

THE ECONOMICS
OF
POWER PRODUCTION



WITH THE COMPLIMENTS OF THE CANADIAN SECTION
OF
THE SOCIETY OF CHEMICAL INDUSTRY.

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Canadian Section

SESSION 1905-1906

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Introduction

The Society of Chemical Industry is an organization which was founded in England in 1881 and numbers at present 4,200 members. Its chief object is the promotion of those industries in which chemistry plays a part, be it large or small, and consequently manufacturers, engineers and chemists fill its ranks. The *Journal*, which is published fortnightly in London is the most important periodical on applied chemistry and chemical engineering in the world, and is widely recognized as an invaluable aid to all those whose occupation demands some chemical knowledge.

It is issued fortnightly and contains reports *in extenso* or in abstract of the papers read before general and sectional meetings, with discussions thereupon; abstracts of all British, French and United States' patents on chemical and chemical engineering subjects; classified lists of British applications for patents and "Complete Specifications Accepted"; abstracts of articles relating to applied chemistry, selected from British and foreign technical journals, and transactions of learned societies; and a classified *Trade Report*, giving information on the Board of Trade returns, statistics, alterations in tariffs, Customs regulations, laws affecting chemical industries, consular reports, and new openings for trade. The following divisions, under which the abstracts are arranged, serve to show what industries are represented in the Society:—

1. General Plant, Apparatus and Machinery.
2. Fuel, Gas and Light.
3. Destructive Distillation, Tar Products, and Petroleum.
4. Colouring Matters and Dyestuffs.

5. Preparing, Bleaching, Dyeing, Printing and Finishing Textiles, Yarns and Fibres.
6. Colouring Wood, Paper, Leather, etc.
7. Acids, Alkalis, Salts, and Non-Metallic Elements.
8. Glass, Pottery and Enamels.
9. Building Materials, Clays, Mortars and Cements.
10. Metallurgy.
11. Electro-Chemistry and Electro-Metallurgy.
12. Fats, Fatty Oils, Waxes and Soap Manufacture.
13. Pigments and Paints; Resins and Varnishes; India-Rubber, etc.
14. Tanning, Leather, Glue, Size, Bone, Horn, Ivory and Substitutes.
15. Manures.
16. Sugar, Starch, Gum, etc.
17. Brewing, Wines, Spirits, etc.
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19. Paper, Pasteboard, Cellulose and Celluloid.
20. Fine Chemicals, Alkaloids, Essences and Extracts.
21. Photographic Materials and Processes.
22. Explosives, Matches, etc.
23. Analytical Chemistry.
24. Scientific and Technical Notes.

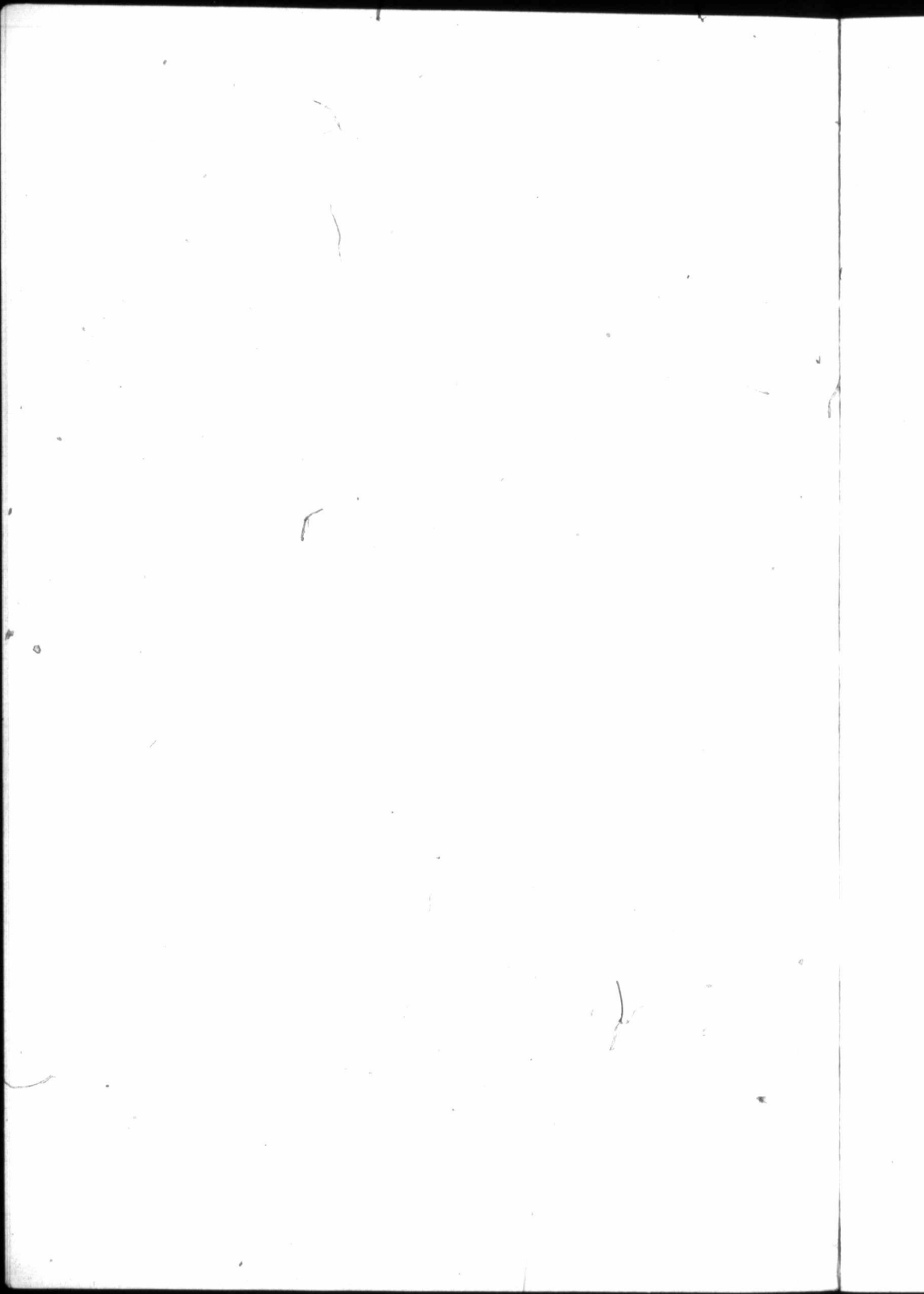
The Canadian section, which has been in existence for four years, devoted the session of 1904-1905 to a consideration of the problems of the power house. The value and efficiency of fuel, the prevention of smoke, mechanical stoking, the improvement of boiler water, the gas engine and its adjuncts, were some of the subjects introduced by capable authorities and discussed by members of the Section. Since much valuable information had been presented in this way, the Society directed that a synopsis be prepared, which appears in the following pages. The Publication Committee of the Society of Chemical Industry, London, has been pleased to sanction the issue of this information in pamphlet form.

The Society of Chemical Industry is interested in almost every branch of manufacturing. It is a matter of everyday remark that chemistry is becoming more and more important in the industrial world and this Society endeavors to furnish a common meeting ground for the manufacturer, the engineer and the chemist. Many of the papers which appear in its journal are quite readily followed and understood by those who have had no technical training, and no progressive Canadian who is interested in industrial affairs should lose an opportunity of keeping in touch with progress abroad as well as at home.

The Canadian Section extend to all who may be interested an invitation to be present at their meetings, the dates of which may be obtained from the Secretary.

The Chairman and the members of the Canadian Section wish to express their indebtedness to the Ontario Government for a grant towards the expense of publishing this work.

Toronto, March, 1906.



Economics of Combustion

I. FUELS AND FLUE GASES.

In the production and transformation of energy in its many forms more or less loss occurs. In order to meet successfully modern competition the user of energy must be eternally vigilant. The form which this vigilance takes at the present day consists largely in a scientific inspection of processes and operations, with the aim of detecting and eliminating waste, and the consequent attainment of an output as near the theoretical as is possible under practical everyday factory conditions. Every fraction of a percentage nearer the theoretical means dollars saved, and consequently a lessening of the cost of production to the manufacturer.

Nowhere is this more true in the whole realm of manufacturing than in the production of steam as a result of the combustion of fuels. Here, under the best practical conditions, a loss of 20% occurs. Under less favorable conditions, an efficiency of from 50% to 75% of the theoretical may be all that is reached. The difference means dollars wasted. The problem of the intelligent manufacturer is to eliminate as much of this waste as possible.

The problem divides itself into several parts. **FIRST**, in order to be able to estimate the waste he must know the theoretical heating power of the various fuels, and determine which is the best under local conditions for his purpose.

In the **SECOND** place, he must use such boilers and grates that as much as possible of the heat produced from the combustion of his coal may be turned into steam. This part of the problem is largely mechanical.

THIRD, he must examine the products of combustion to determine whether all his fuel is being completely consumed. This is the final check, and it lies in the province of the chemist. If an

analysis of the chimney gases shows that incomplete combustion is taking place in the furnaces of a boiler plant, it means that so many dollars are going up the chimney, chiefly in the form of invisible gases.

Valuation of Coal.—The great industrial fuel of Canada is bituminous coal. It varies greatly in character. The specific gravity fluctuates from 1.2 to 1.7. It leaves more ash than wood, and less than most other fuels; the amount of the ash varying with the sample. An examination of thirty British samples by the Admiralty gave an average of 5.55% ash, and, owing to careless picking, American coals show a higher percentage than this. For this ash the consumer must pay as if it were combustible. Bituminous coal contains a high percentage of volatile matter. This varies in amount from 20 to 50%. Bituminous coal usually contains more or less sulphur in the form of pyrites; and from .91 to 1.44% nitrogen, which latter is recoverable, in certain conditions, in the form of ammonia.

As coal varies in composition greatly, even within the seam, it is important that the large consumer should have analyses made, in order that he may have an idea of what he is buying.

The presence of moisture in coal means not only that the consumer must pay for water at the price of coal, but also that he must burn his good coal to evaporate this moisture, whereas his heat should be used in producing steam in the boiler—not in the furnace.

