ACETYLENE GAS

AND

CALCIUM CARBIDE.

THOMPSON.

The "FOWLER"

PATENT PORTABLE GENERATOR

FOR

OPTICAL LANTERNS, PHOTOGRAPHERS, etc.

Possesses the following Important Advantages:—

Perfect in Principle and Construction.

ABSOLUTELY SAFE in use.

Automatic Action.

Steady Light.

No Smoke.

Possesses the following Important Advantages:—

Gas Thoroughly Purified.

Quantity of Gas generated may be regulated, or action stopped at any moment.

No Loose Fittings.

Requires no fixing.

Write for Catalogue and all particulars as to Sizes and Price.

CALCIUM CARBIDE supplied at market prices.

THE "FOWLER" ACETYLENE GAS CO.,

OFFICE AND WORKS—

298, Marsh Lane, Bootle, LIVERPOOL.

J. K. CLARKSON, Manager & Secretary.

T. R. FOWLER, Consulting Engineer.

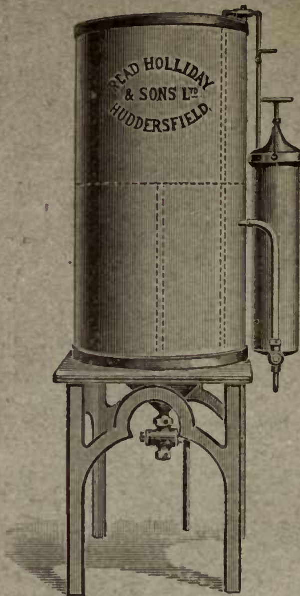
READ HOLLIDAY & SONS, Ltd.

PATENT

AUTOMATIC ACETYLENE GAS GENERATOR

Hundreds of these Machines in use!

Portable Machines for Contractors, Dock-yards, Canals, &c.



Simplest and Best.

These Machines will AUTOMATICALLY Feed Existing Gasometers of any size.

Machines are made all sizes to suit customers, and the methods of working are very simple, There is nothing to get out of order; and **any person, maidservant, gardener, or groom can re-charge it** and do all that is necessary without risk. A few words as directions are attached to every machine. This apparatus is constructed **to generate the gas automatically** as used. **and when charged requires no further attention.** The generators can be discharged of residual matter (lime) and REFILLED in a FEW MINUTES, and in less time than an ordinary paraffin lamp can be trimmed and refilled. **There is no danger** of any excessive pressure in machines. **Every Machine is tested** before leaving the workshops to insure all being perfect. These Machines comply with Insurance regulations. Special Apparatus made for Lighting Villages, &c. An Apparatus for over 1,000 Lights requires only the attendance of a man for an hour a day.

ACETYLENE GAS BURNERS. **No Deposit. Most Illumination. Small Cost.**

For Particlars apply to Patentees and Makers:

READ HOLLIDAY & SONS, Ld.,

Acetylene Gas Engineers and Carbide Manufacturers,

HUDDERSFIELD, England.

ACETYLENE GAS

AND

CALCIUM CARBIDE.

ACETYLENE GAS,

ITS

NATURE, PROPERTIES

AND USES; ALSO

CALCIUM CARBIDE,

ITS

COMPOSITION, PROPERTIES

AND

METHOD OF MANUFACTURE.

BY

G. F. THOMPSON,

CONSULTING ENGINEER.

LIVERPOOL.

PUBLISHED BY THE AUTHOR,

LOMBARD CHAMBERS, BIXTETH STREET,

1898.

PREFACE.

The present work originated in a lecture delivered by the Author before the Liverpool Polytechnic Society, the primary object of which being to make known the properties of Acetylene, and by pointing out its many and distinct advantages in contradistinction to its supposed dangerous character, remove the suspicion attaching to it, and allay the unfounded and somewhat undefined fears which have been aroused by the occurrence of a few accidents through its agency.

Acetylene, owing to its high value as an illuminant and other valuable properties, is intensely interesting from both scientific and commercial standpoints, but owing to the fact that its real properties are but little known, and that a few accidents have occurred in consequence thereof, reports have been freely circulated as to its being a highly dangerous compound, the result being that it is regarded by the general public with a considerable amount of suspicion.

It was with a view to dissipating the erroneous impressions prevalent that the Author was prompted to bring the subject before his Society, and by giving some particulars of the nature and properties of Acetylene and its base, Calcium Carbide, extend the knowledge of this simple yet valuable gas.

That a large number are interested in the subject was proved by the receipt of numerous enquiries respecting Acetylene and applications for copies of the lecture. The receipt of these communications impressed the Author with the evident necessity for an authoritive work on the subject, and he has therefore been prompted to prepare such a work, which he now submits and dedicates to all those who may in any way be interested in artificial lighting generally, or in Acetylene in particular, as an illuminant or as applied to other purposes.

Coal gas as an illuminant having now been in use nearly a century, it would appear reasonable to suppose that public knowledge of the subject would be fairly accurate and general, yet there are few things in common use involving scientific principles or chemical reactions in regard to which more ignorance or erroneous ideas are displayed. That such is unfortunately the case is proved by the fact that fatalities through its agency are of frequent occurrence, cases of poisoning and explosion being common, the latter occurring occasionally even at Gas Works, where it might be expected a good knowledge of the nature of Gas prevailed and the greatest care would be exercised in connection therewith.

These accidents are reported by the press almost as every-day and common-place events, are read by the general public, commented upon and soon forgotten, but when an accident occurs in connection with any new innovation, be it trifling or serious, sensational accounts of same are immediately published, greatly to the detriment of the innovation, however valuable or important it may be, and the pessimistic tendency of the average mind usually prompts a condemnation of the whole thing without any consideration as to its possible advantages.

Acetylene regarded as an innovation has suffered from this cause, but in that respect it is not alone; all innovations of a scientific origin have in more or less degree suffered in like manner.

Coal gas during the early days of its introduction was regarded with considerable distrust owing to a few mishaps which occurred, but which were almost invariably traceable to ignorance or carelessness, or both.

The adoption of the electric light was also much retarded in its early stages by similar causes, unfounded fears being aroused regarding the danger and subtlety of electricity.

Acetylene being the latest scientific production and a *terra incognita* to the majority, public apprehension is aroused by the slightest mishap, and accounts of accidents have been distorted and exaggerated, but the introduction of a compound of this description, with comparatively unknown properties, must for a time be impeded by accident through improper usage.

Acetylene as an illuminant compared with ordinary coal gas involves much less risk in its use, its distinct and pungent odour making its presence known long before any dangerous quantity might be present, and in comparison with water gas the risk is still less owing to the fact that the latter is practically inodorous and its presence is not detected until symptoms of poisoning are developed.

These facts, therefore, shew that a great deal of unfounded and unnecessary fear has been aroused in regard to Acetylene which is not only unjust to it, but absurd in view of the general enlightenment of the present age.

The Author was early convinced of the importance of the discovery by which the synthetic production of Acetylene became a commercial possibility, and he has taken an active interest in the subject from the time when Calcium Carbide first became a commercial article.

The present work has been prepared with a view to its being a complete *resumè* of the subject and is in every respect a record of the state of knowledge at the present time in regard to Acetylene, and no pains have been spared to render it worthy of being accepted as a standard work on the subject.

The design of the work is to expound the general principles governing the subject and the various conditions involved; no description of specific apparatus is therefore attempted, owing to the variety of forms adopted by the several manufacturers, each one possessing features and advantages peculiar to itself.

The Author, while not assuming to be an authority in regard to the chemical aspect of the subject, yet claims to have acquired some knowledge of the nature and properties of Acetylene, and to have ascertained the best conditions under which it may be generated and utilized.

The Author desires to acknowledge the courtesy of Professor Vivian B. Lewes in permitting him to quote the results of some of his experiments in regard to the properties of Acetylene. He also wishes to acknowledge information derived from articles in "*The Journal of Gas Lighting*," "*The Engineer*," "*Engineering*," and other periodicals, and communications to learned societies by Professor Lewes, M. Moissan, Dr. Pictet, M. Ravel, Dr. Bunte, and other eminent scientific authorities who have given special attention to the subject.

G. F. T.

LIVERPOOL, *April, 1898.*

CONTENTS.

INTRODUCTION.

CHAPTER I.

HISTORICAL. SOURCES OF ACETYLENE.

CHAPTER II.

ACETYLENE, NATURE AND PROPERTIES GENERALLY.

CHAPTER III.

ACETYLENE AS AN ILLUMINANT.

CHAPTER IV.

COMMERCIAL PRODUCTION OF CALCIUM CARBIDE.

CHAPTER V.

CALCIUM CARBIDE, COMPOSITION AND PROPERTIES.

CHAPTER VI.

GENERATING.

PRINTED BY
GEO. McALLISTER & Co.,
LIVERPOOL.

INTRODUCTION.

The many and important scientific discoveries of recent years and the practical applications thereof have wrought marked changes and much improvement in many conditions of commercial, industrial, and social life, and the beneficial effects thereof are seen in the activity of invention, the development of higher ideals and the advancement of the standard of excellence generally.

Although great improvement is evident in almost all conditions of life, yet, in no department has progress been more marked or rapid than in the matter of artificial illumination.

During a period which is almost within the memory of man, the standard of excellence in artificial lighting has been raised from the feeble and flickering rush light to the brilliancy of electricity and incandescent gas.

Before the advent of coal gas, the oil lamp and wax candle were regarded as excellent illuminants, but the adoption of gas at once raised the standard of both degree and quality of light, and for a long period it was considered the acme of perfection in artificial illumination.

The introduction of electricity for lighting purposes tended to raise the standard still higher, and at the same time, to materially alter the conditions of artificial illumination by the introduction of the new elements of perfect safety and application under circumstances prohibitive to gas, which, together with its greater convenience and adaptability have made the possible uses, applications and effects of artificial light practically unlimited, popular taste has been educated and a demand created accordingly.

The incandescent gas system has to a large extent supplied the demand for a higher degree and better quality in light, and at the same time has proved the salvation of coal gas as an illuminant. But while the Welsbach mantle has increased the luminosity of coal gas, it has not tended to make it any more portable nor applicable in remote or isolated situations.

It is under the latter circumstances and in comparison with ordinary gas and electricity that the attributes of Acetylene become most conspicuous, and mark it as the ideal illuminant under certain conditions, possessing as it does advantages attributable to no other source of artificial light.

The demand for a light of high illuminating value other than electricity or incandescent gas and free from the drawbacks of such, and the objections to, and dangers of oil lamps, is therefore entirely met by the Acetylene flame, which affords at once an illumination of high degree and perfect quality, and while supplying an existing want has found for itself special fields of usefulness in its peculiar suitability for, and ease of adaptation to all photographic and optical purposes in which perfect actinic quality and absolute steadiness are the chief *desiderata*.

Amongst the more important scientific events of this latter part of the Nineteeth Century, the discovery that in the intense heat of the electric arc, bodies unaffected by the highest calorific temperature may be easily fused, must be accorded a prominent position.

This property of the electric arc has made possible a much more extended research in the field of thermo-chemistry, and at the same time has enabled the production of compounds impossible to obtain by other means.

One of the most important of the new compounds producible through the agency of the electric furnace is Calcium Carbide, a substance formed by the fusion together of calcium and carbon.

This substance possesses the property of combining with and decomposing water, and is on the other hand decomposed by the water, one result of which chemical reaction being the formation of a rich hydro-carbon gas, "Acetylene."

The evolution of gas under these conditions is a true case of synthetic formation, the gas being produced by the direct combination of its elements, carbon and hydrogen. The process, therefore, by which the formation of Acetylene is effected is the converse of that by which ordinary illuminating gases are produced, and the synthetic as differing from the analytic or distillation method insures one distinct advantage, viz., that the product so built up is practically free from those deleterious elements and compounds from which gas produced by destructive distillation of carbonaceous materials is seldom or never free.

The discovery of a means whereby the synthetic production of Acetylene on a large scale from common and comparatively inexpensive materials is now a practical possibility, is one of the most important results of scientific research, inasmuch as it has not only enabled the economical production of a valuable hydro-carbon compound, but has at the same time thrown much light upon one of the most wonderful of natural phenomena, viz., that mysterious working of Nature by which apparently inexhaustible stores of liquid and gaseous hydro-carbons have been and are still being formed.

