	1.087	1.091	1.095	1.099
27.	1.063	1.067	1.070	1.074	1.078	1.082	1.086	1.090	1.094	1.098	1.102
26.	1.066	1.069	1.073	1.077	1.080	1.084	1.088	1.092	1.096	1.100	1.104
25.	1.068	1.072	1.075	1.079	1.083	1.086	1.090	1.094	1.098	1.102	1.106
24.	1.071	1.074	1.078	1.081	1.085	1.089	1.093	1.097	1.101	1.105	1.109
23.	1.073	1.076	1.080	1.084	1.088	1.092	1.095	1.099	1.103	1.107	1.111

BAROMETER.—(Continued.)

Temp.	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5
22.	1.075	1.079	1.083	1.086	1.090	1.094	1.098	1.102	1.106	1.110	1.114
21.	1.078	1.081	1.085	1.089	1.093	1.096	1.100	1.104	1.108	1.112	1.116
20.	1.080	1.084	1.087	1.091	1.095	1.099	1.103	1.107	1.111	1.115	1.118
19.	1.083	1.087	1.090	1.093	1.098	1.102	1.106	1.110	1.114	1.118	1.121
18.	1.085	1.089	1.093	1.097	1.100	1.104	1.108	1.112	1.116	1.120	1.124
17.	1.088	1.091	1.095	1.099	1.102	1.106	1.110	1.114	1.118	1.122	1.126
16.	1.090	1.094	1.099	1.101	1.105	1.109	1.113	1.117	1.121	1.125	1.129
15.	1.092	1.096	1.100	1.103	1.107	1.111	1.115	1.119	1.123	1.127	1.131
14.	1.095	1.099	1.102	1.106	1.110	1.114	1.117	1.121	1.125	1.129	1.133
13.	1.097	1.101	1.105	1.109	1.112	1.116	1.120	1.124	1.128	1.132	1.136
12.	1.100	1.103	1.107	1.111	1.115	1.119	1.122	1.126	1.130	1.134	1.138
11.	1.102	1.106	1.110	1.114	1.117	1.121	1.125	1.129	1.133	1.137	1.141
10.	1.105	1.108	1.112	1.116	1.120	1.123	1.127	1.131	1.135	1.139	1.143
9.	1.107	1.111	1.114	1.118	1.122	1.126	1.130	1.133	1.137	1.141	1.145
8.	1.109	1.113	1.117	1.121	1.125	1.128	1.132	1.136	1.140	1.144	1.148
7.	1.112	1.115	1.119	1.123	1.127	1.131	1.135	1.139	1.143	1.147	1.151
6.	1.114	1.118	1.122	1.126	1.130	1.133	1.137	1.141	1.145	1.149	1.153
5.	1.117	1.120	1.124	1.128	1.132	1.136	1.140	1.144	1.148	1.152	1.156
4.	1.119	1.123	1.126	1.130	1.134	1.138	1.142	1.146	1.150	1.154	1.158
3.	1.122	1.126	1.129	1.133	1.137	1.141	1.145	1.149	1.153	1.157	1.161
2.	1.125	1.128	1.132	1.136	1.140	1.144	1.148	1.152	1.156	1.160	1.164
1.	1.127	1.131	1.135	1.139	1.143	1.146	1.150	1.154	1.158	1.162	1.166
0.	1.130	1.133	1.137	1.141	1.145	1.149	1.153	1.157	1.161	1.165	1.169

TEMPERATURE FACTORS.

Note: The preceding factors are calculated from the formula

$$f = \frac{17.64(b-a)}{460 + t}$$

in which (b) is the height of the barometer. (a) is the tension of aqueous vapor, and (t) is the temperature fahrenheit. For instance, if the barometer is 30.0 and the temperature 100°, the factor will be:

$$f = \frac{17.64(30-1.918)}{460 + 100} = .885$$

AQUEOUS VAPOR TENSION.

Temp. F°		Mercury ins.	Temp.		Mercury.
1	=	.046	51	=	.374
2	=	.048	52	=	.388
3	=	.050	53	=	.403
4	=	.052	54	=	.418
5	=	.054	55	=	.433
6	=	.057	56	=	.449
7	=	.060	57	=	.465
8	=	.062	58	=	.482
9	=	.065	59	=	.500
10	=	.068	60	=	.518
11	=	.071	61	=	.537
12	=	.074	62	=	.556
13	=	.078	63	=	.576
14	=	.084	64	=	.596
15	=	.086	65	=	.617
16	=	.090	66	=	.639
17	=	.094	67	=	.661
18	=	.098	68	=	.685
19	=	.103	69	=	.708
20	=	.108	70	=	.733
21	=	.113	71	=	.759
22	=	.118	72	=	.785
23	=	.123	73	=	.812
24	=	.129	74	=	.840
25	=	.135	75	=	.868
26	=	.141	76	=	.877
27	=	.147	77	=	.927
28	=	.153	78	=	.958
29	=	.160	79	=	.990
30	=	.167	80	=	1.023
31	=	.174	81	=	1.057
32	=	.181	82	=	1.092
33	=	.188	83	=	1.128
34	=	.196	84	=	1.165
35	=	.204	85	=	1.203
36	=	.212	86	=	1.242
37	=	.220	87	=	1.282
38	=	.229	88	=	1.323
39	=	.238	89	=	1.366
40	=	.247	90	=	1.401
41	=	.257	91	=	1.455
42	=	.267	92	=	1.501
43	=	.277	93	=	1.548