Generally speaking, the amount of the ash increases as the size of the coal decreases. Not only is the ash so much dead material to be paid for, but it is an expense because it clogs grates, and also in the cost of labour for its removal. A difference of 3% in the amount of ash in two samples of coal means a saving on a car load of 25 tons of over \$2.50, or, in other words, the price of $\frac{3}{4}$ of a ton of coal at \$3.50 a ton.

The analyses of a few representative coals are here given:

"BOG HEAD CANNEL" COAL.	
	Per cent.
Moisture	0.60
Volatile and combustible matter	71.30
Fixed carbon	21.20
Sulphur	0.30
Ash	6.60
Total	100.00

"PITTSBURG BITUMINOUS" COAL

	Per cent.
Moisture	1.28
Volatile and combustible matter	37.36
Fixed carbon	57.33
Sulphur	0.72
Ash	3.31
Total	100.00

"PENNSYLVANIA ANTHRACITE," WILKESBARRE, DELAWARE AND HUDSON CANAL CO.'S "VEIN NO. 5,"

	Per cent.
Moisture	4.182
Volatile and combustible matter	1.283
Fixed carbon	85.320
Sulphur	0.794
Ash	5.421
Total	100.000

"Samples collected from the Hauto Screen building of Lehigh Coal and Navigation Co., Pennsylvania," gave the following:

Size of Coal	Moisture	Volatile Matter	Fixed Carbon	Sulphur	Ash	Total
Egg	1.722	3.518	88.489	0.609	5.662	100
Stove	1.426	4.156	83.672	0.572	10.174	100
Chestnut	1.732	4.046	89.715	0.841	12.666	100
Pea	1.760	3.894	79.045	0.637	14.664	100
Buckwheat	1.690	4.058	76.918	0.714	16.620	100

These coals are separated into different sizes according to the mesh of the screen over which they pass. The sizes noted in the above table passed over and through sieve meshes of the following dimensions:

Broken, or grate size	through 4.00 in. over 2.50 in.
Egg size	" 2.50 " " 1.75 "
Stove size	" 1.75 " " 1.25 "
Chestnut size	" 1.25 " " 0.75 "
Pea size	" 0.75 " " 0.50 "
Buckwheat size	" 0.50 " " 0.25 "

Commercial analysis of coal may be conducted in two ways: 1, Proximate Analysis, of which examples are given above; and 2, Elementary Analysis. The latter shews that the chemical elements that take part in the combustion are few, viz., Carbon, Hydrogen, Oxygen, Sulphur—

ELEMENTARY ANALYSIS OF FUELS.

	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Calorific Value
							B.T.U.
Wood (oak).....	50.18	6.08	42.64	0.10	.....	1.00	3,000
Peat.....	54.38	5.08	29.54	1.31	.....	8.69	4,000
Lignite.....	66.32	5.63	22.86	0.56	2.36	2.27	5,000
Bituminous coal.....	78.57	5.29	12.88	1.84	0.39	1.03	8,250
Wigan Cannel.....	80.06	5.53	8.09	2.12	1.50	2.70	8,750
Charcoal.....	81.97	2.30	14.15	.....	.....	1.60	8,000
Anthracite.....	90.39	3.28	2.98	0.83	0.91	1.61	9,000
Coke.....	92.48	0.47	0.93	0.73	1.14	4.27	8,000
Petroleum.....	85.00	13.00	2.00	.....	.....	.....	11,000 (Bloxam.)

The proximate analysis of a coal may be very quickly made. A weighed portion is dried at a gentle heat; the dried sample is weighed—the difference in the two weights representing the moisture driven off. The dried coal may now be heated out of contact with air in a crucible, until all gases and tarry matters have been driven off, leaving only carbon (coke) in the crucible. This is again weighed, the loss shewing the percentage of volatile carbonaceous matter in the original sample. The coke is now ignited in the presence of air. When its combustion has been completed, there will be left in the crucible merely a residue of incombustible ash. The loss in this process is entered as "fixed carbon."

Details of this process are given in Appendix A., p. 15.

Elementary Organic Analysis is a much more difficult process, requiring skill and practice. A description of this method is quite unsuitable for inclusion in these notes.

Having looked briefly at the composition of some varieties of coal, it may be useful to inquire into the relative heating powers of their components. When completely burned in oxygen they

are as follows: Carbon, 14,650 B.T.U.; Hydrogen, 62,100 B.T.U.; Sulphur, 3,996 B.T.U.

The contraction B.T.U. stands for "British Thermal Units"; and a word of explanation may be desirable. Such terms as this are not used as cabalistic signs to place difficulties in the path of the uninitiated—they are merely a technical shorthand, and convey very simple quantitative information. For example, the British Thermal Unit is that quantity of heat which will raise one pound of water through one degree F. of temperature (exactly, from 39.1° F. to 40.1° F.) That is to say, one pound of carbon in undergoing complete combustion will heat 14,650 lbs. of water to just that extent—neither less nor more.

The heating power of the separate elements or of a sample of coal may be determined by means of a calorimeter, a piece of apparatus in which a weighed quantity of a combustible is burned in such a manner as to heat an ascertained amount of water—the rise in temperature being observed by means of a sensitive thermometer.

A description of one of the simplest and most accurate types of calorimeter will be found in Appendix B., p. —

It will be noted above that sulphur has a very small calorific value. In addition to the loss in heating power due to its replacing other elements the presence of sulphur means a loss in other ways. The effect of sulphur fumes on fire boxes, brick arches, flues and stacks, is too well known to need comment. Sulphur in coal usually occurs in the form of pyrites or sulphide of iron. Pyrites, or brasses, as they are sometimes called, burn to sulphur dioxide and iron oxide. This oxide of iron unites with the earthy parts of the ash to form the familiar scum or slag. This gets upon the grates, is hard to remove, and worst of all prevents the complete combustion of fuel. This means loss. The existence of pyrites in coal is indicated by a red colour given to the ashes by the iron oxide produced.

An examination of the calorific power of fuel leads to the practical question, viz.:—What properties should one look for in fuel? It is a very good rule that the heating power of a fuel is determined by the percentage of fixed carbon it contains, other

things of course being equal. As a result of this experience, tables have been made, one of which by Kent is given here.

Fixed Carbon dry, ash free:	Heating value B.T.U. per pound.	Equiv. Water Evap. from and at 212 per pound.
100.....	14500.....	15.00
97.....	14700.....	15.28
94.....	15120.....	15.65
90.....	15480.....	16.03
87.....	15660.....	16.21
80.....	15840.....	16.40
72.....	15660.....	16.21
68.....	15480.....	16.03
63.....	15120.....	15.65
60.....	14580.....	15.09
57.....	14040.....	14.53
54.....	13320.....	13.79
51.....	12600.....	13.04
50.....	12240.....	12.67

If we were to put this in the form of a curve, we should see that the evaporative power rises with the increase in the percentage until there is 80% free carbon, from that point falling slowly to 100% free carbon. The rule, then, holds in the case of coals containing a large percentage of ash and volatile matter.

To proceed to the third part of the problem: how can complete combustion be attained, and gauged? The engineer knows that with the best boilers and furnaces, and with the utmost care in every particular, not more than 80% of theoretical efficiency can be realized. In practice, an efficiency of even 60% is quite common. Where does this loss occur, and how may it be corrected? These are the next practical questions to be answered.

The loss of heat is due to the following causes:—

1. Heat lost in the evaporation of water contained in the coal, and that produced by the combustion of the hydrogen.
2. Radiation.
3. Heat carried up the chimney.
4. Incomplete combustion.

*A very large amount of water is produced during the combustion of coal or of ordinary illuminating gas. All the hydrogen contained in the fuel combines with atmospheric oxygen to form water vapour. Thus, in burning one pound of a bituminous coal containing five per cent. of hydrogen, nearly half a pound of water is produced.

It is the purpose of this section to shew how this loss may be detected and measured. Smoke is, of course, an evidence of incomplete combustion. A smoking chimney means that energy is being lost. The blackness of the chimney gases is, however, more an indication of what is going on below than a measurement, for the reason that a large part of the lost heat is in the form of invisible gases. Indeed, only a *very small proportion* of the wasted heated vapours due to incomplete combustion are visible. If we wish to be exact we must take a sample of the gases passing up the chimney flue, and from an analysis of them we are in a position to shew how much heat is being lost as the result of partial burning. The two heat-producers which fuels contain are carbon and hydrogen. In burning, carbon combines with the oxygen of the atmosphere in two proportions. The first of these, composed of one equivalent of carbon and one equivalent of oxygen, is carbon monoxide. This is the product of incomplete combustion, and is therefore itself combustible, burning in the presence of a fresh supply of oxygen.

The product of this second burning is composed of one equivalent of carbon and two of oxygen—carbonic acid. Two equivalents of the hydrogen of the fuel in burning unite with one equivalent of oxygen to form water.

As it takes several tons of air to burn one ton of coal, and as there are four volumes of unchanged nitrogen to one volume of the active oxygen in the atmosphere, the hot furnace gases are diluted and cooled very greatly, even in the best conditions.

If the coal were completely burned under a boiler, we should find in the exit gases the following:—

1. The carbon all burned to carbon dioxide.
2. The hydrogen all burned to water.
3. The nitrogen of the air unchanged.
4. A small amount of oxygen, for the reason that it is necessary, to render the combustion complete, to draw more than the theoretical quantity of air through the grate. (See table, p. 16).
5. Other gases due to the presence of impurities in the coal.

In practice, we find the chimney output to consist of:—

1. Solid carbon, giving the gases a black colour.
2. Carbon dioxide, due to the complete combustion of the carbon.

3. Carbon monoxide, due to the incomplete combustion of the carbon.

4. Water, due to the combustion of the hydrogen.
5. Oxygen, the excess taken in over the necessary amount.
6. Nitrogen, the diluting element of the atmosphere.
7. Unconsumed hydrogen.
8. Unconsumed hydrocarbons.

Smoke is unconsumed carbon. A thick black smoke means a considerable loss in heating effect. With the solid carbon there are always unconsumed hydrocarbons of a tarry nature. These make a deposit on the flue, and thus the incomplete combustion results in not only loss of heat, but prevents, even with frequent cleaning, free contact of the heated gases with the boiler.

As an example of the loss due to the escape of invisible combustible gases, Stillman quotes a case where the presence of only one-fifth of one per cent. of carbonic oxide by volume in the flue gases represented a loss of 34 lbs. in every ton of coal (1.7%) and another case where one per cent. of carbonic oxide represented a loss of 168 lbs. per ton (8.4%).