Although the evolution of Acetylene from calcium carbide as a laboratory experiment has been known to chemistry for a considerable length of time—the carbide being prepared by a somewhat elaborate process—yet the direct combination of calcium and carbon in the formation of the carbide was thought to be impossible until accidentally revealed by the action of the electric furnace.

The process by which Acetylene is evolved from the carbide being of a very simple nature, the apparatus necessary for its generation need not be either elaborate or expensive, and the acquisition of a practical knowledge of the *modus operandi* is within the scope of the most ordinary intellect.

The photometric value or illuminating power of the Acetylene flame is more than 15 times that of coal gas, being about 50 candle power when consumed at the rate of one cubic foot per hour ; the flame also possesses other qualities besides that of intense brilliancy, viz., purity, steadiness and freedom from noxious bye-products, and is at the same time a comparatively cool flame.

The quality of the Acetylene light is almost equal to that of sunlight, being practically pure white, which is proved by the close resemblance of its spectrum to the solar spectrum. This attribute therefore makes the Acetylene light, in this respect, superior to all other artificial illuminants, as owing to its actinic property all colours appear the same as by daylight. This quality renders the light particularly suitable for photographic purposes.

Under proper conditions as to density and pressure the flame is perfectly steady and free from the flickering peculiar to coal gas. In this respect, the light is equal to incandescent gas and electricity.

Acetylene possesses a peculiar and unmistakeable odour of such a pungent and penetrating character as to render the atmosphere practically unbearable long before the percentage of gas present would be sufficient to cause risk of explosion. This property is of much advantage as constituting a safe-guard in its use, the slightest leakage being readily detected.

Acetylene is of much greater density, and consequently of a higher specific gravity than other hydro-carbon gases; consequently it will not flow through a given sized aperture as readily or as quickly as coal gas ; and when it is considered that the largest sized Acetylene burners pass only about one cubic foot per hour, it follows that if the gas were escaping at this rate, there would be in a given time an accumulation of only one-fifth the quantity of coal gas which would escape through an ordinary burner during an equal period.

That Acetylene is much less poisonous than coal gas is proved by the fact that it is a nearly pure gas, and practically free from sulphuretted and phosphoretted hydrogen with which coal gas is always more or less contaminated, and which constitute the really poisonous elements of such gas.

In comparison with other hydro-carbon flames that of Acetylene is a comparatively cool one, developing a temperature of only about two-thirds that of the flame of coal gas, and when it is considered that for a given degree of illumination only one-fifteenth the quantity of Acetylene is required, and that the flame is of a much lower temperature, it is evident that the atmosphere of a room would not become heated to anything approaching the same degree as if the light were derived from coal gas.

From the foregoing it will be obvious that the so-called "dangers" of and other objections to Acetylene raised by prejudiced persons ignorant of its properties are purely imaginary, and that on the other hand the many advantages peculiar to the Acetylene flame as a source of artificial light, the simplicity of the process of production, its portability and applicability under circumstances where an equal illumination by other means would be almost impossible, tend to prove this gas to be an ideal illuminant, possessing as it does properties which make its light in many respects superior to that obtained by other artificial means.

The extreme simplicity of the process by which Acetylene may be generated, while being one of its chief advantages, has at the same time proved a disadvantage owing to its very simplicity having attracted enthusiastic but unskilled amateurs, and others who have entered the field of experiment with a very imperfect knowledge of the nature or properties of Carbide or of Acetylene, the result being that in a few cases accidents have occurred through its agency attended with more or less disastrous consequences. It is therefore the blind unintelligent experiments of ignorant persons which constitute the *real* dangers of Acetylene, and it has consequently suffered by the want of knowledge or carelessness of its votaries, the disastrous results of whose ill-advised enthusiasm have had the effect of bringing into disrepute one of the most valuable articles which chemical research has evolved and electrical science made a commercial possibility.

In all operations in which known physical conditions are involved or known substances employed, the possible or probable results, instead of being speculative or purely conjectural, may, by having due regard to natural physical forces and properties of matter and careful consideration of the factors in the case, be pre-determined—theoretically—with more or less degree of accuracy before being practically tested by trial or so-called "experiment."

In view of the fact that literature bearing upon all branches or departments of physical science is available, experiments of a purely speculative character in the fields of Chemistry or Mechanism are inexcusable. But if entered upon in ignorance of or indifference to underlying principles, or conditions involved, and with indefinite views as to the effects sought or thought possible of attainment, the most probable results will be waste of time and material, disappointment, and perhaps even disaster.

"A little knowledge is a dangerous thing," and usually tends to beget one or other of two conditions of mind, namely, a childish and undefined fear on the one hand, or a reckless temerity and indifference as to consequences on the other.

This reasoning emphasizes the fallacy of entering upon physical operations with insufficient or imperfect acquaintance with the properties of matter or laws of nature, and without clearly formed ideas as to the effects sought or possible of attainment.

Should this work, therefore, by an exposition of the nature and properties of Acetylene and of Calcium Carbide add to the scientific knowledge of the subject, and so prove of assistance to those interested and enable them to avoid speculative or risky experiments, and the probable disappointing or disastrous consequences thereof, the labour expended upon its compilation will not have been in vain.

CHAPTER I.

HISTORY OF ACETYLENE.

Acetylene is not, as many appear to suppose, a recently discovered gas, but on the contrary has been known to experimental chemistry for a considerable length of time—something over sixty years.

Its discovery or original production and recognition as differing from other gaseous compounds was one result of the researches and experiments made by the eminent chemist, Edmund Davy, to ascertain and determine the properties of the Monad and Dyad metals.

During his investigation of the metal Potassium and while endeavouring to obtain it from its carbonate, he produced a compound of potassium and carbon, which was decomposable by water, the reaction causing the evolution of a highly inflammable gas, which he is said to have named "Klumene."

About the year 1859 the eminent French chemist Berthelot, while conducting researches in the field of the Hydro-carbon compounds, discovered the fact that a stream of hydrogen passed through an electric arc playing between carbon electrodes was converted into a rich hydro-carbon gas, and which on analysis he found to bear a chemical relationship to the organic radical Acetyl, and he therefore named the compound "Acetylene."

At about this same period the celebrated German chemist Wöhler found that a mixture composed of an alloy of zinc and calcium and carbon when fused together at a high temperature was converted into a substance which, on being decomposed with water, gave off Acetylene Gas, and to Wöhler, therefore, is due the credit of having first produced Calcium Carbide, and of having discovered a means whereby Acetylene could be produced synthetically upon a comparatively large scale from simple and inexpensive materials.

Berthelot's and Wöhler's investigations and experiments, while revealing the true nature and valuable properties of Acetylene, were of great scientific importance as throwing considerable light upon some of the mysteries of Natural Phenomena, and as explaining those wonderful workings of Nature by which almost inexhaustible quantities of both liquid and gaseous hydro-carbons have been formed and are now being drawn from the Storehouse in the form of Petroleum and Natural Gas.

To produce Acetylene by Berthelot's method, a stream of hydrogen is caused to pass through an electric arc playing between carbon electrodes, the gas thereby becoming heated to a high degree, some of it combines with the particles of free carbon in the electric arc, forming Acetylene, which is carried forward by the stream of hydrogen. To obtain the Acetylene the mixed gases are passed through a solution of cuprous chloride when the Acetylene separates in the form of a red solid copper compound, this substance upon being decomposed by hydrochloric acid yields pure Acetylene.

The gas may also be produced by the decomposition with water of Carbides of the Monad and Dyad metals other than Calcium, and Carbides of several of these metals have been obtained by various experimenters.

Maquenne, in the early part of the present decade, succeeded in producing Barium Carbide (BaC_2) by heating together in an iron bottle a mixture of barium carbonate, carbon (charcoal), and powdered magnesium in the proportion of barium carbonate 64·64, carbon 9·75, magnesium 25·61 per cent. He found, upon subjecting the mixture to a high temperature for four minutes, the following reaction took place:

$$BaCO_3 + 3Mg + C = BaC_2 + 3MgO.$$

The carbide produced was amorphous and yielded, on decomposition with water, Acetylene mixed with free hydrogen.

Soon after this event Travers produced Calcium Carbide by fusing together a mixture of chloride of calcium, metallic sodium and carbon, which, on decomposition with water, gave off Acetylene in large quantities.

Although these experiments and discoveries were very interesting and of great scientific value, the production of Acetylene on a commercial scale from these compounds was practically precluded owing to the costly nature of the elements.

The production of Acetylene might still have been regarded as merely a pretty laboratory experiment had not a most fortunate circumstance revealed the fact that the desired reaction could be brought about by means of the electric furnace, and that Calcium Carbide could thereby be manufactured on a commercial scale from simple and inexpensive materials. This discovery may therefore be justly regarded as one of the more important scientific events of the latter part of the nineteenth century.

It has been found that in the high temperature of the electric furnace carbides of calcium and other metals of that group can be produced in a simple and economical manner by the fusion of the oxides or carbonates of those metals with carbon, and by the decomposition of such compounds with water, the synthetic production of practically pure hydro-carbon or Acetylene Gas is now a commercial possibility.

Prior to this discovery the only known and recognized manner in which hydro-carbon illuminating gas could be produced upon a commercial scale was by the destructive distillation of solid or liquid carbonaceous materials and the after separation from the resulting gas of a number of other elements or compounds termed "bye-products."

The fact that calcic carbide could be produced by the fusion together of oxide of calcium and carbon in the electric furnace was discovered independently by Willson in America and Moissan in France, and the credit of first discovery is claimed by each country. But although in the former case, it was one result of practical trial on a large scale, and in the latter of scientific laboratory research, it was, in each instance, accidental; neither one of the experimenters being at the time cognisant of the other's work, the credit is therefore equal.

There now, however, appears to be little doubt but that *crystalline* carbide of calcium was first produced by means of the electric furnace, by Thomas Leopold Willson in America, and that he had made a large quantity of the material prior to Moissan's announcement of his observations as to its formation under similar conditions.

The story of Willson's discovery is most interesting, as shewing how sometimes important innovations take their origin in apparently insignificant incidents.

During the year 1889, Mr. T. L. Willson, an electrical engineer, then of Leaksville, in North Carolina, while experimenting with an electric furnace with a view to obtaining the metal Calcium by the reduction of its oxide in the electric arc, fused together a mixture of powdered lime and anthracite, but upon opening the furnace, instead of finding, as he anticipated, a quantity of white shining metal, he found instead a dark-coloured, heavy, crystalline substance resembling scoria or larva from a volcano.

The material upon examination being found not to be the substance sought—its true character not being recognized—it was regarded as useless and was thrown into some water near by. Immediately the water began to effervesce, and so violent was the ebullition and so strong the odour of the gas bubbling out, that it attracted attention and some more of the material was made, which upon being more carefully examined than was the first lot, was found to be carbide of calcium; it was put into water and the gas as it bubbled out was caught. The gas proved to be pure Acetylene, and thus was discovered the possibility of producing Acetylene synthetically upon a commercial scale, and such the origin of a discovery likely to have an important bearing upon industrial progress in the near future, opening up as it does commercial possibilities scarcely conceived by the most speculative imagination.

This phase of the subject is treated in Chapters IX. and X., in which the possible uses and applications of Acetylene, other than as an illuminant, are fully considered.

Carbides of Manganese, Sodium, Thorium and Yttrium have been produced through the agency of the electric furnace, all of which, on decomposition with water, give off Acetylene, mixed in more or less quantity with ethylene, methane and free hydrogen, also small quantities of liquid hydro-carbons.

Carbides of other metals of the Dyad and Earth-metal groups may be produced by fusion of the elements in the electric arc and will, on decomposition with water, also yield Acetylene, but their use is practically precluded owing to rarity or cost of production.

Calcium being the most abundant of the earth-metals and consequently the least costly, and at the same time usually found in a fairly pure state, as Lime or Chalk, it becomes at once the most suitable for the production of carbide on a commercial scale.

CHAPTER II.

ACETYLENE: ITS NATURE AND PROPERTIES GENERALLY.

Acetylene, or as it is scientifically named "Ethine," is a simple hydro-carbon compound consisting of twenty-four parts by weight of carbon, and two parts by weight of hydrogen, its chemical symbol being C_2H_2, meaning that it is a compound of two atoms of carbon combined with two atoms of hydrogen ; it is a clear colourless gas of a sp. gr. of 0·92.