AQUEOUS VAPOR TENSION.—(Continued.)

Temp. F°		Mercury ins.	Temp.		Mercury.
44	=	.288	94	=	1.596
45	=	.299	95	=	1.646
46	=	.311	96	=	1.697
47	=	.323	97	=	1.751
48	=	.335	98	=	1.806
49	=	.348	99	=	1.862
50	=	.361	100	=	1.918

CENTIGRADE AND FAHRENHEIT SCALE.

Cent.		Fahr.	Cent.		Fahr.	Cent.		Fahr.	Cent.		Fahr.
0	=	32.0	26	=	78.8	51	=	123.8	76	=	168.8
1	=	33.8	27	=	80.6	52	=	125.6	77	=	170.8
2	=	35.6	28	=	82.4	53	=	127.4	78	=	172.4
3	=	37.4	29	=	84.2	54	=	129.2	79	=	174.2
4	=	39.2	30	=	86.0	55	=	131.0	80	=	176.0
5	=	41.0	31	=	87.8	56	=	132.8	81	=	177.8
6	=	42.8	32	=	89.6	57	=	134.6	82	=	179.6
7	=	44.6	33	=	91.4	58	=	136.4	83	=	181.4
8	=	46.4	34	=	93.2	59	=	138.2	84	=	183.2
9	=	48.2	35	=	95.0	60	=	140.0	85	=	185.0
10	=	50.0	36	=	96.8	61	=	141.8	86	=	186.8
11	=	51.8	37	=	98.6	62	=	143.6	87	=	188.6
12	=	53.6	38	=	100.4	63	=	145.4	88	=	190.4
13	=	55.4	39	=	102.2	64	=	147.2	89	=	192.2
14	=	57.2	40	=	104.0	65	=	149.0	90	=	194.0
15	=	59.0	41	=	105.8	66	=	150.8	91	=	195.8
16	=	60.8	42	=	107.6	67	=	152.6	92	=	197.6
17	=	62.6	43	=	109.4	68	=	154.4	93	=	199.4
18	=	64.4	44	=	111.2	69	=	156.2	94	=	201.2
19	=	66.2	45	=	113.0	70	=	158.0	95	=	203.0
20	=	68.0	46	=	114.8	71	=	159.8	96	=	204.8
21	=	69.8	47	=	116.6	72	=	161.6	97	=	206.6
22	=	71.6	48	=	118.4	73	=	163.4	98	=	208.4
23	=	73.4	49	=	120.2	74	=	165.2	99	=	210.2
24	=	75.2	50	=	122.0	75	=	167.0	100	=	212.0
25	=	77.0									

SPECIFIC GRAVITY OF GASES.

Gas.	Spec. Grav. (Air=1.00)	Weight of 1 Cubic Foot in Grains at 60 F. and 30.0 Barometer	Cubic Feet Equal to 1 Pound.
Hydrogen (H_2)...............	0.06926	37.15	188.42
Methane (CH_4)	0.558	297.20	23.55
Carbon Monoxide (CO)	0.9678	520.10	13.46
Olefiant Gas (C_2H_4)..........	0.971	520.10	13.46
Nitrogen (N_2)	0.97137	520.10	13.46
Oxygen (O_2)	1.10563	594.40	11.77
Hydrogen Sulphide (H_2S)....	1.1912	631.54	11.09
Carbon Dioxide (CO_2)........	1.529	817.30	8.56
Water Vapor (H_2O)..........	0.615	334.35	20.93

BOILING POINTS OF WATER AT DIFFERENT PRESSURES.

Temp. F°	Bar. ins.	Temp.	Bar. ins.
184	16.676	201	23.937
185	17.047	202	24.441
186	17.421	203	25.014
187	17.803	204	25.468
188	18.196	205	25.992
189	18.593	206	26.529
190	18.992	207	27.068
191	19.407	208	27.614
192	19.822	209	28.183
193	20.254	210	28.744
194	20.687	211	29.331
195	21.124	212	29.922
196	21.576	213	30.516
197	22.030	214	31.120
198	22.498	215	31.730
200	23.454	216	32.350