To insure complete combustion there should be, as has been shewn, an excess of air drawn through the burning fuel; but if too much is allowed to pass, it simply cools the flue gases without aiding combustion, and thus represents a loss which is often large. This loss is not usually sufficiently considered.

Carbon dioxide is a very heavy gas. In consequence, the greater its proportion in flue gases, the higher the density of the whole mixture. It follows that by taking the specific gravity of a sample of flue-gas, we can calculate whether sufficient air is being used, or the contrary. This relationship has been worked out in considerable detail, and the following table is one result (Stillman):

P. of CO ₂ indicates that 1.9 times the theoretical amount of air is in the flue gases			
5%	"	3.5	"
6%	"	3.0	"
7%	"	2.5	"
8%	"	2.3	"
9%	"	2.0	"
10%	"	1.7	"
12%	"	1.5	"
17%	"	1.0	"

An instrument (dasymer) has been devised by means of which variations in the specific gravity of the gases from a flue can be read continuously, in the same way as a pressure in a power boiler can be observed by means of a pressure-gauge. For details of this instrument and references on gas analyses, see Appendix C, p. 48.

Thus, by a proper knowledge of the heating power of a sample of coal, the user of steam may get a proper idea of what he has to start with, and by an analysis of the chimney gases may be in a position to tell what is being lost by his appliances, and by his method or lack of method. Taking these facts into account in connection with those brought out by a boiler test, he has a fairly complete idea of how economically he is producing his steam. The value of an examination of the flue gases lies in having a check on the completeness of the combustion, and also on the proper regulation of the draughts. By such an analysis unseen and often unsuspected losses may be detected and averted.

This is an age of keen competition. Nowhere is this more true than here in Ontario, where coal does not occur naturally, and where the price will rise rather than fall. Here especially must the user of steam exercise every precaution to guard against loss. It is only by a careful intelligent facing of the problem that he can expect to compete with his wide-awake neighbour.

2. SMOKE CONSUMERS AND MECHANICAL STOKERS.

The question of smoke abatement is one to which much attention has been devoted, especially in England, for many years. Of all ordinary fuels, bituminous coal gives off the most and blackest smoke. The smoke of wood, for instance, is of a very light color, and does not therefore blacken objects to any very great extent.

Of late, our cities have shown such rapid industrial growth that the smoke question has already assumed great importance. In some cases, ordinances have been passed, requiring users of steam power to use smoke-preventing apparatus. There are many forms of smoke consumers on the market, the agents of each claiming that it not only consumes the smoke, but effects an appreciable economy in the coal bill. It is not the purpose of this article to advertise any special forms of apparatus; as it is felt that whilst several of them possess merit in lessening the smoke

issuing from the stack, yet it seems clear that different conditions call for different remedies, and it is not yet demonstrated that any one device has been able to show its claims to be a "smoke preventer."

Some of these appliances consume a great deal of smoke, it is true; but a relatively small change in conditions is frequently sufficient to very seriously limit their efficiency, even in this essential. When, moreover, the question of economy of running is taken up, it is found that a great diversity of opinion exists; and it appears certain that some forms of smoke consumers actually increase instead of diminishing the cost of power production. Besides this waste in operation, some of them are costly to instal—often necessitating extensive structural alterations; and in a few cases the cost of repairs (always difficult to estimate) is very high.

The solid constituents of smoke can be easily examined microscopically by drawing a sheet of cold glass through a flame, and observing the aspect of the blackened surface. In its essence, it will be seen to consist of minute particles of carbon, each surrounded by a sort of greasy halo. Any fuel will yield smoke when burned with an insufficient supply of air—even natural gas can be so burned as to yield a commercial lampblack known as "gas-black"—indeed, as a rule it may be stated that those carbonaceous substances which burn with the brightest flame under proper conditions, will yield the most smoke when burned under unfavorable ones.

A smoky chimney is not to-day looked on as a measure of enterprise—indeed, many of the stacks that show most smoke are attached to establishments in which there is only a small consumption of coal. In fact, as will be shown, any attempt at smoke prevention, or even smoke abatement, raises problems of great complexity. With hand firing, at any rate on the small scale, it appears that a careful, intelligent fireman is a greater agent of economy and complete combustion than any mechanical apparatus as yet devised. Even on a larger scale a great deal can be effected by the same means.

Some essentials of good firing are as follows:

- (1) The pieces of coal should be uniform in size.
- (2) The fire-doors should not be left open too long or opened too frequently.

- (3) Coal should be added in moderate or small quantities, and in thin layers, towards the front of the grate.
- (4) When the volatile constituents have been driven off, the coal can be pushed back towards the bridge.

Nos. 1, 2 and 3 promote complete combustion without undue loss of heat. The great function of No. 3 is to ensure the actual consumption of the volatile portions of the coal; for, as mentioned elsewhere, *volatile combustible which is allowed to come unburned into contact with the heat-transmitting surfaces of the boiler will never be burned.* The reason for this is that its mere contact with these surfaces cools it below the temperature of combustion, and this part of the coal escapes through the stack as merely unconsumed heated gas. Although it is invisible, however, it figures in the coal bill, and it is apt to be forgotten.

The first efforts at smoke consumption were made by James Watt in 1785, by means of what is believed to have been the first mechanical stoker, a device for pushing the coal, after coking at the front, to the back of the grate, towards the bridge. Watt also in the same year proposed to consume smoke by passing it together with the gases from fresh fuel and air through very hot pipes. Since Watt's time numberless inventions have been patented, none of which has so far succeeded in demonstrating its superior efficiency by driving the rest from the market. Nearly all of these inventions depend on the following classified principles, either singly or in combination:—

- (1) Air admitted above the fire at front of furnace.
- (2) Air admitted above the fire at rear of furnace or in front of bridge.
- (3) Air admitted at rear of bridge.
- (4) Double combustion.
- (5) Brick arches above fire.
- (6) Hollow bridge walls and air ducts in the setting which heat the air prior to its entering the furnace.
- (7) Coking arches in front.
- (8) Down draft furnaces.
- (9) Powdered fuel—mechanical draft.
- (10) Gas furnaces.

- (11) Mechanical stokers, divided into two classes, viz., over and underfeed, and the overfeed sub-divided into two, viz., sprinkling and coking.

It is unnecessary here to follow the course of the development of smoke consumers. It is sufficient to say that two or three significant facts again and again brought out:

- (1) That the inventions mostly consist of repetitions of older designs with minor modifications.
- (2) That *intelligence* in their operation is an essential—often lacking.
- (3) That if the necessary intelligence and care are exercised, there are many cases where good results can be obtained without special apparatus (up to a certain size of installation).
- (4) Some of the inventions have certainly done much to reduce smoke, but many of them have been too costly, either in original cost or in operation; and many (perhaps all) yield indifferent results under exacting conditions—such, for example, variable loads.

Disregarding gaseous fuel systems, the smoke-consumers which are in most general use to-day depend on:—

- A. FORCED OR INDUCED DRAUGHTS—Generally through fans or steam-jets.
- B. OVERFEED MECHANICAL STOKERS:—For example:
 1. Pulverized fuel, fed into the furnace with an adequate supply of air.
 2. Inclined grates, with coal fed in from above in various ways.
- C. UNDERFEED STOKERS:

For reference the following list of firms is appended:

The Royal Automatic Smoke Consumer & Fuel Saver Co., Toronto.

The Imperial Smoke Consumer Co., Toronto.

The Smokeless Fuel Saving Co., Toronto.

Wild's Smoke Consumer, Toronto.

The Jones Underfeed Stoker Co., Toronto.

The Murphy Furnace Co., Toronto.

The Rooney Furnace Co., Indianapolis.

RESULT OF COMPARATIVE TEST AT THE PLANT OF THE CANADIAN PACIFIC COMPANY,
TORONTO, BETWEEN HAND FIRING AND THE STOKER.

Test No. 531.

1904

Particulars	Hand	Stoker	Stoker
Date of Test	July 4	July 5	July 6
Duration of Test	9	9	9
Kind and size of boilers	R. T.	6 x 16	6 x 16
Kind of coal (all from same mine)	Lump	Lump	Slack
Amount of coal as weighed	6382	5155	5286
Amount of Moisture	Dry	Dry	
Percentage of Moisture			
Total dry coal burned	6382	5155	5286
Total ash	573	452	469
Percentage ash	9.1	8.8	8.8
Total combustible	5809	4703	4817
Total amt. of water apparently evaporated	45224	46641	45360
Total equiv. from and at 212 deg.	47033	48600	47401
Average gauge pressure	82.75	79.67	80.43
Average feed temperature	208.2	205.5	203
Av. hourly coal consumption	709	573	587.3
Av. hourly equiv. evaporation	5226	5400	5267
Average horse power developed			
1 H.P.	34 1/2 lbs.	151.4	156.5
152.7			
Heat accounted for in water per lb. coal B.T.U.			
Actual evap. per lb. dry coal	7.086	9.047	8.581
Equiv. evap. from and at 212 per lb. dry coal	7.354	9.427	8.987
Actual exp. per lb. combustible	7.785	9.917	9.417
Equiv. evap. per lb. combustible	8.096	10.334	9.84
Pounds coal required to evap. 1,000 lbs. water from and at 212 degrees	136	106.1	111.3
Cost in cents to evaporate 1,000 lbs. water—Lump at \$3.50 per ton; Screenings at \$3.00 per ton	\$0.238	\$0.185	\$0.1669
Net Relative Economy	100	123.7	130
Net Saving effected by Stokers		17.5%	25%

BOILER WATERS AND THEIR PURIFICATION

That certain of the natural waters are soft while others are hard is a fact with which everyone is familiar; tap water and rain water would immediately occur to most of us as illustrations of these two classes. To collect our ideas we may recall that hard waters are very palatable, that they deposit a coating or scale in the vessels in which they are boiled and that for washing purposes a certain amount of soap must be used before a lather is produced, while the soft waters on the contrary are less palatable, do not form a scale on boiling and produce a lather immediately with soap. These differences are due to the fact that hard waters hold in solution certain materials, usually compounds of lime and magnesia, the soft waters being practically free from dissolved substances. The natural conditions which lead to a supply of either class are readily understood. Water is a powerful solvent and chemical analysis shews that not even rocks and soils are exempt from its action; thus, in a district underlaid by limestones and dolomites the soft rain water during its drainage to the streams and lakes dissolves those constituents which render it hard. Such rocks, however, as those which occur in the Muskoka district are but very slightly attacked by water, and hence we have in this region a large supply of soft water. If a line be drawn from Midland to Kingston it may be said roughly that all waters to the north are soft and all to the south, including the Great Lakes, are hard. In the latter district, however, are situated a large majority of the manufacturing plants and the use of hard water, accompanied as it invariably is by the formation of boiler scale, is, therefore, worthy of some consideration.