It is, owing to its synthetic formation, the most pure, and at the same time, the richest hydro-carbon gas containing no less than 92·5 per cent. of carbon, hence the high illuminating power of its flame which far exceeds that of any other known gas.

When perfectly pure and free from water vapour it has an illuminating value of 50 candle-power per cubic foot, coal gas under similar conditions as to pressure having only an average of 16 candle-power per *five* cubic feet; the Acetylene light is therefore more than 15 times the photometric value of that of carburetted hydrogen or coal gas.

The light emitted by the Acetylene flame is practically pure white and more nearly the quality of sunlight than that of any other known illuminant.

Its spectrum more closely resembles the solar spectrum than that of any other artificial light, so that delicate shades of colour appear the same as by daylight. This constitutes one of the most valuable properties of Acetylene as an illuminant.

It has a most unmistakeable and penetrating odour somewhat resembling garlic, and when present in the proportion of only one part in 10,000 parts of air is distinctly perceptible, and long before there might be sufficient gas present to cause explosion or asphyxiation, the inhalation would produce headache in persons breathing it ; it also affects the eyes, producing a smarting sensation. This property is much in its favour as a safeguard in its use, the slightest leakage being at once detected.

One burner passing one cubic foot per hour is sufficient to brilliantly illuminate an apartment of 2,500 cubic feet area, and if the gas were escaping at that rate for a period of nine or ten hours there would not, at the end of that time, be sufficient gas present to make an explosive mixture with that quantity of air ; therefore, the danger of explosion through leakage or through taps being inadvertently left open, is in the case of Acetylene as compared with coal gas very much less, for the reason that the largest Acetylene burners pass only a little more than one cubic foot per hour, whilst on the other hand, an ordinary gas burner passes five cubic feet per hour for only about one-third the light value of the Acetylene, and further, the specific gravity of Acetylene being 0·92 as against 0·43 for coal gas, it follows that a very much less quantity of Acetylene would flow through a given sized aperture in a given time than would be the case with coal gas. It is therefore obvious that the prevailing popular belief as to Acetylene being more dangerous than coal gas is fallacious.

The quantity of oxygen required for its complete combustion is relatively low, being at the rate of two and a-half volumes to one of Acetylene, so that when burned at the rate of one cubic foot per hour the consumption of oxygen is only two and a-half cubic feet per hour, producing about two cubic feet of carbon dioxide (CO_2).

For an equal degree of illumination with coal gas, the consumption of oxygen would be about nineteen cubic feet, and the quantity of carbon dioxide given off about 8·25 cubic feet besides certain quantities of sulphur dioxide, and sulphuretted and phosphoretted hydrogen; whereas, in the case of Acetylene, the quantity of carbon dioxide is less than one-fourth that quantity, and when the gas is purified, practically no sulphuretted or phosphoretted hydrogen or other deleterious products of combustion.

Acetylene and oxygen ignite at a temperature of about 480° C, and the temperature of the flame is about 1,000° C.

The maximum degree of heat is developed when Acetylene is burned with an equal volume of oxygen, the temperature of combustion then being about 3,800° C. M. Ravel places the temperature as high as 4,000° C.

Coal gas, on the other hand, requires a temperature of 600° C to ignite it, but developes on combustion in the ordinary manner a temperature of 1,350° to 1,400° C, so that the Acetylene flame, in comparison with that of coal gas, is a distinctly cool one.

Acetylene, although a practically pure gas, usually contains some impurities in greater or less proportion, those commonly present being sulphuretted and phosphoretted hydrogen, due to the presence of sulphate of calcium—gypsum —and calcium phosphide in the lime, and to sulphur and phosphorous in the coke employed in the manufacture of the carbide. Although these elements are to a large extent driven off in the fusion of the calcium and carbon, still, if present in large proportion certain quantities remain in the carbide.

Acetylene is also generally contaminated with ammonia in more or less quantity formed by the combination of nitrogen derived from the coke with the hydrogen of the water during the process of decomposition of the carbide, and which, when present with oxygen in the form of an aqueous vapour acts upon copper, silver, or mercury, forming acetylides of those metals which are explosive, and will detonate if heated to a sufficient degree, or are subjected to percussive action.

That Acetylene is a poisonous gas is now proved to be untrue ; when pure it is relatively harmless and much less poisonous than coal gas owing to the almost entire absence of sulphuretted and phosphoretted hydrogen, which are always present in more or less quantity in the latter.

It is a fact that the range of explosibility is wider in the case of Acetylene than coal gas, but owing to its greater density and other properties already referred to, the risk is considerably less.

The actual range of explosibility in mixtures of Acetylene and atmospheric air appears to be from a proportion of five per cent. to sixty per cent. of gas to total volume of mixture, mixtures having less than five or more than sixty per cent. being practically non-explosive.

The maximum explosive power—as ascertained by various authorities—appears to be developed when Acetylene is in the proportion of from 7·8 to 8·3 per cent. to the total volume of gas and air, the variations doubtless being due to differences in the quality of the gas used.

In the case of coal gas, the explosive range is confined to mixtures containing from 7·0 per cent. to 30·0 per cent. of gas.

Gas evolved from pure carbide is much less explosive than that obtained from impure carbide, for the reason that the latter may contain a certain amount of calcium phosphide, which on decomposition forms, with the hydrogen of the water, phosphoretted hydrogen. This gas is spontaneously inflammable, and may, if sufficient be present, more especially if some atmospheric air be also present, ignite and explode the Acetylene. Explosions due to this cause have actually occurred in two or three instances, attended with more or less serious consequences.

Acetylene, like other gases, will not "fire back" through very small apertures or wire gauze, whether the gas be mixed with air in explosive proportion or not. No risk of explosion will therefore be incurred if orifices in burners are not over 0·02 inch in diameter.

Acetylene, being a highly endothermic compound, is liable when pure, if compressed without at the same time being cooled, to explode spontaneously and become resolved into its elements, carbon and hydrogen, even though no oxygen or atmospheric air be mixed therewith. The most serious accidents which have yet happened have been attributable to this property, which is developed when the gas is compressed to a pressure of 30 lbs. per square inch and over.

Acetylene is soluble in water and many other liquids. Water absorbs the gas at the rate of 100·1 per cent., *i.e.*, 100 volumes of water will absorb 110 volumes of gas ; but if the water be saturated with salt or alkali—20 per cent. by weight of salt is practically a saturated solution—its absorptive capacity is reduced to about 5 per cent.

Paraffin absorbs the gas at the rate of 250 per cent., 100 volumes of the mineral oil being capable of absorbing 250 volumes of Acetylene.

Acetylene at O° C can be liquified at a pressure of about 325 lbs. per square inch, and forms a mobile and highly refractory liquid much lighter than water, *i.e.*, of a specified gravity of 0·43. as compared with water.

Acetylene has also a high value as an enricher of coal gas. Professor Lewes has found that 10 per cent. added to a poor coal gas raised its light value to 20 candle-power, and that 20 per cent. of Acetylene added to water gas gave it an illuminating value of 20 candle power.

Bullier states that 20 per cent. of Acetylene added to ordinary coal gas (French) increased its illuminating power by 100 per cent.

T. L. Willson has patented a method of enriching and at the same time dehydrating or drying coal gas : it consists in passing the gas through vessels containing calcium carbide. The carbide at once absorbs all moisture from the gas and at the same time gives off Acetylene, which mingles with the coal gas and becomes thoroughly mixed therewith. The Acetylene remains gaseous under all conditions and the enrichment is therefore permanent.

The process has the merit of extreme simplicity and of insuring the thorough admixture of the gases. But in view of the fact that the quantity of moisture in suspension in coal gas, in the form of aqueous vapour, is seldom greater than 0·3 per cent. by volume, the quantity of Acetylene generated thereby would be insufficient to improve to any appreciable extent the illuminating value of the gas.

It has been proved that the admixture of Acetylene with coal gas in quantities under 10 per cent. effects practically no improvement in its illuminating power; it therefore follows that to enrich coal gas, by the admixture of a minimum of 10 per cent. of Acetylene, about 1 ℔. of water per 100 cubic feet of gas would be necessary.

CHAPTER III.

ACETYLENE AS AN ILLUMINANT.

The acme of perfection in artificial illumination would be realized if an exact equivalent of solar light could be found, but that being impossible, the light which most nearly fulfils the conditions and approaches the quality of sunlight must be regarded as the best artificial illuminant.

In artificial illumination, by whatever means obtained, the properties necessary to a realization of the ideal are :—

1. Perfect steadiness.
2. Pure actinic quality.
3. Diffusive power.
4. Low temperature.

Science, so far, has failed to discover a means or source of artificial light embodying and fully developing all these properties.

Of all systems of lighting, the incandescent electric is perhaps the best owing to its very nearly realizing the ideal, but it fails in regard to the second and third qualities, it being usually of a yellowish tint, and its diffusion only obtained at a sacrifice of some of its power by enclosing the filaments in frosted or slightly opaque bulbs.

The incandescent gas, although an admirable light, and having considerable power of diffusion, is faulty in the matter of tint, it being usually of a lurid, bluish hue, very trying to the eyesight, and imparting a ghastly appearance to those of naturally pale complexion, besides its property of altering the shades or tones of many colours.

The only light, therefore, which most nearly realizes the ideal is that afforded by the Acetylene flame, it being at once steady, practically pure white, diffusive and cool, but the full development of its properties is dependent upon the fulfilment of certain conditions in regard to the generation and combustion of the gas, to insure its being pure, cool and dry, and the pressure at which it issues from the burners must be such as to insure admixture with oxygen sufficient for its complete combustion.

The illuminating power of any hydro-carbon gas is in direct ratio to the relative proportion of its constituents and perfect combustion of the carbon is essential to the development of its highest degree of luminosity.

Perfect combustion means that all the carbon combines with oxygen in the process of burning and becomes transformed into carbon-dioxide.

The imperfect combustion of gaseous or other hydrocarbon illuminants results in reduction of light value and is attended with liberation of free carbon and emission of deleterious products of combustion.

Acetylene having the highest proportion of carbon of all known gases, it follows that its flame should therefore possess the highest photometric value, but, at the same time, the full development of its high illuminating power is dependent upon the complete combustion of its carbon constituent, and owing to the richness in carbon, its combustion is attended with much greater difficulty than is the burning of other hydro-carbon compounds.

It is owing to its richness in carbon that Acetylene polymerizes at a comparatively low temperature, and this property constitutes one of the greatest, if not the chief difficulty in its use as an illuminant. The heat of the flame, communicated to the material forming the tip of the burner, polymerizes some of the gas as it issues through the orifices, and a carbonaceous deposit is formed therein, restricting the flow of gas and causing the flame to smoke.

The proper development of the Acetylene flame is dependent upon the fulfilment of certain chemical and mechanical conditions if best results are to be attained.

The chemical condition is purity.

The mechanical conditions relate to density, pressure, and form of burner.

Purity of the gas is the first condition necessary to the development of the highest light-value of the flame.

The second condition is, that it shall be at its maximum density, and this is insured by the thorough cooling and dehydration of the gas.

The pressure should be unvarying, and should be—at the burners—equivalent to about two and one-half inches of water, never less than two inches, otherwise the flow of the gas issuing from the orifices of the burners is not sufficiently vigorous to insure its intimate admixture with the oxygen of the air.

The best form of burner is that in which two jets of gas are caused to impinge upon one another and produce a resulting flat flame. This principle is absolutely essential in the burning of Acetylene as being the only one by which sufficient oxygen becomes intimately mingled with the gas to insure its complete combustion.

The Bray Union jet burner appears to develop the highest degree of luminosity, the No. 0000 passing about one cubic foot per hour having given a light value of 55 candle power. But owing to the tips of these burners becoming heated by the combustion of the gas taking place almost in contact therewith, carbonaceous matter quickly accumulates in the orifices and upon the faces of the burners, which soon causes the flame to become distorted and to terminate at one or both outer corners in smoky tips ; but, in view of the small cost of these burners, their frequent renewal is not a serious factor in the question of expense.

Owing to the extreme liability of the gas to polymerize, the heat of combustion communicated to the tips of the burners causes the deposit of carbonaceous matter within the apertures through which it issues, but this contingency is obviated if actual ignition does not take place in the immediate vicinity of the orifices.

To overcome the difficulty arising from this cause, and to obviate the necessity for constant cleaning or changing of burners, a rather novel type of duplex burner has been designed, in which, two minute jets issue from orifices inclined towards one another, set at about one quarter inch apart. The two jets impinge upon one another, and the full development of the flame does not take place until, by the impact of the jets, the gas becomes intimately mixed with air. The orifices which really govern the flow of the gas are situated at the bases of small cavities, into which air is admitted through a series of holes inclined in the direction of the flow of the gas. By this arrangement, the jets of gas emerge from the cavities surrounded by envelopes of air which prevent its actual contact with the material of the burner at the point of ignition and polymerization of the gas is thus avoided.

Burners embodying this principle are supplied by The Acetylene Illuminating Company, Limited, of London, and Messrs. Read Holliday and Sons, Limited, of Huddersfield. The latter firm have recently patented an improved and very efficient burner of this type which the Author has found to give perfectly satisfactory results.

A *sine quâ non* in the use of burners of this description is, that the pressure of the gas is fully up to the necessary degree, otherwise the jets of gas do not induce adequate currents of air in the burners to insure best results.

The burners usually employed are of three sizes, and pass according to pattern, various quantities ranging from about one-half to one and a-half cubic feet per hour.

The Bray Union jet type are made in sizes designed to pass, about one and a-half, one, and three-quarter cubic feet per hour, and are marked 000, 0000, 00000, respectively.

Messrs. Read Holliday and Sons' duplex jet atmospheric burners are numbered "1," "$\frac{3}{4}$," and "$\frac{1}{2}$," indicating the quantity of gas designed to pass per hour.

The "Naphey" duplex jet burner supplied by The Acetylene Illuminating Company, Limited, passes slightly over one cubic foot per hour, and with pure gas affords a light of about 50 candle power.

Heating the air before its admixture with the gas, as in the Pope and Pintsch systems, is said to increase the luminosity of the Acetylene flame by insuring complete combustion of the carbon.

In America, the practice of diluting Acetylene with air before passing to the burners is in vogue, but it is to be deprecated owing to the attendant risk of explosion. As stated in the chapter, on the properties of the gas, mixtures of any proportion from 5% to 60% being explosive, there is always the liability of the mixed gas and air "firing back" if proper precaution be not taken and great care exercised. Dilution of the gas at the burner is the more desirable and safe method, and this is made a *fait accompli* by the atmospheric burners, to which reference has already been made.

A most interesting experiment was described by Prof. Lewes, in a lecture before the Institute of Naval Architects, to determine the relative value of various illuminants, and with a view to ascertaining the penetrative power of each kind through fog of average density. By the courtesy of Prof. Lewes, the Author is enabled to quote the results obtained.

The apparatus employed consisted of a glass cell, 18 inches by 18 inches, by 3 inches, which was filled with a solution containing 0·1075 gramme of sodium hypo-sulphite to the litre.

"The illuminating power of the light to be tested was first read on the photometer in the ordinary way, and the cell containing the clear liquid was then interposed half-way between the source of light and the screen, and a second reading was taken, the difference between the two giving the amount of light intercepted by the cell and the liquid it contained. ·05 gramme of hydrocloric acid per litre was then added to the liquid, and the solution was allowed to stand until the fine haze of sulphur particles which separated from the hypo-sulphite had finished forming. When the haze had completely formed, a third reading with the "fog" cell interposed was taken on the photometer, and from the three results, it was possible to deduce the amount of light absorption due to the haze, as apart from the absorption of the cell and its liquid contents, the actual results being as follows :—

Percentage of loss of light from various illuminants in passing through artificial fog solution.

Coal gas	11·1
Oil gas	11·5
Acetylene	14·7
Incandescent gas (*Welsbach*)	20·8
Electric Arc	26·2

From the data yielded by these experiments, it was found that less light was absorbed from the yellow coal gas and oil gas flames than from the whiter Acetylene flame, whilst this, in turn, was far superior in penetrative power to the Welsbach incandescent mantle or the light from the electric arc.

These figures merely give the loss of light in passing through the thickness of fog solution employed, but it is evident that they will also give approximately the ratio of the penetrative power of these illuminants in mist-laden air."

The Acetylene light, owing to its actinic quality, steadiness and intensity, is perhaps the best artificial illuminant for all photographic purposes, but when used in this connection it is desirable that it be double reflected or intercepted by a screen of oiled tissue paper for the purpose of insuring perfect diffusion, which condition is essential to the attainment of best results as owing to its intensity there is a liability of the illumination of the object being too "hard" and a consequent loss in artistic effect.

The Acetylene light is also eminently suited to all optical lantern purposes, and is fully equal to lime-light, while being on the other hand cheaper and easier to manipulate, and at the same time, more safe and portable. The apparatus necessary for a two-hour demonstration not being so heavy nor dangerous as are cylinders of oxygen and hydrogen gas for affording lime-light for a like period.

Acetylene also possesses an additional advantage in the fact that it need not be generated until required for use, and then only in such quantity as may be necessary for a given length of time.

Another advantage in this connection, when delicately coloured slides are shewn, being that the light in no way affects the tone or shade, the full colour-effect is therefore developed, insuring such slides shewing to best advantage.

Acetylene as an illuminant for cycle lamps is perhaps an ideal application, and that it finds favour with both inventors and users is evidenced by the fact that there are now about a dozen distinct types of lamp, of both British and foreign origin, in the market, each and all selling freely.

In the application of Acetylene to cycle, carriage or other portable lamp, two somewhat difficult, although interesting problems present themselves, *viz.*, the regulation of the flow of water to the carbide, and the accommodation of surplus gas.

The first difficulty has been overcome more or less successfully by the provision of such means as prevent the flow being at a greater rate than that necessary to the production of the requisite quantity of gas per minute, or per hour, and which consists in governing the flow by means of a delicately adjustable tap or valve, or by causing the water to pass through a tube practically filled with cotton wick or other fibrous material by which the flow is restricted to so many drops per minute, according to the nature or quantity of such filling.

The second difficulty which may arise in any and every lamp through variation in the flow of water, may, if no provision be made for its escape, set up an undesirable or dangerous pressure therein. This contingency has been met in two ways: First, by such arrangement of parts as allow of the surplus gas forcing back the water, and so finding its way out through the water vessel; or Second, by passing the gas into or through a collapsible rubber bag, which expands to accommodate gas when the pressure rises to a degree sufficient to distend the same.

This latter system is faulty, owing to the scope of its action being limited.

In some lamps examined by the Author, precautionary measures in regard to quantity or pressure of gas have been either overlooked or purposely disregarded as unnecessary, and the explosion of such a lamp quite recently is within his own personal knowledge.

In those lamps in which the water is compelled to percolate through fibrous material there is always the liability of such becoming choked, owing to its acting as a filter and collecting matter abstracted from the water. The best method, therefore, of governing the flow would appear to be by means of a delicately adjustable valve, which can be so made as to allow only the requisite quantity of water to pass at its maximum opening. The opening and closing of such valve in the starting and stopping of the light tends to keep same free by the continual disturbance of any deposit or accumulation of matter due to corrosion.

In applying Acetylene to domestic lighting the ordinary gas fittings may be used, but should be carefully examined and tested before admitting the Acetylene thereto, as any slight leakage, imperceptible in the case of coal gas, is distinctly noticeable when Acetylene is turned on.

The United States Lighthouse Board have recently made a trial of Acetylene as a substitute for electricity in the lighting of buoys. Cylinders of liquified Acetylene, provided with valves for reducing the pressure from 600 lbs. per square inch to the equivalent of two inches of water, being located within the buoys. Duplex-jet burners passing one cubic foot per hour were used, and the light afforded thereby when concentrated by suitable lense condensers is said to have been of 250 candle power.

It has been further proved that the illuminating value of the light given by a 300 candle power Acetylene burner is three times that of the 200 candle power electric light now in use.

There is also a distinct advantage in the matter of cost, an Acetylene-lighted buoy being made for $350, whereas the electric buoys cost $1,000 each.

Acetylene is now extensively used for train lighting in France, Germany, and other Continental countries, the gas being compressed and stored in cylinders in a manner similar to method adopted in the case of oil gas.

Acetylene has also been successfully adapted to Municipal lighting, the town of Totis, in Hungary, and other places on the Continent being now lighted throughout by this illuminant.

Totis was the first town to adopt Acetylene for its Municipal, commercial and domestic lighting, but towns in France, Switzerland, and other countries have now adopted the gas to greater or less extent.

The comparative cost of lighting by various illuminants, taking ordinary coal gas as the standard of comparison, is as follows :

Comparative cost of lighting by various means for an equal degree of illumination.

Coal gas (ordinary burner) at 2/9 per 1,000 cu. ft.	1·00
Do. (Welsbach Incandescent)	·47
Petroleum	·62
Acetylene (Carbide at £20 per ton)	·85
Electricity, at 4½d. per B.T.U.	1·68

In the estimate of the cost in the Welsbach system the amount is for gas only ; if interest upon cost of special fittings and renewal of mantles be included, the comparative cost would probably be nearer ·75.

Acetylene therefore compares very favourably with coal gas, whether under ordinary or the more favourable incandescent conditions, whereas it is only about half the cost of electricity at the low rate of 4½d. per B.T.U.

The relative photometric value or light-power of an illuminant is determined either by comparison with the standard candle or with another illuminant of similar nature and of known power.

The British standard is the sperm candle and is the amount of light emitted by such medium when consumed at the rate of about 120 grains per hour.

The apparatus usually employed for computing the illuminating value of artificial light is known as the Photometer, and consists of a disc of white paper having a "grease spot" in the centre. It was the invention of the eminent Bunsen, and although it has been varied in form and construction, in principle it remains the same.

When the degree of illumination on each side of the disc is equal the whole of the light is reflected therefrom and the grease spot apparently disappears, but when the illumination is unequal, the spot at once becomes visible, more particularly on the side facing the stronger light, owing to the fact that the greased portion being more translucent than the ungreased part, some of the light passes through, causing the greased place to appear of a darker shade.

When a hydro-carbon-flame light is to be tested in comparison with another of known value, equal flames of each are arranged so that their centres of greatest luminosity coincide with the centre of the grease spot on the disc, the light of known value is then placed at a certain distance from the disc, and the one to be tested moved either nearer to or farther from the disc, until the spot disappears; or the two lights may be placed in fixed positions and the disc moved relatively thereto. The difference in the distances of the tested light and the known one, from the disc, gives the relative light value of the former as compared with the latter.

When testing gases, the respective pressures thereof, or quantity burned per hour, must be alike, and the burners of similar pattern and size, and should, after one reading, be exchanged and a second reading taken to insure accuracy.

A simple and efficient Photometer may be made in the following manner.

Take a sheet of good white writing paper having a smooth but not glossy surface, slightly damp same by pressing between moistened blotting sheets, and while damp fix between two flat, hard–wood rings, about six inches diameter inside, and one inch wide by three-eighths of an inch thick, screwed together at sufficiently frequent intervals to insure the paper being clamped equally all around. When dry, mark in the centre a star or other shaped spot with paraffin wax—a piece of ordinary paraffin candle answers the purpose—then warm slightly to melt the wax and cause it to penetrate the paper. A well defined spot of any form desired is thus obtained, but care must be exercised in marking the paper not to apply too much wax, the slightest smear being sufficient.

The warming of the paper should be done over the chimney of a clear-burning lamp, so as to avoid heating the whole of the disc, and at the same time prevent the possibility of the surface of the paper becoming smoked or otherwise discoloured.

In use the disc is mounted vertically upon a pillar or other suitable support, and to obtain accurate results it must be exactly in the line of the two lights and at right angles thereto in both the vertical and horizontal planes. Readings of each light should be taken from each side of the disc, as in no paper are the surfaces of each side exactly alike, and the difference may cause error if not ascertained by the reversal of the photometer, and allowance made therefor.

CHAPTER IV.

COMMERCIAL PRODUCTION OF CALCIUM CARBIDE.

The production of Acetylene in large quantities from Calcium Carbide has only been possible since the discovery that the desired reaction could be brought about by means of the electric furnace. The beauty and advantage of the electro-thermic process, by which practically pure carbide may be produced from inexpensive materials, are its simplicity and economy, and that it at the same time insures the production of a material from which a practically pure gas may be evolved.

The standard of quality in carbide is termed "commercial" purity and means that the percentage of deleterious matter present is not sufficient to affect the light-value of the gas evolved therefrom to any appreciable extent, to increase its explosibility nor render it poisonous, but is at the same time sufficient to cause the gas to be distinctly odourous.