As a rule boiler scale is undesirable because of its non-conductance of heat and also because the tubes are gradually choked up by its deposition, less commonly one of the scale-forming constituents of the water actually corrodes the boiler in addition. Authorities vary in their opinions as to the amount of heat lost through the formation of boiler scale, but it is generally accepted that a layer of 1-16-inch thick will necessitate 10-15% more fuel and thickness of $\frac{1}{4}$ -inch, an increase of 30-40%. The most convincing evidence of this loss is to be found in the state-

ments of two large companies in the U. S. who reported that a saving of 15 to 20% of fuel had been effected by the use of softened water instead of hard.

The deposition of scale if allowed to proceed till the tubes are largely or entirely choked up is followed by a serious drop in the steam-raising capacity of the boiler, nor will the use of more fuel renew the original output. Under these conditions the boiler heads and flue ends are soon ruined and an astonishing bill for repairs is the result. Should a heavy coating of scale be allowed to form over the grates, the consequences are likely to be serious. The grate no longer cooled by direct contact with the boiler water but jacketed as it were by the scale, becomes overheated and finally swells out into a bulge under the internal pressure. It can easily be seen that the process may go on until the sheet is much reduced in thickness, a rupture then takes place and we have an explosion.

Having noticed briefly the evils which follow upon the formation of scale, it will be in order to turn to a consideration of the cause of the trouble, the material which the hard waters carry in solution; from a chemical standpoint this consists usually of the bicarbonates and sulphates of lime and magnesia. These bicarbonates in solution show a curious behaviour in boiling; they are decomposed and the carbonates are precipitated as a fine mud. Sulphate of lime is gradually deposited in the form of a very dense hard scale, acting as a cementing agent for any other material, e.g., carbonates of lime and magnesia, which may be present. Chloride of magnesia is also an undesirable constituent of boiler waters since it results in corrosion. For the removal of these compounds a number of methods have been proposed which may be discussed under the headings:

1. Mechanical Treatment.
2. Chemical Treatment.
 - (a) In the boiler.
 - (b) Outside the boiler.

1. The mechanical treatment consists in passing the feed water through heaters, which results, as has already been stated, in the precipitation of the carbonates of lime and magnesia; this however is only partial and the sulphates pass on unaffected. Most heaters are provided with filters designed to retain the

sludge, the efficiency of the device being dependent upon a frequent renewal or cleansing of the filter beds. This treatment is exceedingly simple and inexpensive and results in a considerable improvement in the water, in addition to the economy effected by the use of hot feed.

2. (a) Chemical Treatment in the boiler:

This method depends upon the introduction into the boiler of some chemical such that the scale-forming constituents are precipitated in the form of a soft sludge which may be readily blown off. The role of purifying agent may be taken by a number of materials, of which many are sold as boiler compounds. There are used for example: soda ash, caustic soda, tri-sodium phosphate, barium chloride, sal ammoniac, catechu and nut galls; in the case of boiler compounds a slimy or sticky substance such as for instance Irish moss, potatoes, linseed, sugar, molasses or oil, is often present in the mixture to prevent the adhesion of the scale to the metal. It would be impossible to discuss the many varieties of boiler compounds or even simple chemicals which are on the market, but certain general principles may be recognized. Alkaline materials like soda ash, whatever effect they may have on the scale, are harmless to the metal, but such substances as sal ammoniac and nut galls, which become acid in the boiler, will produce corrosion. The use of oil is almost universally condemned, for a thin film entangled with solid scale will ruin a boiler or reduce its efficiency more quickly than anything else. Careful experiments have shown that in a boiler the temperature of the plate in contact with the water was when clean 430° , when greasy 617° , an increase of 187° , showing plainly the great loss in the transmission of heat. In practice the presence of oil is always accompanied by leaky joints and flue ends and also by buckles and waves on the bottom if it should settle. Modern practice tends towards the use of simple chemicals of which soda ash and tri-sodium phosphate are the favourites. The method of treatment is exceedingly simple. To the feed-water pipe is connected a valve-regulated smaller pipe which supplies a solution of the chemical desired: the precipitation takes place inside the boiler and the sludge is frequently blown off. The accumulation of soda compounds in the boiler produces foaming or priming, the remedy for which is also "blowing off."

By the employment of this system fairly satisfactory results have been obtained but it is significant that large consumers have in many cases installed water softening plants which will be discussed later. For a single boiler or a small battery the advantages attending the use of chemicals in the feed water can easily be seen. The first cost of a water softening apparatus is avoided and the treatment when properly adjusted to a water whose composition is constant, is automatic. On the contrary the boilers must be more frequently washed out than when softened water is used because the sludge is not entirely removed by the blowing off. It must not be forgotten moreover that the latter operation involves a considerable loss of heat.

2. (b) Chemical Treatment outside the boiler.

As has already been stated the tendency of the day is towards the adoption of this method of purification and to judge from the very rapid increase in the number of water-softening plants installed during the last few years, it may be gathered that large consumers at least find that a treatment of this description is best suited to their purpose. The chemicals employed are almost invariably lime and soda ash. The oldest and simplest treatment involves the construction of two tanks each large enough to hold a day's supply of water. One tank is filled with the hard water, the lime and soda ash are added and the mixture after thorough agitation is allowed to settle. After the precipitate has subsided the softened water is drawn off, or by the use of filters the time allowed for settling may be considerably shortened. To improve this process mechanically a number of devices have been patented and the machines are now on the market. Of these the best known are the Kennicott, We-Fu-Gu, and Davidson. In all the supply of chemicals is automatic and adjustable, an object which is secured by various mechanical means; the methods of mixing and sedimentation vary. It is not within the scope of this paper to discuss details and for these the reader is referred to the companies concerned.

The best softening plants cost per horsepower in capital outlay:

Up to 1,000 h.p.	.....	\$4.00 to \$5.00
1,000 " 2,000 "	.....	3.00 " 4.00
2,000 " 5,000 "	.....	2.00 " 3.00
5,000 " 15,000 "	.....	1.20 " 2.00

The cost of chemicals in a softening plant in America averages 1 to 2 cents per 1,000 gallons, and the cost of attendance is not more than the time of one man.

In 1900 a committee of the Lancashire and Yorkshire Railway instituted an inquiry as to the methods of feed water purification as then in use by the different railways of the world. Reports from eleven countries show that thirteen out of a total of fifty-eight roads used some system of water softening; the mean cost of treatment was 6½ cents per 1,000 gallons.

The problem of water softening on a large scale is neither purely chemical nor purely mechanical, but both aspects must be considered. While mechanical ability is necessary for the economical and efficient treatment, a knowledge of the chemical composition of the water is absolutely essential for the attainment of satisfactory results and a system of control must be established. For the latter purpose reference may be made to Mr. McGill's original papers in the *Journal of the Society of Chemical Industry* under dates 15 April and 31 May, 1901, where a very thorough discussion of the subject will be found. The details of these papers are very technical and though interesting to chemists are unsuitable for insertion in this abstract.

The following are the names of the principal firms in America who manufacture and instal water-softening plants:

The Kennicott Water Softener Company, Railway Exchange Building, Chicago, Ill.

Wm. B. Scaife & Sons Company, Pittsburg, Pa.

Otto Gas Engine Works, 360 Dearborn St., Chicago, Ill.

Wholesale prices quoted in Toronto, November, 1905:

Soda Ash—Carload lots, \$1.00 per 100 pounds; ton lots, \$1.10 per 100 pounds; one-hundred pound lots, \$1.60 per 100 pounds.

Tri-sodium Phosphate—300 pound lots and under, 6c. per pound; over 300 pounds, 5c. per pound.

PRODUCER GAS

Among the competing fuels of to-day, the gases play an important part, and the rapid growth of industrial enterprises in those districts where natural gas occurs, may be adduced in support of this statement. In less favored regions, coal or oil gases which have large calorific values may be employed, but unfortunately their high cost has prevented any widespread use.

In general it may be said that only two varieties of this class of fuels are of importance for the production of power, viz., blast-furnace gas and "producer" gas. The former, which results from the regular operation of the iron-blast furnace, was formerly used simply for heating purposes, but it is now employed largely in driving the blowing engines; it is obvious that this gas is not available for the manufacturer at large, and hence it will not be further discussed in this paper.

"Producer" gas, which has become very important commercially, can be manufactured on the other hand, in small or large quantities, and necessitates the use only of a small and compact plant. The methods of production vary according to the amounts of gas required, but the general process may be described as follows: Air, or air and steam, are passed through a red-hot body of fuel contained in a suitable brick-lined generator. This generator resembles, indeed, a very inefficient furnace, and the fuel and air are intentionally only half-burned. This effect is favored (1) by using a thick bed of fuel; (2) by keeping the temperature below a certain limit (by varying the amount of steam) and (3) by supplying only enough air to allow partial combustion.

It will be here observed once more that this closely resembles very bad firing as sometimes conducted under power boilers. Indeed, the point has been well illustrated by the remark on a case of very bad firing, that the owner was running a gas-producer and not burning the producer gas.

In the typical gas generator the process is usually continuous, fuel being fed in as needed, while the steam and air blasts are introduced simultaneously. Any class of fuel may be employed. If, however, a bituminous coal be selected it is necessary to introduce

"scrubbers," etc., to thoroughly remove the dirt and tarry vapors. To obviate this necessity, coke and anthracite are much used in the smaller generators. The following are analyses of producer-gases:—

	From Anthracite	From Bituminous Coal	From Coke	From Wood
	C	C	C	C
Hydrogen	20.	10.	10.	20.97
Methane		3.		2.61
Ethylene		0.5		.28
Carbon monoxide	25.	23.	29.	13.27
Carbon dioxide	5.	5.	4.5	15.96
Nitrogen	49.5	58.	56.0	46.80
Oxygen	0.5	0.5	0.5	0.11
Calorific value (B.T.U.) ..	144	144	125	140

The apparatus in general use consists of two steel cylinders lined with fire brick, connected on the top and bottom with pipes, a fan for air, a boiler and gasometer. Fuel is charged at the top; air is blown in, also at the top, and comes into contact with the fresh fuel. The product of the partial combustion thus induced, is the "producer-gas." Together with any tarry distillates, the gas is drawn downwards through the deep charge of incandescent fuel and out through the bottom of the producer. It then passes through the boiler, where its high temperature is utilized to generate the steam which is used for the blast; and is farther cooled to about atmospheric temperature in its passage through the water-sprayed, coke-filled trays of the "scrubber," whence it is led to the gasometer. When by means of regulating the amount of air admitted, the fuel bed has been raised to the desired temperature, the air blasts are discontinued. The valves are now adjusted so as to throw the two generators in series—in other words, so that the current will go upwards through the first generator, and thence downward through the second. Steam is at once admitted under the grate in one generator, and on its passage through the incandescent fuel is split up at the temperature of the fire; and, its elements combining with the carbon of the fuel, forms that mixture of gases known as "water-gas." It then travels across the top connecting pipe to the steam generator and down through the latter, passing out from the bottom of this generator to the boiler, to the "scrubber" and thence to the gasometer. The essential feature of this arrangement is that with bituminous coals, the tarry vapors liberated from the green fuel in one generator

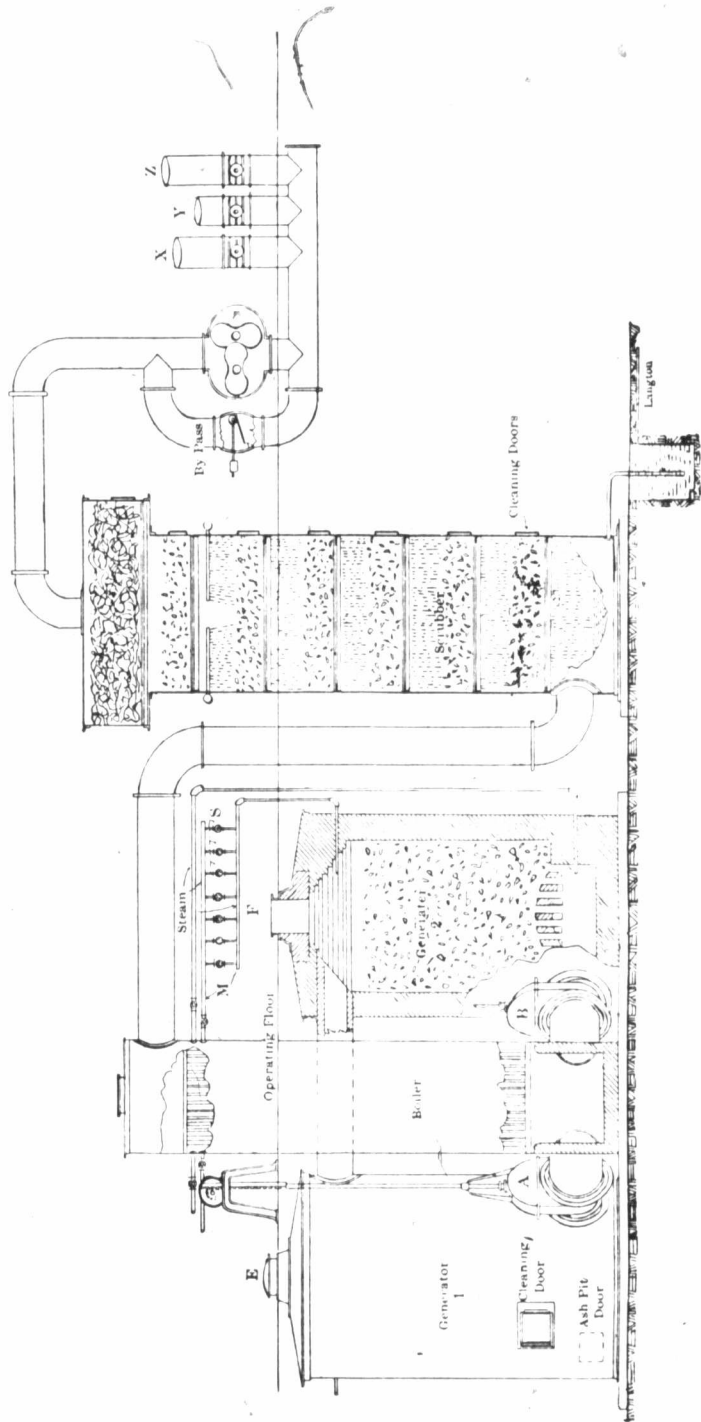


FIG. A.

are forced through the hot fuel bed of the second, by which means they are completely gasified. The current of the steam is reversed at intervals. A good example of this type is illustrated in Fig. A.; it was erected by John Langton for the Moctezuma Copper Company, Nacozari, Mexico, and has been running for five years in a very satisfactory manner, the fuel being wood.

In many of the smaller plants the fan for producing the air blast is dispensed with, and the suction induced by the piston of the gas engine is utilized for the introduction of air; no gas holder is here necessary. Generators of this type are known as "suction producers," and are very satisfactory.

When the amount of gas required exceeds that corresponding to, say, 5,000 h.p., it is usual to instal apparatus for the recovery of the by-products. The best known system of this kind is the Mond, which has of recent years been used with great success. A 20,000 h.p. plant under continuous operation in England produced about 3,000 tons of sulphate of ammonia in a year; after deducting all expenses for operating, the profit on this amounted to nearly \$1.00 per ton of fuel. The only Mond plant in America is at the works of the Solvay Process Company near Detroit, where a saving of fifty cents per ton of coal was effected with a daily consumption of 150 tons.

Attention may fitly be drawn to one of the greatest advantages of producer gas, the entire absence of smoke.

It may be asked why ordinary illuminating gas cannot be used for power purposes. The answer is that it is too dear. The explanation of the difference in price is a simple one. Disregarding minor factors, we may say that, in order to obtain a gas of sufficient illuminating power for house-lighting, the distillation of coal is conducted in such a manner that only a portion of the coal is gasified. Immense quantities of coke, tar, etc., are left in the retorts and mains of gas works. In the case of producer-gas, the conditions are such that the fuel may be entirely gasified. Gas producers therefore yield an immensely larger quantity of gas than ordinary gas retorts—the increase is, in fact, so very large as to make producer-gas a cheap fuel, whereas coal-gas is a dear one.

THE COMMERCIAL DEVELOPMENT OF POWER FROM GAS

By R. A. Ross, E.E.

The development of power from gas engines has been rather a curious one. For nearly thirty years gas engines have been in the market, but during fifteen years of that period the art was practically at a standstill, due largely to the facts that the fuel used was ordinary illuminating gas purchased from the companies at a high price, and that the earlier gas engines were uncertain in operation, while steam developments were advancing so rapidly that engineers were not devoting that amount of attention to the gas engine which it received later. During recent years, the increased cost of coal has diverted the attention of many engineers from the steam engine, whose economic limit is now nearly reached, to gas engines, where economies to which the steam engine can never hope to attain, can readily be made.

The commercial history of the gas engine may be said to have begun in 1876, when a 3 horsepower engine was shown at an exhibition in Europe. In 1879 at a similar exhibition, a 16 horsepower engine was in operation. From that date until within the last ten years, the development was very slow. In 1900, however, gas engines of about 1,000 horsepower, and in 1903 engines of 2,000 horsepower were available, and it only remains to chronicle the fact that the California Gas and Electric Light Corporation have just contracted for three 1,000 K.W. three-phase alternating generators direct-connected to 5,100 horsepower engines, to indicate the rapid development which has been made since the beginning of the present century. The sudden increase which took place in size of units from 1895 to 1900 was due to the use of blast furnace gases, since the smelters found that furnace gas, though of low calorific value, could be utilized for operating blowers for the furnaces, thus obtaining power from what was formerly a waste product. This acted as a spur to the engine builders, who were compelled to build types suitable for a lean gas for large powers. The greatest factor, however, in the development of power from gas is the commercial development of the gas producers.

When first available, the gas producer was committed to the use of hard coal or coke, but recent progress has determined the entire feasibility of using almost any quality of combustible material, from the best hard coal to garbage; and has placed within the reach of the ordinary user a power plant which can be easily and safely installed, and which, even in the smaller sizes, will produce economical results which cannot be approached by the use of the best steam engines and boilers. The trickiness and uncertainty of the earlier forms of gas engines having been eliminated, it seems safe to say that less experience is required to operate the modern producer and gas engine plant than to operate a steam engine and boiler plant.

The advantages claimed are as follows:

- Less coal used per horsepower.
- Cheaper fuel may be used.
- Simplicity.
- No high pressures as in steam plants.
- Readiness to start at a few minutes' notice.
- Elimination of smoke.

As regards the efficiency, it may be said that builders are able to guarantee a brake horsepower from the burning of from 1 to 1½ pounds of coal, depending upon the size of the plant. Comparing this with steam engine and boiler consumption, we find that it corresponds with from 2 pounds to 5 pounds of coal per horsepower per hour, if the same quality of coal be used in both cases. In addition, it is also quite feasible to use cheaper fuels in the gas producer than under boilers, with good economy, giving still greater saving in the total fuel cost. The elimination of high pressure steam is also an important feature, as no pressures are required in the gas plant. The ability to start quickly is especially favourable in electric light and street railway plants where sudden demands may arise, as little time is required to start gas engines; whereas, in the steam plant, either fires must be banked under idle boilers to provide for a sudden demand, or time must be wasted in getting up steam.