Acetylene, as evolved from "commercially pure" carbide, is therefore practically pure, and its freedom from the impurities usually present in other hydro-carbon gases is due to the fact that the greater part of such deleterious matter is separated from the elements composing the carbide in the process of manufacture; Acetylene is therefore not only the most pure, but the richest hydro-carbon gas, and consequently its flame has the highest photometric value or illuminating power of all known gases.

The element calcium is never found in the free state, but always in combination with one or more other elements. Combined with oxygen it is the Monoxide or lime (CaO). Combined with fluorine it is fluor spar (CaF_2). Combined with sulpher and oxygen it is calcium sulphate ($CaSO_4$), known as gypsum, or when combined with carbon and oxygen, calcium carbonate ($CaCO_3$), found in the form of chalk, limestone and marble.

The formation of calcium carbide by the fusion and combination of its elements is entirely due to the high temperature attained in the electric furnace (4,000°C) and not to any purely electrolitic action or process. The highest temperature attainable by other known means is that of the oxy-hydrogen flame, which gives 3,000°C, still 1,000° below the temperature of the electric arc.

Trials have been made to produce calcium carbide by means of the oxy-hydrogen furnace, but have so far been unsuccessful. The temperature of the electric arc, which is the highest known temperature, appears therefore to be necessary to bring about the reaction and consequent combination, by fusion, of the elements.

Dr. Pictet, the eminent French chemist, who is celebrated for his researches in the field of thermo-chemistry, has patented a process of manufacturing carbide by means of a combination furnace, in which the materials to be fused into carbide are raised to the required temperature in three stages. First by the combustion of carbon and oxygen, then by the oxy-hydrogen flame, and finally by means of the electric arc, which completes the process.

The inventor claims that by his method a considerably increased production of carbide per E.H.P. is effected, as none of the electric energy is expended in merely raising the material from the normal temperature to a state of incandescence, the electric current being only required to raise the temperature of the material to the degree necessary to complete the operation.

This process is in operation in one or two places on the Continent, and a company has been formed in this country to exploit the Pictet patents for the manufacture of carbide and for the purification of Acetylene, the latter subject being dealt with in Chapter VII.

Calcium carbide, as manufactured upon a large scale at Niagara Falls, at Foyers, in Scotland, and other places, is made from a mixture of finely powdered lime and coke, in the proportion of 60 per cent. of the former and 40 per cent. of the latter, although the resulting carbide consists of 62·5 per cent. of calcium and 37·5 per cent. of carbon.

The reason for the excess of carbon over the theoretical quantity requisite is because the coke, being composed of other elements in combination with the carbon, is not all converted into carbide, and besides, a small proportion of the carbon being set free, passes away as carbon monoxide.

The mixture of lime and coke is fed into an electric arc, formed between carbon electrodes, the anode being in the form of a stout rod suspended over a hearth or slab of carbon, constituting the cathode.

The material upon entering the electric arc quickly fuses into a semi-fluid and settles upon the hearth, forming for the time being the cathode, the real cathode then becoming merely a connecting link in the circuit.

As the fused mass of carbide accumulates, the upper electrode is raised to maintain the arc, and this adjustment is necessary every few minutes during a run.

The usual duration of a run is three hours, at the end of which time a bloom, or ingot, of carbide is formed, the interior of which is practically pure, but is enveloped in an outer crust of semi-fused material. The blooms when cool are broken up and the inferior material, which is of a different colour to the pure carbide, is picked out. The average yield per furnace is about ·4 lb. per E.H.P. per hour.

The reaction taking place upon the fusion of the elements calcium and carbon is expressed by the equation—

$$CaO + C_3 = CaC_2 + CO,$$

which indicates that the combination of the calcium oxide with the carbon in forming the carbide is attended by the formation or liberation of carbon monoxide.

Athough the proportions of lime and coke in the mixture fed to the furnace may be varied, yet the quantities of calcium and carbon in the carbide will always be the same, the combination of the elements with one another being governed by their chemical affinities.

The mass, or bloom, of carbide as taken from the furnace usually consists of from 80 to 85 per cent. pure carbide, the remainder being the outer covering of semi-fused material which, after being separated from the pure carbide, is ground up and again fed into the furnace together with the fresh material.

The current employed in the electric furnace is of large quantity, but of low intensity, *i.e.*, the voltage being usually from 60 to 70, while the amperage is from 1,000 to

2,000, and the yield of pure carbide per E.H.P. per hour under these conditions has been found to be about 0·4 lb.

Willson states that 1,200 lbs. of coal dust (anthracite) and 2,000 lbs. of powdered quicklime with expenditure of 180 E.H.P. will give in twelve hours 2,000 lbs. of carbide, the cost of which in America is said to be $15.

L. M. Bullier, a French chemist, an assistant of Moissan's, has patented a process by which he claims to be able to produce carbide at a lower temperature than requisite under ordinary conditions. It consists in mixing a flux with the lime and carbon. The mixture specified consists of 56 parts quicklime and 36 parts carbon, to which is added 10 per cent. of fluoride of calcium—fluor spar. This, he claims, makes the carbide more fluid, and easier to run off from the furnace.

The first works established for the manufacture of carbide were at Spray, in North Carolina, where Mr. T. L. Willson had previously erected a plant for the production of aluminium by electrolitic process, and it was at this place, while endeavouring to produce metallic calcium by similar means, that he discovered instead the method of producing calcium carbide, a material of much greater value and importance.

In the plant at Spray, the nett E.H.P. at the electrodes was 169, the current being of 1,310 amperes at 100 volts. The mixture used consisted of 58·5 per cent. of lime and 41·5 per cent. of coke. This plant produced about 92 lbs. of carbide per hour, the yield of pure carbide being 9·48 lbs. per E.H.P. per day. The production of Acetylene per E.H.P. per day was 44 cubic feet. The yield from the carbide being at the rate of 5 cubic feet per lb.

There are now said to be eighteen Carbide Factories throughout the world, the most important being those at Niagara Falls and at Foyers, in Scotland; the former owned by the Acetylene Light, Heat and Power Company, of Philadelphia, and the latter owned by the Acetylene Illuminating Company, Limited, of London.

In the furnaces employed at Niagara the negative electrodes consist of cast-iron crucibles, carried upon small trucks or trollies. These are run into the furnaces through openings in the sides, and when in position beneath the positive electrodes the leads are connected thereto by means of strong clamps.

The positive electrodes, which are suspended above the crucibles, are composed of six slabs of carbon, each 46 inches long, 4 inches thick, by 8 inches wide, clamped together at their upper ends in a strong cast-iron holder, to which the copper leads are attached.

In operation the upper electrode is lowered and contact made with the lower electrode, or crucible; current is then turned on and the upper carbon raised, which establishes the arc. The prepared material is then fed in two streams into the arc and around the upper electrode to a depth of from two to three feet. The material passing into the arc is immediately fused and converted into carbide, which accumulates in the crucible after the manner of slag. When the crucible is filled the current is stopped, the trolley disconnected and withdrawn with its load of crucible and carbide, another trolley and crucible run into the furnace, and the operation repeated.

Each furnace requires 500 H.P., and the production is about two and one-half tons (5,000 lbs.) of carbide per day, or 10 lbs. per E.H.P.

The average yield of the electric furnaces at Foyers, is 8·5 lbs. of pure carbide, per E.H.P. per day, the current employed being of 4,000 to 5,000 amperes at 55 to 65 volts.

The yield of carbide per E.H.P. per twenty-four hours, as given by various authorities, varies from 9 lbs. to 10·6 lbs. 9·5 lbs. may be taken as a possible average.

There are now believed to be four other Carbide Factories in operation in this country, besides the works at Foyers, and the production of carbide in Great Britain at the present time is said to be at the rate of 800 tons per annum.

In Geneva, carbide is manufactured by the Municipal authorities, the electric light plant being utilized for the purpose during the daytime, when only a small percentage of the power is required for lighting purposes.

The cost is found to be equivalent to £6 10s. per ton. The daily production is said to be about six tons.

This method of utilizing generating plant during the day time might be followed with advantage by other Municipal or corporate owners of such plant as affording profitable employment and at the same time equalizing the load.

CHAPTER V.

CALCIUM CARBIDE: ITS COMPOSITION AND PROPERTIES.

Calcium Carbide is a compound of the elements Calcium and Carbon, and is a crystalline, semi-metallic substance, having a specified gravity 2·26, its bulk being—theoretically—12·25 cubic inches per pound. It consists of 62·5 per cent. (by weight) of calcium, and 37·5 per cent of carbon, expressed by the chemical formula CaC_2.

It is of a highly hygroscopic nature, and owing to its strong affinity for water, both in the vapour and liquid states, it readily absorbs moisture from the atmosphere, Acetylene being evolved in the process.

Calcium carbide is not an explosible compound, nor does it possess any explosive properties, as erroneously attributed to it. But owing to its peculiar nature not being generally known and understood, and with a view to insuring public safety against any possible danger which might arise through ignorance or carelessness in the carriage or storage thereof, it is, by a Home Office Order, classed as a dangerous commodity, and made subject to the same general Regulations as petroleum and other so-called "dangerous" goods.

Calcium carbide, being produced at the highest known degree of heat, it is in no way affected by high temperatures. But when water is applied to it in a closed vessel from which the gas has not a free exit, it may set up a pressure at which it becomes explosive and the heat evolved by the reaction, if not dissipated, may cause a rise of temperature to a degree sufficient to ignite the Acetylene : the liability to ignite spontaneously being greater if there be any sulphur or phosphorous present.

Acetylene gas is evolved from the carbide by causing water to act upon it, either by bringing the water to the carbide or by dropping the carbide into water. In any case, by the application of water, a double decomposition takes place, the calcium of the carbide having a stronger affinity for oxygen than for carbon, separates therefrom, and combines with the oxygen of the water, forming oxide of calcium, or lime ; on the other hand, the carbon, having a stronger affinity for hydrogen than for calcium, separates from it and combines with the hydrogen of the water, forming Acetylene. The chemical reaction is expressed by the equation

$$Ca_2C_2 + 2H_2O = 2Ca(HO)_2 + C_2H_2.$$

meaning that the carbide in combining with the water is resolved into calcium-monoxide and Acetylene.

The production of calcium carbide by the fusion of its elements being due to the action and expenditure of a considerable amount of heat, the resulting material is an endothermic compound, hence the decomposition of carbide or similar substances is attended with the liberation of some of the heat expended in its production, and it is the evolution of this heat which causes the rise of temperature to take place when water is brought into contact with the carbide ; but only a certain proportion of the endothermic heat is liberated by this reaction. The residue remains locked up in the resulting gas until its decomposition is brought about by combustion on combination with oxygen in the action of burning ; the heat then liberated raising the particles of carbon in the gas to a high temperature and corresponding degree of incandescence, hence the luminosity of the flame.

The theoretical yield of gas from the carbide, if chemically pure, would be at the rate of 5·8 cubic feet per pound, but as chemical purity is not attainable when carbide is manufactured on an industrial scale, the yield from *practically* pure commercial carbide is from 5·5 to 5·6 cubic feet per pound.

The average yield when "commercially pure" is 5·2 cubic feet per pound ; but for ordinary purposes it will be more approximately correct if the yield is assumed as 5 cubic feet, owing to the presence of a certain proportion of low quality material and to the hydration of the carbide through exposure to the atmosphere when being broken up and packed, or otherwise handled.

The quantity of water actually required or consumed in the decomposition of carbide is slightly over half a pound, *i.e.*, ·56 ℔. = 15·5 cubic inches per pound, and the combination of this quantity of water with one pound of carbide, when practically pure, results in the formation of ·40 ℔s. of Acetylene (= 5·59 cubic feet), and 1·16 ℔s. of lime, but these proportions will vary considerably, according to the degree of purity or quality of the carbide.

Carbide of calcium manufactured by the Acetylene Illuminating Company, Limited, at Foyers, is guaranteed to yield an average of five cubic feet per pound. Carbide manufactured on the Continent rarely yields above an average of 4·6 cubic feet per pound.

Professor Lewes has patented a formula for the preparation of carbide which on decomposition shall give off a gas burning with a non-smoking flame. The claim is for mixing with the lime and coke or charcoal a certain proportion of black oxide of manganese.