Within recent years municipal authorities have been becoming more and more stringent as regards the smoke nuisance. Since in the gas plant the products of combustion leave the engine as a burned-out gas free from smoke, this nuisance is eliminated. In an ordinary furnace the endeavor is to obtain complete combus-

tion, in the gas producer, the object is to produce incomplete combustion—the final burning of the product taking place explosively in the gas engine cylinder. In burning coal in the ordinary boiler furnace the greatest production of heat is sought, and in attaining this object it is essential that the gas be burned to carbon dioxide as nearly as possible. In the producer, on the other hand, only enough heat is required to gasify the fuel, the resulting product being carbon monoxide, which completes its combustion to carbon dioxide in the cylinder of the engine. In other words, in the ordinary heating furnace, fuel is vaporized, distilled, gasified and burned; in the producer only the first three operations take place. A rough estimate of the number of cubic feet of producer gas obtained from one pound of the various fuels is given below, in which the heating value per cubic foot varies from 125 to 140 British Thermal Units, depending upon the efficiency of production:

- Coke—104 cubic feet.
- Bituminous coal—75 cubic feet.
- Brown coal—55 cubic feet.
- Turf—15 cubic feet.
- Wood—35 cubic feet.

The gases which have been used for power production may be roughly divided into five groups, in accordance with their heating values as shown in the table below, which also indicates roughly the number of cubic feet of each gas necessary to produce one brake horsepower per hour in various sizes and classes of engines:

	B.T.U. per Cubic Feet	Cubic Feet per B.H.P.
Natural Gas.....	900 to 1,000	12 to 13
Coal Gas.....	600 to 700	15 to 20
Water Gas.....	250 to 300	30 to 40
Producer Gas.....	125 to 150	60 to 80
Blast Furnace.....	90 to 110	100 to 120

It does not follow, however, that the commercial efficiency of the gases above enumerated is in proportion to the heat efficiency, as, for instance, the cost of the production of coal and water gases is so much higher than that of producer gas that the

latter is the only artificial gas which is considered in dealing with large power plants.

Natural gas is found in great abundance in certain districts in the United States, and it will be noted that it has the highest calorific value, although its constituents in various localities differ very largely.

Coal gas, or what is known as ordinary illuminating gas, has been used in small engines operated from local gas plants, but on account of its high cost, it presents very few attractive features apart from the elimination of the boiler. Coal gas is made from the distillation of bituminous coal in retorts, the vapors being distilled in the low temperature part of the furnace and made a fixed gas in the hot part; the tarry matter is then extracted, leaving coal gas and coke as the product.

Water gas, which has to a large extent superseded coal gas for illuminating purposes, is produced by the intermittent, alternating or continuous blowing of steam and air through a thick bed of incandescent fuel; and, being almost non-luminous, it is carburetted for illuminating purposes by hydro-carbon vapors which are made into fixed gases in a superheater. Dowson gas, which has obtained a large use in Europe, is of this class. When used for power the carburetting is omitted. Up till recently this was the fluid used most largely for gas engines, but only in comparatively small sizes.

Producer gas is the most interesting from a power point of view, being produced more cheaply and simply than any of the others above mentioned. It is obtained from the distillation of either anthracite or bituminous coal, or, in fact, from any combustible material. A part of the heating value of the fuel is used in vaporizing the remainder; the product is carbon dioxide, which on rising through the upper part of the incandescent bed of fuel becomes converted into carbon monoxide. The combustion and vaporizing is assisted by blowing the fire with air or steam, or both, and the product which is to be utilized for power is a mixture of carbon monoxide and hydrogen, which carries 80 to 85% of the calorific value of the fuel to the engines.

Blast furnace gas is a lean gas derived from blast furnaces, consisting chiefly of carbon monoxide and a great deal of inert nitrogen. In blast furnace operation it is possible only to utilize a portion of the heat value of the fuel for metallurgical reasons,

as it is not found advisable to burn the carbon monoxide to carbon dioxide, owing to deleterious chemical action upon the metals which are being smelted. The vast volumes of gas given off from these furnaces have been utilized to a large extent for the production of power by means of gas engines connected to blowing machinery and other apparatus necessary for smelting purposes, and great economic savings have by this means been made in operation. It was this field, as before stated, which first attracted the attention of gas engine builders towards larger sizes of gas engines. The gas, however, carries with it a great deal of dust and dirt and must be thoroughly washed before being used in the engine to prevent scoring of the cylinders and working parts. It will be noted that it has the least calorific value of any of those mentioned.

As regards the combustible constituents of the various gases, it will be seen in table 2 that natural gas is the highest in marsh gas. Water gas is an approximately equal mixture of carbon monoxide and hydrogen. Producer gas is largely composed of carbon monoxide with a comparatively small portion of hydrogen, while blast furnace gas has in its combustible constituents a very large portion of carbon monoxide.

TABLE 2.

COMBUSTIBLE CONSTITUENTS IN PERCENTAGE OF TOTAL VOLUME.

	Natural Gas	Coal Gas	Water Gas	Producer Gas	Blast Furnace Gas
Carbon monoxide ...CO...	50	6.00	45.00	27.00	23.5
Hydrogen .....H.....	2.18	46.00	45.00	12.00	6.00
Marsh Gas .....CH ₄ ...	92.60	40.00	2.00	2.00	3.00
Olefiant Gas .....C ₂ H ₄	31	1.00	0.00	0.00	0.00

Producer gas is the one which is of interest at the present time and it only is considered later in this paper. It is manufactured in various types of apparatus, some of which include those used to separate by-products, which are of commercial value. Apart from this separation of by-products, which is only commercially practicable in fairly large plants, the apparatus used consists of a producer in which a thick bed of coal is blown into incan-

descent by a mixture of air and steam, the resulting hot gas being passed through an economizer and superheater to heat the incoming air. It is then passed through a wash box where it deposits its solid matter, then through a scrubber filled with coke over which water trickles to separate deleterious matter and to cool the gas, then through a purifier which eliminates the tarry matter; finally it passes to the gas holder, ready for use in the engine. Steam for blowing the furnace is produced in a small boiler by the action of the hot gases passing through the economizer and superheater.

Gas power plants may be divided into two types called respectively pressure and suction plants. In the first, air and steam is blown through by the action of a steam jet or fan, in the second, the suction produced by the stroke of the engine is depended upon to draw air through the producer. Suction plants are usually confined to those of small size, and owing to the caking of bituminous coal only anthracites are used. The pressure plants on the other hand, having an external source of power to furnish definite quantities of steam and air to the producer, are utilized for the larger developments, and either bituminous or anthracite coal may be used. In the smaller plants a gas holder is omitted frequently, the engine being depended upon to draw gas in sufficient quantities directly from the producer on its suction stroke. In starting up the suction plant, however, it is necessary to obtain a flow of gas by the action of a fan or blower generally operated by hand. The steam injected with the air performs several functions:

1st.—It raises the calorific power of the product.

2nd.—It increases the combustion, by adding hydrogen, which is derived from the steam.

3rd.—It reduces the nitrogen by supplying a certain amount of the necessary oxygen from the steam, and it lowers the exit temperature of the gas. In other words, it provides a cooler gas in the holder.

It also prevents clinkering in certain classes of coals subject to this trouble. The steam being developed in a boiler heated from the hot gases from the producer and delivering steam to the grates of the furnace, simply transfers heat from the gas to the furnace in the form of steam, and the losses, probably averaging 3 to 5%, are more than compensated for by the interchange of

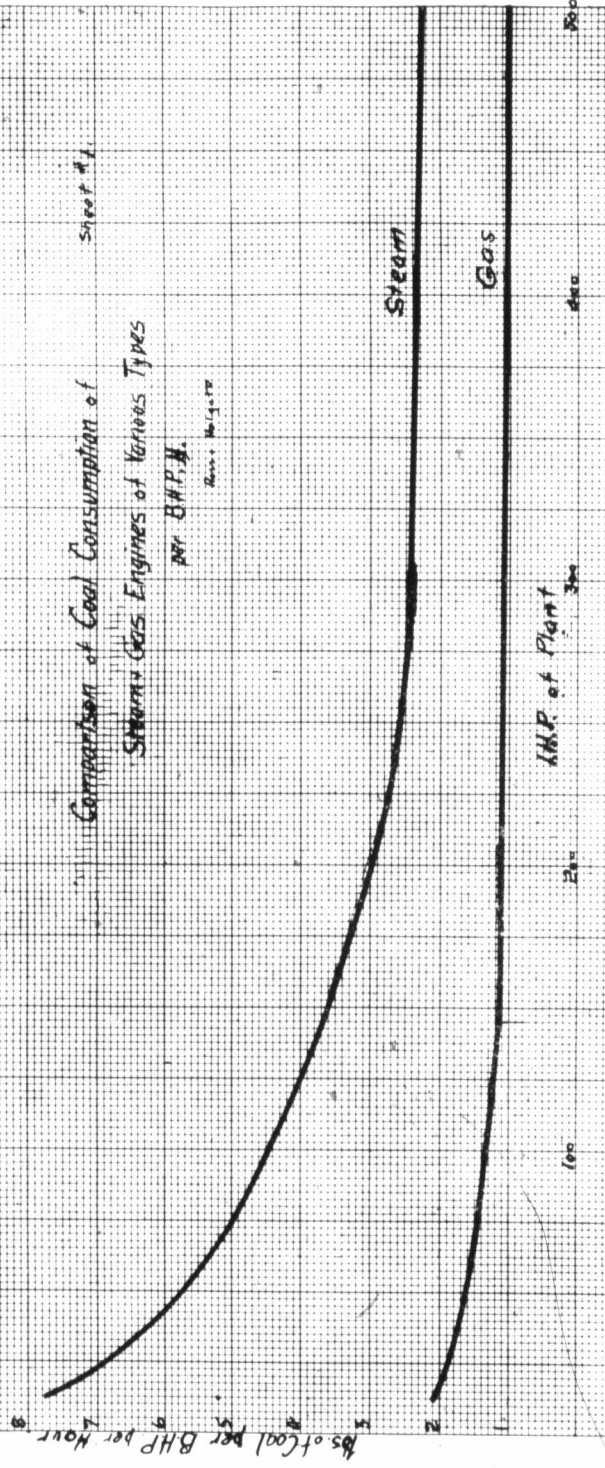
heat from the hot gas which it is desirable to cool to the air and steam for the furnace itself. For the larger plants, very successful producers are made by the Mond Company, whose special claim to recognition is due largely to the recovery of by-products. The by-product which is of most value is sulphate of ammonia of which about 90 pounds can be obtained per ton of coal. It may be valued at from \$1.80 to \$2.00. The recovery of this by-product of course involves the addition of other apparatus with consequent complication, so that it is not found advisable to instal recovery apparatus except in the case of fairly large plants.