Gas evolved from this carbide would be diluted with methane, or "marsh gas" (CH_4), which would serve as a diluent of the Acetylene, and so tend to make the combustion thereof more complete by reason of the reduction in the proportion of carbon to hydrogen.

It is possible that the light emitted by the combustion of the mixed gas would not be so nearly white as from pure Acetylene, owing to the fact that methane burns with a yellowish flame.

The Author is not aware as to whether any carbide has been made according to Professor Lewes' formula, but if carbide could be formed of such materials as to yield a non-smoking gas, one of the greatest difficulties in the use of Acetylene would be at once overcome.

Carbide may be rendered less hygroscopic by saturation with mineral oil, and a process has been patented for such treatment thereof, whereby it is claimed that its susceptibility to the action of water is considerably reduced. It consists in steeping the carbide, soon after being taken from the furnace and while still hot, in heavy mineral oil or tar.

The advantage resulting from any method of rendering the carbide less susceptible to the action of water would be that the reaction of decomposition, being somewhat retarded and therefore less vigorous, the temperature would not rise to so high a degree as when the chemical action is unrestrained.

Any process, therefore, which accomplishes this end, even though imperfectly, would be of advantage, inasmuch as it tends to insure the evolution of gas in a more pure state and to prevent possible loss by polymerization, which takes place in more or less degree, according to the temperature developed when the same is excessively high.

CHAPTER VI.

GENERATING—SYSTEMS AND APPARATUS.

The simplicity of the process by which calcium carbide may be decomposed and Acetylene evolved therefrom renders the generation of this gas a very easy matter, and the apparatus employed may be of most simple and inexpensive character, consisting of a Generator and Gasometer, or both may be combined in one.

The process, although the reverse of complex, is at the same time most wonderful as an example of the marvels of chemical affinity, the spontaneous reaction set up by the contact of water with carbide is of a compound character, and is attended by secondary chemical phenomena. Some knowledge, therefore, of the physical conditions involved is most essential before any experiments are entered upon in this field of practical chemistry.

Calcium carbide is decomposed by the action of water thereon, due to the chemical affinity of its elements for the elemental constituents of water ; and on the other hand, water is decomposed in the process of combination with the carbide, the double reaction taking place being represented by the equation,

$$Ca_2C_2 + 2H_2O = 2Ca(HO)_2 + C_2H_2.$$

expressing the fact that the compound of calcium and carbon combining with water produces two new compounds, oxide of calcium (lime) and Acetylene.

Calcium carbide being an endothermic compound, considerable heat is evolved during the process of decomposition, and if there be not sufficient water in the generating apparatus to dissipate such heat, or, if no provision be made for cooling the gas, it comes away hot and highly charged with water vapour which not only reduces its illuminating power, but may cause trouble by condensation in the pipes.

There are, generally speaking, three systems under which the gas may be generated ; they may be termed the "Automatic" or "Dry," the "Non-Automatic" or "Wet," and the "Retarded Reaction" system, the latter being a species of compromise between the automatic and non-automatic systems. All apparatus embody one or other of these principles and vary only in arrangement of parts and detail of construction.

In the automatic system, a certain quantity of carbide is usually contained in a closed vessel and water admitted thereto in more or less quantity as gas is required, the flow of water to the carbide being governed or regulated either by the *quantity* or *pressure* of the gas generated ; the gas as evolved from the carbide, either flowing into and raising the bell of a gasometer, or, on the other hand, displacing water and setting up a hydraulic balance.

In the first case, the increase in quantity does not set up a correspondingly increased pressure, as once the weight of the gasometer is balanced by the pressure of the gas, its rising to accommodate more gas does not, of course, cause any increase in the pressure thereon.

In the second case, when the gas is caused to displace a certain body of water at a given initial pressure, that pressure is increased as the gas accumulates and displaces a correspondingly increased volume of water, and such pressure continues to increase until the whole of the balancing water is raised to a higher level unless such water be allowed to overflow at a predetermined point at which the maximum desired pressure is reached.

On the conditions of operation being reversed, *i.e.*, when the water is required to displace the gas, the pressure of the latter decreases as the head of water becomes reduced, so that with this arrangement there is a constantly varying pressure of gas. This disability is met and to a large extent neutralized by the use of regulating valves, by which the pressure of the gas, as delivered to the service pipes, is maintained at an approximately even level, although the pressure in the generators may vary considerably.

This system has many advocates, and it certainly possesses the one great advantage of extreme simplicity; the compensating medium being a fluid as differing from a mechanical contrivance, such as a rising and falling bell, the liability to derangement is consequently reduced to a minimum, and when gas apparatus is in the charge of persons having no scientific or mechanical knowledge this is a recommendation.

In actual practice slight variations of pressure are of little or no consequence as effecting the degree of light, providing the pressure does not fall much below one and one-half inches of water, and so reach the smoking point. The displacement system, therefore, while being perhaps more suitable for comparatively small installations, it possesses features of distinct advantage where domestic servants or other untechnical or inexperienced persons are concerned.

Where the accommodation of a large and widely-varying quantity of gas is required the gasometer system would appear to be most suitable, as providing large storage area, and as obviating the possibility of any fluctuations of pressure. The legal restrictions as to pressure practically preclude the storage of a large quantity of gas under a high head of water.

In all automatic generators the evolution of the gas, in greater or less quantity, goes on continuously until the carbide is spent, the whole of the water admitted each time being absorbed by the carbide. The chemical reaction proceeds vigorously until all free water is absorbed. The undecomposed carbide, owing to its highly hygroscopic nature, absorbs moisture from the hydrate, or spent portion of the carbide, until all water is decomposed, so that, although the actual contact of the carbide with the water may be intermittent, the generation of gas is practically continuous, although variable in quantity. The hydrate, according to the conditions or form of apparatus, may contain from 10 to 25 per cent. of water, the greater part of which the undecomposed carbide will, if not separated therefrom, absorb through the agency of capillary attraction.

In some forms of apparatus the carbide is contained in a vessel separated from the gas holder, and as the container of the latter descends through withdrawal of gas, it operates a valve by which water is admitted to the carbide, and as the gas bell again rises it closes the same and stops the flow of water.

In another form of automatic generator the carbide is carried in a species of basket attached to the top of the gas bell or container, which, on descending, causes the carbide to be dipped into the water, gas thereupon being evolved raises the bell and lifts the carbide clear of the water.

In one class of automatic apparatus in which the pressure of the gas is caused to displace water, the carbide is usually placed in a tray or basket, located in a certain fixed position in regard to the water-level, the water being depressed therefrom or rising thereto as the pressure of the gas increases or decreases.

In a modified form of apparatus embodying this principle the water, on rising as the pressure of the gas is reduced, overflows at a certain point, and is conducted by suitable means to the vessel containing the carbide, the normal level of the water in the gas vessel being maintained by a supply governed by a ball-valve or other equivalent device.

This general principle has been embodied in apparatus in a variety of ways by ingenious inventors, but none, so far as the Author is aware, have overcome the one disadvantage thereof, the varying pressure.

A circumstance which should not be lost sight of in the design of the apparatus is the fact that not only does the undecomposed carbide absorb water from the hydrate, but owing to the heat evolved by the action of decomposition, some of the water is thereby vapourized and the gas evolved comes away charged in more or less degree with moisture, some or all of which may condense upon the undecomposed carbide and cause evolution of gas, in addition to that due to the principal reaction, and provision should therefore be made for this additional gas, generated after that resulting from the direct action of the water upon the carbide.

When automatic generators are employed some provision should be made for cooling the gas before allowing it to pass into the piping, otherwise it may carry with it more or less moisture in the form of aqueous vapour, which will condense in the pipes and cause trouble by "popping" or stoppage. The presence of water vapour in the gas also lowers its illuminating value, and at the same time renders the gas more dangerous, owing to the fact that if ammonia, sulphur or phosphorous be derived from the carbide, such water vapour carries with it the free ammonia, sulphur or phosphorous, or ammonium sulphide, which tend to render the gas more explosive, at the same time causing it to give off, in burning, deleterious products of combustion, which would not be the case if the gas were cool and dry.

Further, if ammonia be present in any appreciable quantity, it, together with the moisture, may form, on contact with copper, acetylide of copper, which is an explosive compound, and ignites either through the agency of calorific heat or that developed by percussive action.

In the "non-automatic" system a quantity of carbide sufficient to yield a certain volume of gas is put into a vessel or "generator" containing, comparatively, a large body of water. The carbide, being immersed in and surrounded by the water, the gas evolved in bubbling through the same becomes not only cooled but washed, and thereby freed from much impurity, which otherwise would remain associated therewith, unless separated therefrom by purification.

The gas generated on the non-automatic system is usually stored in gasometers of capacities designed to hold the quantity of gas required for use during certain periods.

This system possesses one great advantage in the fact that all risk of excessive pressure, high temperature, or escape of gas is avoided. But on the other hand, it has the disadvantage of necessitating, for a given quantity of gas, much more bulky and costly apparatus than the automatic system, but where space occupied is not of serious consequence the non-automatic system insures the preparation of the gas in the best possible condition for use, *i.e.*, thoroughly cooled and washed, before passing to the piping and burners.

A system of generating which has much to recommend it has been patented by Mr. Frederick Dresser, A.M. Inst., C.E., and which the Author has termed the "Retarded Reaction" process.

It is a species of compromise between the automatic and non-automatic methods, and consists in enclosing the carbide in bags, composed of canvas or other porous material of somewhat close texture, before immersion in water.

Immediately water penetrates the bag and comes into contact with the carbide reaction commences and gas is evolved, which distends the bag and prevents the direct contact of the water with the carbide, at the same time the bag being rendered buoyant, it rises up within the generator to a height determined by the length of a cord or chain to which it is attached.

The gas, in passing through the interstices of the fabric of which the bag is composed, is split up into a number of minute streams and is thereby brought into intimate contact with the water, which not only insures the thorough cooling, but the perfect washing of the gas, and further the direct contact of the water with the carbide being prevented by the distension of the bag, the process of decomposition is thereby retarded, and the temperature due to the reaction does not rise to a degree sufficient to affect the gas detrimentally. The generation of the gas at a comparatively low temperature is thus insured.

This is a matter of considerable importance not only as avoiding the contingencies already referred to, but as obviating the possible polymerization and loss of some of the gas.

When the decomposition of the carbide is complete, the bag is withdrawn, bringing away the whole of the residuum. The bags after being emptied and dried are again charged ready for use.

This system overcomes one disadvantage of the ordinary non-automatic process in the fact that the withdrawal of the residuum of each charge obviates the necessity for the frequent emptying and cleaning of the generators.

All generators, whether upon the automatic or non-automatic systems, should be so designed as to insure the exclusion of all or nearly all air before the generation of gas commences, otherwise an explosive mixture may be formed which may ignite through the issuing gas and air "firing back." This, of course, would only be probable if no burners or those having large orifices were employed.

Another important reason for the exclusion of practically all air from apparatus before the generation of gas is commenced, is to obviate the possibility of explosion through spontaneous ignition of the gas. Some specimens of carbide have been found to contain calcium phosphide in sufficient quantity to cause the Acetylene given off to be impregnated to such an extent with phosphoretted hydrogen as to ignite spontaneously in the process of generation.

Although this may be a remote contingency when "commercially pure" carbide is used, yet the possibility of such action taking place and constituting a source of danger is a strong argument in favour of precaution as to exclusion of air from generators.

Generators of the automatic order should be so designed and constructed as to avoid any material escape and loss of gas or introduction of any large quantity of air when removing the residuum and re-charging with fresh carbide.

Carbide, when decomposed, becomes greater in both bulk and weight, the increase being about 75 per cent. in bulk, and (when wet), 25 per cent. in weight, so that ample provision should be made in automatic generators for this swelling up, and no carbide vessel should be charged to a greater extent than 50 per cent. of its total capacity.

The actual quantity of water required and absorbed in the decomposition of carbide is at the rate of ·5lb. = 15·5 cubic inches per lb. of carbide.

In non-automatic generators, the vessel should have a capacity or water area of about one cubic foot per pound of carbide to be introduced at one time. This proportion insures the temperature of the water never rising to a degree higher than that termed "sensibly warm."

Provision should be made for the withdrawal of the residuum and so obviate the necessity for emptying the generator, as each time the water is renewed it must be again saturated with gas before any appreciable quantity is given off, and the loss of gas thus occasioned may be avoided by attention to this point.