It is not proposed to deal in this paper with the gas engine, as the subject is too complicated for a short discussion, involving a consideration of the rival claims of single and double acting engines, scavenging types, etc., and a treatment of all the complications entering into the relative merits of each type: the present object being to ascertain the commercial value of gas power as compared with steam. From the commercial standpoint the competition of gas power with steam is a question of reliability and cost of production.

As regards the first, it may be stated confidently at the present time that a gas engine plant is just as reliable as (and probably more so than) a steam plant, as it has none of the troubles due to high pressure such as exist in the latter. Concerning the cost of developing power, this involves not only fixed charges, such as interest and depreciation, but the operating cost including fuel, wages, supplies and repairs. Regarding the first, it may be stated generally that for small plants, the capital cost per horsepower will be higher for gas producers and engines than for boilers and steam engines. In the large sizes, however, approximating 500 horsepower, the cost of first-class steam plants and of first-class gas plants will be about the same; therefore, for the gas plant to justify its existence, it must show a saving in the operating costs to make up for the increase in fixed charges. Of these operating costs, speaking generally, it may be assumed that the cost of supplies and repairs will not be very different. As regards wages: In the large plants, at least, this item will be somewhat smaller than for steam, due to the small quantity of coal and ashes to be handled, and the simpler operation of the producer as compared with the boiler. In other words, the wages saving will be largest in the boiler room.

Comparison of Coal Consumption of
 Steam Gas Engines of Various Types
 per B.H.P.H.

Sheet #1



It is, however, in the saving of fuel, which is the largest item of power cost, that the gas engine is superior to the steam engine. In the larger sizes of gas engines, say from 200 horsepower upwards, gas engine builders will guarantee a brake horsepower on one pound of coal. With similar sizes and class of commercial steam engines, the coal consumption will vary from 2 to 3 pounds per brake horsepower hour, depending upon the capacity of plant. When still smaller plants are considered, say of 25 horsepower, the relative coal consumptions are in the ratio of 2 pounds of coal in one case to 6 pounds in the other. This condition of things is shown in curve No. 1, in which the upper curve shows the pounds of coal required per brake horsepower hour for steam plants of various sizes, and in plants which are commercially suitable to the various demands. In other words, for engines of 500 horsepower, compound condensing engines with water tube boilers are considered, and as the size decreases, condensing, simple non-condensing, automatic and throttling engines are counted as being commercial. Similarly, in the case of gas plants, the more expensive classes are considered as being used from the 500 horsepower down to the 200 horsepower. Somewhat simpler plants down to 75 horsepower, and from 75 horsepower down to 25 horsepower, the simplest commercial plants are estimated upon. It will be argued no doubt by the advocates of steam and gas plants that conditions in either case can be bettered; and this is no doubt true, the attempt being merely made to indicate what can be expected under commercial conditions as they exist to-day.

In curve No. 2 is shown under the same commercial conditions indicated above, the total cost of a brake horsepower for different indicated horse-power capacity of steam plants. These capacities are chosen because engines are usually sold on their indicated horsepower rating, whereas what is required by the user is the actual delivered brake horsepower, thus eliminating all uncertainties due to the fluid and the mechanical efficiencies of the engines.

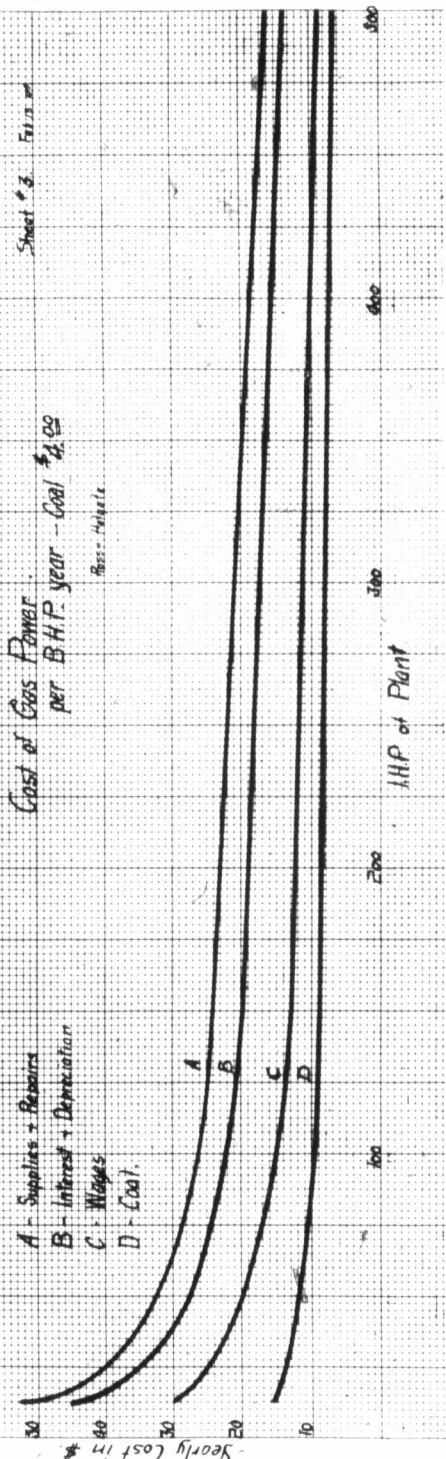
In curve No. 3 is indicated the total cost of power under the same conditions as indicated above for gas engines.

In curve No. 4 the total operating costs from sheets 2 and 3 are plotted for comparison. By a study of those comparative curves it will be seen that the saving by the use of gas will vary

7

Cost of Gas Power per B.H.P. year - Coal \$4.00

- A - Supplies + Repair
- B - Interest + Depreciation
- C - Wages
- D - Coal



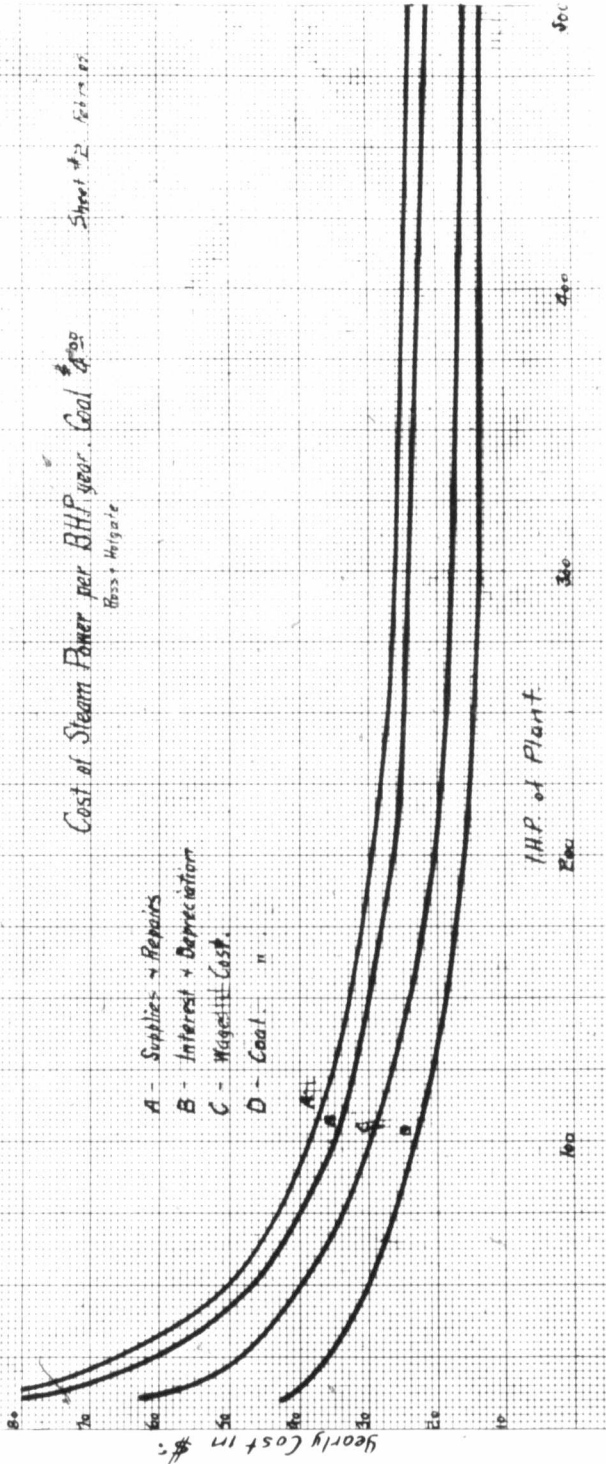
Sheet # 3

No. 2.

Cost of Steam Power per BHP year. Coal \$1.00
Gas + Highgate

Sheet # 2 6-17-02

- A - Supplies + Repairs
- B - Interest + Depreciation
- C - Magellian Cost.
- D - Coal " "

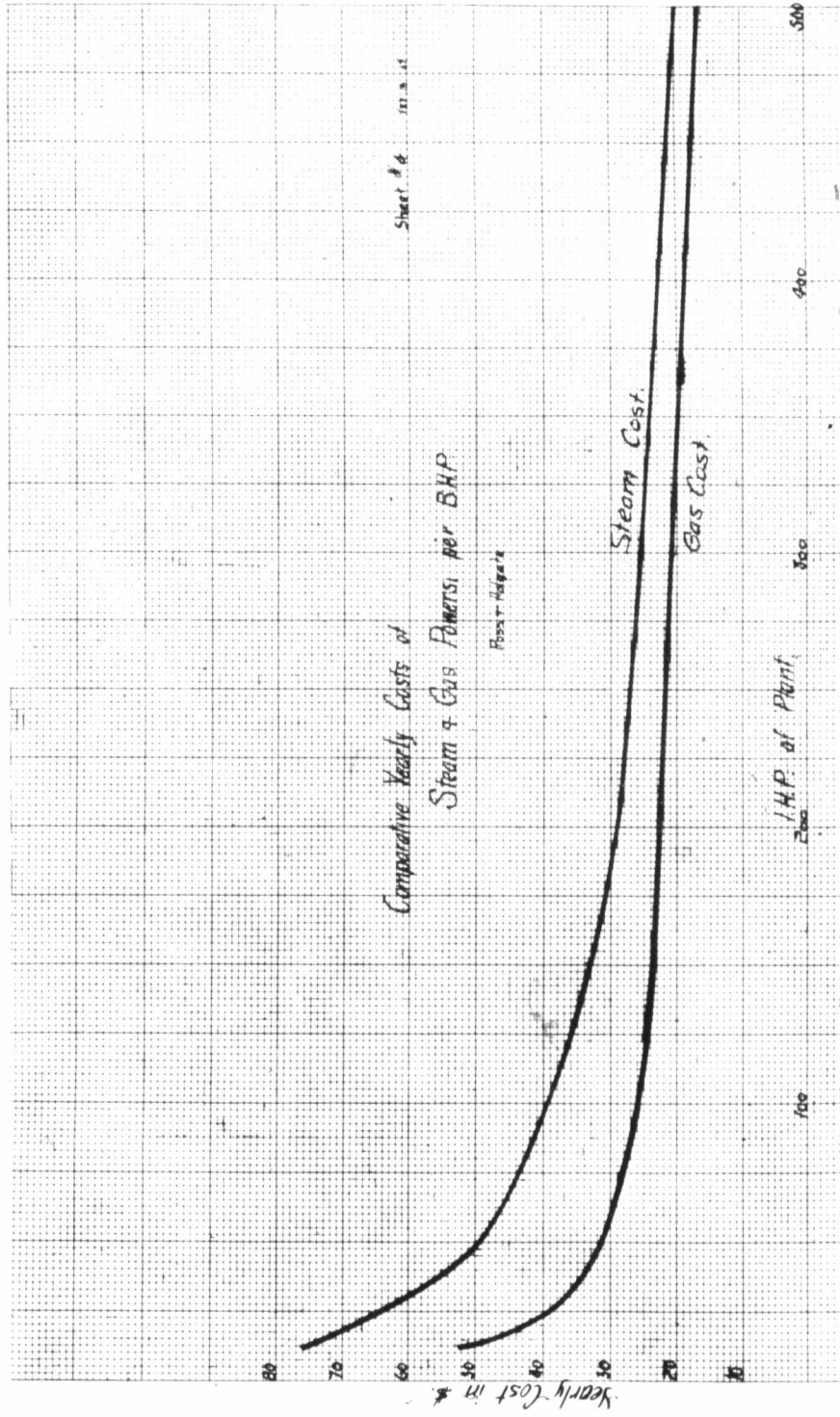


from 25 to 40% as compared with similar steam plants, and will repay the total capital investment in the gas plant in from four to ten years, and it will be noted that in no case does the commercial efficiency of the steam plant exceed that of the gas plant. Under this condition of things it is not difficult to see that rapid developments are bound to occur in the development of power from gas which will have an effect not only upon the manufacture of steam plants, but also will tend to circumscribe to a certain extent the commercially possible transmission distance from water power plants. In certain cases, however, the steam plant will undoubtedly hold its own, especially in those manufacturing establishments where exhaust steam is used for heating the buildings, and where live steam has to be available for other purposes in any case. It is especially desirable that this paper be not considered as advocating gas power for every demand, as each case must be studied by itself and due weight given to the local conditions and existing demands. Eliminating, however, these special conditions demanding the use of steam to the exclusion of practically every other kind of power, the field is a very broad one, and it can be confidently stated that with the increase in the cost of coal, the future of the gas power plant is an assured one.

Comparative Yearly Costs of
Steam & Gas Motors per B.H.P.

Sheet # 4 100 x 11

Power Magazine



Appendix A

SAMPLING OF COAL

When valuing coal, it is of the greatest importance that a fair sample should be taken. This is obvious when we consider that many impurities occur in lumps—*e.g.*, slate, pyrites. A small sample, therefore, taken at hazard from a car of good coal may show 30 to 40% of ash, or in some other way entirely misrepresent the bulk. The variability of coal is so great that in order to get a fair average, experience shows that the only practical way is to make a very intimate mixture of samples drawn from different parts of a lot. This may be best accomplished by taking a shovelful of the coal from various portions of the load, and placing the selected part on one side. A liberal number of such samples should be taken, and a cone-shaped heap formed. Now proceed to deal with this large sample by what is known as quartering. Flatten the top of the heap, and divide it by a line through, and then another at right angles to the first. The cone-shaped heap of coal is now divided roughly into four quarters. Take two of these, from opposite sides, and shovel the selected quarters into a fresh heap, rejecting the remainder altogether. Now form a second cone-shaped pile, again flattening at the top. Divide this into four quarters as before (a piece of board is a good instrument for marking the divisions): take two opposite quarters and separate them, again clearing away the rejected portion. Repeat this operation, mixing well each time, breaking large lumps down to average size, as often as may be necessary in order to reduce the original heap of coal to a sample of a few pounds, when it is ready for further similar treatment in the laboratory. In the laboratory the coal is ground down to a fine even powder, and the quartering continued until the sample may be considered small enough. A small portion is now drawn from this thoroughly uniform sample and analysed as described.

THE VALUATION OF COAL FOR STEAMING PURPOSES

From the Chemical Engineer.

PROXIMATE ANALYSIS

Moisture.—Dry one gram of coal in an open porcelain or platinum crucible at 104° - 107° C. for one hour, best in a double walled bath containing pure toluene. Cool in a desiccator and weigh covered. The loss in weight represents moisture*. Coals containing more than two per cent. moisture can not be pulverized without loss of some of this from air drying. In this case a determination should be made using from 10-100 grams of coarsely ground coal, and also one upon the finely ground coal. In reporting the analysis the percentage of moisture in the coarsely ground sample is given. The results obtained by the use of the finely ground one are merely to correct the determination of volatile combustible matter, ash, etc., which would otherwise be too high since they are made upon the finely ground sample, containing less moisture than the true percentage. To correct the other constituents, when the moisture is made upon the coarse sample: Divide the difference between the two moisture determinations by 100 less the percentage of moisture in the fine sample. Multiply the per cent. of each constituent as found in the finely ground sample by the above quotient and subtract the resulting product from the amount of the given constituent. The difference is the per cent. of the given constituent in the coarse sample.

Volatile Combustible Matter.—Place one gram of fresh undried finely ground coal on a platinum crucible, weighing twenty or thirty grams and having a tightly fitting cover. Heat over the full flame of a Bunsen burner for seven minutes. The crucible should be supported on a platinum triangle with its bottom six or eight c.m. high when burning free, and the determination should be made in a place free from draughts. The upper surface of the cover should burn clear, but the under should remain covered with carbon. To find volatile combustible matter subtract

* Method of Committee of Am. Chem. Soc. on Coal Analysis.

per cent. of moisture found in the finely powdered coal from the loss found here. Correct for moisture in coarse coal if necessary.

The above method is that recommended by the Committee on Coal Analysis of the American Chemical Society.

Ash.—Burn the portion of powdered coal used for the determination of moisture, at first over a very low flame, with the crucible open and inclined, till free from carbon. The weight of the residue, which should be tested for unburned carbon by moistening with alcohol, represents the ash. Correct for moisture in the coarse ground coal if necessary.

Fixed Carbon.—Add together the percentage of ash, moisture and volatile matter and deduct the same from 100. The difference is the fixed carbon.

Appendix B*

PARR'S CALORIMETER

Parr's Standard Calorimeter is probably the simplest apparatus on the market. The results obtained by its means are satisfactory and rapid, and do not require so much manipulative skill as is the case with most calorimeters.

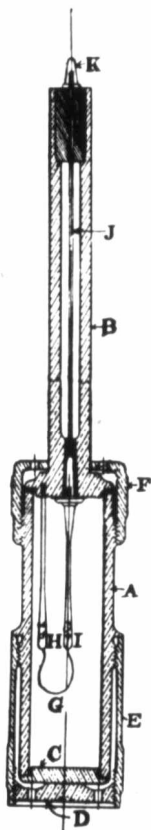


Fig. 1.

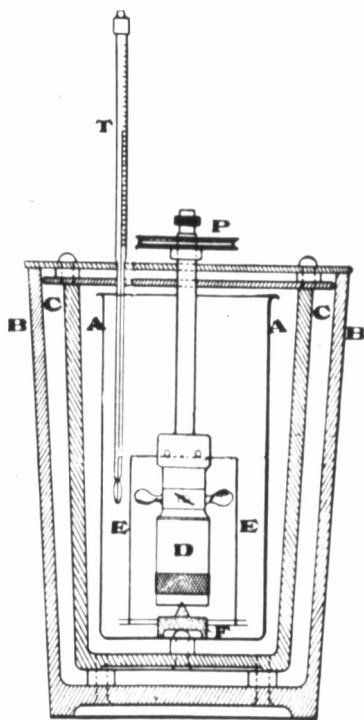


Fig. 2.

OPERATION

The facility of operation may be shown by a brief description of the apparatus.

Figure 1 shows the cartridge in which is placed a weighed

quantity of coal, previously ground to pass through a 100 mesh sieve and dried in the usual way at 105-110° C. (220-230° F.) There is also put into the cartridge a chemical compound which is thoroughly mixed with the coal by shaking. The cartridge is then placed in a measured quantity of water in the insulated calorimeter can A, as shown in Fig. 2. The stirrer is set in motion, operated by a cord about the pulley P. After a constant temperature has been attained, ignition is effected by means of a short piece of hot wire dropped through stem of the cartridge.

Extraction of the heat is complete in from four to five minutes. The maximum reading is taken and the rise in temperature, multiplied by a simple factor, gives the heat in British thermal units per pound of coal.

By a slight modification of the apparatus ignition may also be effected by an electric fuse and where a proper current is available this method is preferred by some users. See Fig. 1.

Fig. 2 shows the relative position of parts. The can A is filled with two litres of water. The combustion takes place within the cartridge D. The resulting heat is imparted to the water. The rise in temperature is indicated by the finely graduated thermometer T.

A full account of this calorimeter can be found in the *Journal of the American Chemical Society*, Vol. 22, No. 10, Vol. 21, No. 2.

Appendix C

The instrument referred to as a dasymeter is made by Messrs. Siebert & Durr, Munich. It consists of a fine balance in an enclosed case, through which a current of the furnace gases is drawn. The arrangement is such that any change of density in the gases disturbs the balance, the degree of disturbance being registered on a graduated scale.

The technical analysis of flue gases is treated tolerably fully in Stillman's *Engineering Chemistry*, and numerous references may be found in the *Journal of the Society of Chemical Industry*.