A quantity of fresh water, equal to the consumption, should be added each time the generator is re-charged.

CHAPTER VII.

PURIFYING AND DRYING.

Acetylene generated from "Commercial" carbide is always more or less impure; if, therefore, its highest illuminating power is to be developed, and at the same time perfect safety in its use insured, and its combustion is to be unattended with deleterious products, it should be both purified and dehydrated or dried.

The gas from British made carbide, although practically pure, is always impregnated in greater or less proportion with other compounds, usually sulphuretted and phosphoretted hydrogen and ammonia, the average amount being about two per cent.

The presence of sulphuretted hydrogen is due to either sulphur in the coke or gypsum in the lime, employed in the manufacture of the carbide, or to both.

The phosphoretted hydrogen is formed by some of the hydrogen combining with traces of phosphorous in the carbide, derived from the coke or due to the presence of phosphoric acid in the lime.

The presence of ammonia in Acetylene is doubtless due to its formation by the combination of its elements during the process of decomposition of the carbide by the water and of the water by the carbide.

Ammonia (NH_3) is never formed, nor can it be produced by the direct combination of its elements, nitrogen and hydrogen, and is only formed upon the decomposition of compounds containing these elements, when hydrogen in the nascent condition comes into contact with nitrogen. It is therefore reasonable to assume that its formation takes place simultaneously with the formation of the Acetylene and of the calcium oxide by the combination of the hydrogen of the water with the nitrogen associated with the carbon of the carbide.

The greater part of the ammonia thus formed is, however, retained by the hydrate or spent carbide, its presence being distinctly discernable in the residuum when being removed from the generating apparatus.

Ordinary carburetted hydrogen illuminating gas, as obtained by the destructive distillation of coal, is always charged in greater or less degree with sulphuretted-hydrogen, carbon-dioxide, and ammonia, which compounds are to a large extent separated therefrom by the process of purification, which consists in first passing the gas through water, by which the greater part of the ammonia is absorbed, then, over or through slaked lime or iron oxide mixed with sawdust, which absorbs the sulphur and carbonic acid, and finally by passing the gas through dilute sulphuric acid to remove the remaining traces of ammonia.

Coal gas, although purified in this manner, is seldom or never free from the compounds which the purifying process is designed to eliminate. These compounds form the deleterious products of combustion, which constitute the principal objection to coal gas as an illuminant.

On the other hand Acetylene, owing to the small percentage of impurity present, is more easily and at the same time perfectly purified, and the separation therefrom of deleterious elements is not a matter of very great difficulty.

The simplest method by which Acetylene may be purified is by passing the gas through a mass of broken-up coke saturated with sulphuric acid. The gas in forcing its way through the mass is split up into a number of streams, and is thus brought into intimate contact with the acid which absorbs not only the ammonia and moisture, but a large proportion of other impurities, if any be present. The gas may also be freed from ammonia by passing it through coke or pumice stone saturated with hydrochloric acid.

The coke or other material employed as the vehicle for the purifying medium should be cleansed periodically by washing with water, and the same may be re-used any number of times

Gas produced from very impure carbide should also be passed through or over slaked lime or iron oxide—mixed with some neutral granular material—for the purpose of separating therefrom all traces of sulphuretted hydrogen.

To insure the best results being attained, it is desirable to cool the gas thoroughly before purifying, and thus cause the moisture in suspension in the form of vapour to condense and separate from the gas, and by this means reduce the quantity to be absorbed by the purifying and dehydrating media.

Gases may be dehydrated or dried by passing through or over highly hygroscopic liquid or solid substances, or materials. Gas passed through concentrated sulphuric acid becomes purified and at the same time deprived of all moisture present owing to the affinity of the acid for water.

For merely dehydrating after purification by other means, crystallized chloride of calcium ($CaCl_2$) is perhaps the best and most simple medium, and when employed, this material should be broken up into small pieces, such as would pass through a grid having meshes one inch square ; but for large quantities of gas the pieces may be of greater size, but the quantity must be proportionately increased.

The drying material should be contained in a vessel having a perforated diaphragm or grid a short distance from the bottom, beneath which the gas is admitted. This is for the purpose of preventing any moisture of condensation being absorbed by the dehydrating medium. A tap or other means should be provided for withdrawing the water from time to time.

Crystallized chloride of calcium may be revivified and its hygroscopic properties renewed by heating to the temperature of redness.

Dr. Pictet recommends passing the gas successively through a concentrated solution of calcium chloride, then through sulphuric acid 40 per cent. concentration, then washing in a solution of lead salts, and finally drying by passing through crystallized chloride of calcium ; this may be requsite in the case of very impure gas, but when made from "commercially pure" carbide such elaborate treatment is unnecessary, except when the gas is to be compressed to the liquid state. Absolute purity is then a *sine quâ non*.

Under ordinary conditions, the gas will be thoroughly purified by being passed through material saturated with sulphuric or hydrocloric acid, and afterwards drying by passing through calcium chloride.

When gas is to be stored, its purification is most essential, as the impurities present may cause corrosion of the metal of the gasometers and other parts of the apparatus, and danger through leakages arise.

CHAPTER VIII.

STORAGE OF ACETYLENE.

There are certain conditions under which artificial illumination may be required which, owing to circumstances, render inconvenient, if not altogether preclude the generation of gas or electricity when and where required, and it is in cases of this nature that gas stored in certain quantities in a concentrated form perhaps most nearly realizes the ideal.

Ordinary coal or oil gas, compressed and stored in steel cylinders or flasks is, at the present time, being extensively used for lighting railway carriages, buoys, and for other purposes where a good and portable light is necessitated by the circumstances of the case.

Acetylene stored in this way and under similar conditions affords illuminating material in both quantity and quality of light, far in excess of any other hydro-carbon compound, and for that reason it, in comparison with other illuminating media, possesses a very high value.

The manufacture of Acetylene at central depôts and the supplying of the same in highly concentrated form is in vogue in America, France and other countries, works having been established for producing and compressing the gas and supplying same in bottles or flasks for train lighting and other purposes.

Although gas or other highly expansive body stored under great pressure is to some extent undesirable, owing to the ever-present risk of explosion, yet the system, in the case of gas for illuminating purposes, possesses such great advantages that, notwithstanding the objection thereto on the score of risk, the system is much in favour, and the dangers thereof are more problematical than real. When it is considered that the flasks and cylinders employed are made of a strength sufficient to withstand as much as ten times the strain to which they are subject in practice, and that, in addition thereto, they are perhaps more severely tested than any other commercial article, the probability of accident through bursting is most remote.

The most serious accidents which have so far occurred through explosions of Acetylene have been in connection with the compression of the gas, but at the same time have been traceable to impurity of the gas, to want of knowledge of its properties when under pressure, or to neglect of proper precaution.

There are three methods or systems under which Acetylene may be stored—

1.—In the gaseous condition.
2.—By absorption in neutral fluid.
3.—By liquifaction.

The relative space occupied by a given volume stored under the three conditions being, approximately :—

In gaseous conditions	...	2000·0
By absorption in liquid	...	6·6
In liquified condition	...	5·0

The gaseous condition being assumed as at usual pressures up to the equivalent of three inches of water. But at whatever pressure stored, the space occupied by a given volume is in the inverse ratio to the pressure.

The limit of pressure in generators and gasometers fixed by the Home Office Regulations as to storage and carriage of Acetylene is $1\frac{1}{20}$ atmospheres = ·73 lb. per square inch above atmosphere, gas stored at pressures over this limit being subject to the provisions of the Explosives Act.

When Acetylene is stored in the gaseous condition in gasometers at ordinary pressures, the holders should be constructed with internal domes so that the water area exposed to the gas may be as small as possible, for the purpose of avoiding loss of gas by absorption. The liquid employed for sealing the gas bell should be a saturated salt or alkaline solution, for the reason that such solutions absorb little or no gas, and do not freeze except at extremely low temperatures; stoppage of apparatus by freezing in cold weather is thus avoided.

Acetylene may conveniently be stored by absorption in acetone and other liquids, and its explosive properties are greatly decreased, if not entirely destroyed, by solution in a neutral fluid.

The co-efficient of expansion of Acetylene solution is much lower than that of liquified Acetylene, so that vessels in which such solutions are stored may be filled, the risk of accident through bursting being relatively less.

The fluid capable of absorbing the largest amount of Acetylene, and which again gives up practically the whole volume is Acetone (C_3H_6O). It is a limpid, mobile, combustible liquid, of a specific gravity of ·814. It burns with a white, smokeless flame, and even when mixed with an equal volume of water is still inflammable.

At ordinary atmospheric pressure and at a temperature of 27° C, acetone will absorb twenty-five times its volume of Acetylene, and its absorptive capacity increases nearly in direct ratio to pressure. At a pressure of 175 to 180 lbs. per square inch, one volume of acetone will absorb 300 volumes of Acetylene. On relieving the pressure the gas passes out, and the exhausted liquid can again be charged.

The absorptive capacity of acetone decreases in the inverse ratio to its temperature, so that at 57°C it only absorbs about half the quantity it is capable of absorbing at 27°C.

Acetylene may be liquified at pressures varying according to temperature from 325 lbs. per square inch at 0°C to 700 lbs. per square inch at 35° C, the necessary pressure increasing in proportion to rise of temperature. Under these conditions it becomes a mobile, highly refractory liquid of a specific gravity of 0·43, weighing 28·15 lbs. per cubic foot, the ratio of the gaseous to the liquid conditon being 396:1.

Although the system possesses great advantages, the danger is also great, as unless the gas be perfectly pure and the temperature kept at or below the freezing point of water there is a risk of explosion during the process of compression, and it is a fact that the majority of the accidents which have occurred through explosions of Acetylene have been in connection with the compression and liquification of the gas.

For ship and buoy lighting storage in the liquified form is imperative, owing to the conditions rendering the employment of generating apparatus or gasometers practically impossible; the system is therefore peculiarly applicable and advantageous in these cases. Although the tendency of Acetylene in this condition to expand under the influence of heat, causes high pressures to be set up in the cylinders or flasks in which it is stored, yet if proper precaution be taken to keep them at a low temperature the danger is remote.

At temperatures up to 33°C the pressure in the cylinders would not exceed 700 lbs. per square inch, and even when the temperature is raised to 46°C the pressure does not exceed 1,000 lbs. per square inch. So that when it is considered that flasks or cylinders used for the storage of compressed gas are usually tested at pressures up to 3,000 lbs. per square inch, it is obvious that a good margin of safety exists.

In comparison with the storage of certain quantities of gas under the foregoing conditions, the quantity of carbide necessary to yield say 2000 cubic feet of gas—at the rate of 1 lb. per 5 cubic feet—would be 400 lbs., having a bulk measurement of but slightly over 3 cubic feet. But, as a set-off against this, the apparatus necessary to the evolution of the gas would, together with the carbide, occupy considerably more space for a given quantity than the gas in the liquified condition, and further, the difficulties and dangers attending the generation of gas on shipboard, more particularly in rough weather, point to the employment of Acetylene in the compressed form as the best under the circumstances.

CHAPTER IX.

ACETYLENE AS A MOTIVE POWER.

Acetylene, although applicable as a motive power, is not an economical source of energy, and if the combustion be at all imperfect, difficulties arise owing to deposit of carbonaceous matter in the cylinders and passages of engines in which used.

The thermo-dynamic value of Acetylene compared with coal gas has been ascertained to be from 2·7:1 to 2·8:1. But, in view of the fact that the cost of this gas is, at the present price of carbide, about 34/- per 1,000 cubic feet, and that an equivalent dynamic value—at the higher ratio—in coal gas would cost only about 7/6, there is little likelihood of Acetylene being employed for power purposes, while the price of carbide remains at £20 per ton.

But, although Acetylene would be a comparatively costly agent for the development of dynamic energy, yet, some particulars of the results of experiments conducted for the purpose of determining its dynamic value are of interest as affording data enabling comparison of the thermo-dynamic value of Acetylene with that of coal, coal gas, and mineral oil.

Experiments in the use of Acetylene for motors have been made by M. Ravel, in France, who found that 11·45 cubic feet of the gas developed one I.H.P. per hour, whereas 34·4 cubic feet of coal gas was required for an equal power in the same engine.

These figures would appear to prove that Acetylene posseses a thermo-dynamic value compared with coal gas of 3:1, but this result was obtained with doubtless practically pure Acetylène, as against a possibly low quality coal gas.

34·4 cubic feet may be necessary, in the case of French gas, for the development of one I.H.P. per hour, but that quantity, compared with the consumption of British gas in the latest types of British-made engines, is excessively high. The average consumption per horse-power-hour in this country being from about 20 cubic feet in small engines to 16 cubic feet in larger engines.

Experiments upon a somewhat larger scale made by Herr Von Ihering, in Germany, shewed Acetylene to have a thermo-dynamic value of 2·7 as compared with coal gas and from the conditions under which the experiments were made and the results obtained, and taking into consideration the nature and properties of Acetylene, it is reasonable to suppose that in proportion as the size of the motor is increased, Acetylene should give relatively more favourable results and that a value of 3:1, as compared with coal gas might be realized.

Acetylene has been employed experimentally in the engine of a motor cycle, a mixture containing but six per cent. of gas being used. The results are said to have been very satisfactory.

Liquified Acetylene would appear to be particularly suitable as a motive power for light vehicles owing to the small bulk and weight of a comparatively large quantity.

The low ignition temperature of Acetylene and air mixtures (480°C), was found to make the firing of the charge an easier matter than in the case of coal gas. But it was also found that the suddenness of the explosion—owing to the rapidity of the flame propagation—rendered it difficult to utilize the whole of the energy capable of being developed by a given volume of Acetylene.

The best explosive effect, *i.e.*, the highest pressure developed by detonation of a certain volume of mixed gas and air is produced when the gas is about 8·0 per cent. of such volume, but the best effect in an engine has been found to be realized when the gas bears a proportion of 6·8 to 7·0 per cent. to the total volume, as with this percentage the propagation of the flame of ignition is not so rapid as with mixtures having higher proportions of gas, hence the explosion is not of so sudden a character and the impetus given to the piston is consequently more effective owing to the duration of the explosion being greater than when the mixture contains a higher percentage of gas.

The calorific value of Acetylene, per volume, when burned on the Bunsen system is about 2·5 times that of ordinary coal gas.

The calorific values of various heat giving agents per pound, expressed in British Thermal Units, also their relative values, taking coal as the standard, are as follows :—

	B.T.U. per pound.	Relative Value.
1.—Coal (good steam) ...	... 14,500 ...	1·00
2.—Coal Gas ...	... 17,800 ...	1·22
3.—Petroleum ...	... 20,500 ...	1·41
4.—Acetylene ...	... 21,170 ...	1·46

Owing to the higher specific gravity of Acetylene the number of cubic feet per pound is only 13·45, as compared with 28·79 for coal gas, hence the apparently slight difference in calorific value per pound.

The British Thermal Unit is the standard of calorific value, and signifies the amount of heat necessary to raise one pound of water 1° F., *i.e.*, from 39·1° to 40·1° F., deduced from Joule's determination of the mechanical equivalent of heat.

Calcium carbide and liquified Acetylene have each been suggested as fuel for steamships, and having regard to the calorific value of the latter, compared with coal and petroleum, it would appear to have advantages. The gas in the carbide form is out of the question, its heat value—on a basis of five cubic feet per ℔.—being but 7,870 B.T.U. per ℔.

In view of the present cost of carbide, it would be idle to discuss the application of Acetylene to motive power purposes, either ashore or afloat; but from the data herein given, the relative calorific value of Acetylene in comparison with other heat-giving agents may be estimated, and in the event of the price of carbide being reduced to a point at which the use of Acetylene would be economical, the figures may prove useful.

CHAPTER X.

ACETYLENE APPLIED TO ARTS AND INDUSTRIES.

The possibility of forming organic compounds from inorganic originals or bases was first proved by the discovery that cyanogen (CN) could be produced synthetically, and constituted the first link in the establishment of the relationship now known to exist between organic and inorganic compounds.

This was followed by the discovery that Ethine or Acetylene could be produced synthetically by the direct combination of its elements and this latter discovery formed the explanation of one of the most wonderful of natural phenomena, throwing, as it did, considerable light upon those mysterious workings of Nature by which vast stores of both liquid and gaseous hydro-carbons have been built up, and which have proved of such great value to mankind.

Prior to this discovery hydro-carbon compounds were thought to be obtainable only by the decomposition of compounds of organic origin.

The possibility of producing cyanogen and ethine and from them a wide range of organic compounds has effectually removed the line of demarkation between organic and inorganic chemistry, previously thought to exist.

The varying proportions in which carbon and hydrogen combine is almost infinite, each one forming a distinct compound, differing from other compounds of the same elements.

The derivatives of the hydro-carbon compounds are also practically infinite in their number and variety, carbon and hydrogen possessing affinities for and combining freely with a large number of other elements.

Acetylene, being a compound of hydrogen and carbon, possessing properties other than those of high photometric value as an illuminant and calorific value as a source of energy, its possible industrial applications are many and various.

From Acetylene a large number of other hydro-carbon compounds may be derived by different methods of treatment and by the employment of various chemical re-agents, it is thus possible to obtain, through its agency, compounds of an organic nature from purely inorganic mineral substances.

Acetylene, on being heated in confinement to the temperature of dull redness, is converted into Benzene, C_6H_6.

Benzene, again being heated in confinement to temperature of bright redness, is transformed into Naphthaline, $C_{10}H_8$, from which—by combination with Bromide, Chlorine and other elements—may be produced an infinite variety of compounds, all of an interesting nature scientifically, some having a high value commercially, not the least of which being the dye-stuffs, "Magdala Red" and "Campobello Yellow."

Acetylene may also be converted, by combination with nascent hydrogen, into Ethylene (C_2H_4), which, on being dissolved in sulphuric acid, forms Ethylsulphuric acid ($C_2H_6SO_4$), which, upon being distilled with water, yields Ethyl-alcohol, or "Alcohol."

Alcohol, C_2H_6O, as indicated by the formula, is a compound of carbon, hydrogen and oxygen. Acetylene consisting of the first two elements, it only remains to add the third, oxygen, together with the additional quantity of hydrogen requisite, and the synthesis of alcohol is thereby effected.

The production of alcohol, practically direct from calcium carbide, may be effected in the following manner :—

Calcium carbide and metallic zinc are treated together with water, acidulated with sulphuric acid. Acetylene and hydrogen are thus evolved together, and the latter, being in the nascent state, readily combines with the Acetylene.

This combination results in the production of Ethylene C_2H_4. This gas, upon being passed into a vessel containing concentrated sulphuric acid (H_2SO_4), combines in certain proportion with both the oxygen and hydrogen thereof, forming ethylsulphuric acid ($C_2H_6SO_4$). This compound, upon distillation with water, is resolved into alcohol and sulphuric acid, the former being obtained by condensation of the vapour by passing same through a coil, surrounded with cold water in the usual manner.

It will thus be seen that the synthetic production of Acetylene on a commercial scale is likely to effect, beneficially, various industries, and not the least will be the manufacture of spirituous liquors, which will be free from those dangerous essences which are said to be always present in alcohol obtained from vegetable sources.

The future prospects of Acetylene as an illuminant, and as applied to arts and manufactures will be largely dependent upon the production of calcium carbide at a price which will permit of and insure economy in its use. When it is considered that the actual cost of production of this commodity is about one-third of its selling price, the possibility of the present market price being considerably reduced is more than prospective.

The cost of Acetylene for lighting purposes, as compared with the cost of coal gas, is easily computed. The present price of carbide is £20 per ton = 20/- per cwt. Assuming an average yield of five cubic feet per ℔., the cost of Acetylene, at this rate, would be 35s. 8½d. per 1,000 cubic feet. To compare the cost with that of coal gas, this amount must be divided by, at least, fifteen, which gives 2s. 4½d. as the cost of an equivalent in candle-power hours. This compares favourably with 2s. 9d., the present price of coal gas in Liverpool, and which price may be regarded as a fair average.

In view of the fact, that a number of manufactories are now producing calcium carbide in more or less quantities, and the prospect of the price being reduced in the near future, Acetylene may yet prove to be the most economical of all illuminants, and its application to various industrial purposes become a *fait accompli.*

HOME OFFICE AND FIRE INSURANCE REGULATIONS.

Calcium carbide having been classed as a "Dangerous" commodity, it has been made subject to the provisions of the Petroleum Acts and to the general Home Office Regulations governing the storage and conveyance of same, in addition to which, an Order in Council was issued in February, 1897, containing special Regulations and Provisions regarding calcium carbide, and empowering Municipal Authorities to issue Local Regulations to be applicable within the areas over which they hold jurisdiction.

Calcium carbide, in quantities up to five pounds, may be stored without a license, providing that the same be kept in lots of one pound or under in separate air-tight metal receptacles.

If it is desired to store more than five pounds in one place, a license to do so must be obtained, the cost of which is five shillings.

These licenses are issued by the Local Authorities, are granted for periods of twelve months, and the conditions thereof are according to the Home Office Regulations under the Petroleum Acts.

Abstracts of the Local Regulations are issued by the Municipal Authorities of all large towns, and copies thereof may be obtained gratis.

In Liverpool, copies of the Local Regulations may be procured on application at the Licensing Department, Municipal Offices, Dale Street.

The Fire Insurance Regulations as to location of Acetylene Gas Apparatus, and storage of the gas and of calcium carbide, which were at one time unreasonably stringent, having now been modified, small generating apparatus, in which the charge of carbide does not exceed two pounds is now permitted within insured premises, providing proper precautions be taken to prevent leakage, and provision made for the escape of surplus gas into the outer atmosphere.

Large apparatus must be placed outside the insured premises, and a cut-off or stop tap must be provided in the piping conveying the gas to the insured buildings, such tap to be placed as near as possible to the generating or storage apparatus.

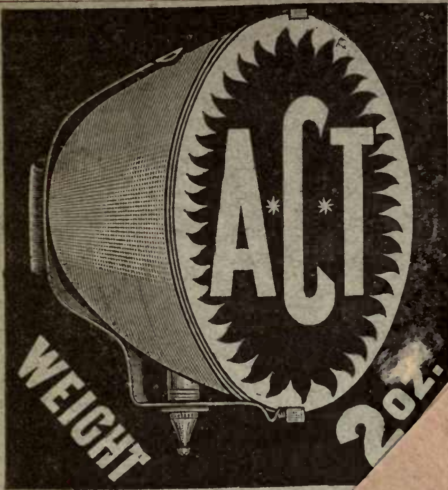
Provision must also be made for allowing surplus gas to escape into the outer atmosphere should the pressure rise to a higher degree than four ounces per square inch.

The storage of liquified Acetylene is absolutely prohibited upon insured premises, and insurance companies are agreed not to admit liability for damage due to the explosion of Acetylene gas occurring elsewhere than in the building which is, or the contents of which are the subject of the insurance.

The future prospects of Acetylene will largely depend upon two conditions or factors, *i.e.*, the price of carbide and the amount of interest taken in its application, and intelligence exercised in its use.

That the price of carbide will be considerably reduced in the near future is more than probable, but whether such enthusiasm will be aroused in regard to Acetylene as will lead to a general desire for a better knowledge of its properties, and thereby a modification of the prejudice which still obtains, remains to be seen. But there is little doubt that, with a better understanding of the subject, a further relaxation of both the Legislative and Fire Insurance restrictions would follow as a natural consequence.

Even under present conditions, Acetylene is proving a great boon in its various applications, and there is every probability of its being more generally adopted and valued at its true worth, as its advantages become better known.



THE
A. C. T.
IS
THE LAMP

FOR . .
YCLES,
RRIAGES,
ORS or
YACHTS.

The A.C.T. Lamp
complies with the ... ements.
cannot accumula...
has no screws ...
regul... s th...
has a ge... np.
is the ... the market.
has ...
in ... ounces.

The A.C.T. Generator
... uminium.
... isting Oil Lamps.
is the lightest, cheapest, and safest in the market.
is clipped to the frame, like a pump.
will give Gas for six hours.
will burn any sized Carbide from lump to dust.

Note—The combined weight of the Generator and Lamp is less than the ordinary Oil Lamp

Price,	LAMP	In Nickel, 5/6 ...	In Aluminium, 6/-
„	GENERATOR	„ 10/6 ...	„ 12/-

Further particulars will be furnished by—

The Acetylene Gas Light, Power, & Calcium Carbide Co., Ltd.

18, Ironmonger Lane, LONDON, E.C.