THE UTILIZATION OF HEAVY OILS

IN

THE MANUFACTURE OF CARBURETED WATER GAS

A THESIS

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It is the purpose of this thesis to give in as clear a form as possible, a comparatively new process in the manufacture of carbureted water gas that has met with the favor of those in whose hands rests the guidance of one of man's oldest public utilities, as the term is used in the present sense.

This system, or method, or series of methods, at the present time is in its fifteenth year of use by the experimental companies employing it, but it is somewhat new to the Gas Industry in general, since the majority of the installations have only come into being in the last two years.

The system, if it may be so called, is one in which practically all of its fundamentals as they differ from regular operation are concerned, were accumulated from operation and not one that was designed in one group and then assembled. It is for this reason that it may be said that there is no man or single group of men that were responsible for its development. The bulk of the experimental work was done by the engineers of several of the country's largest gas companies who had the financial backing as well as the direct need for such a change in the usual procedure.

Many of the ideas that are given have been used at various times by different operators, in years gone by, as obvious means of bridging emergencies, but it remained until the last few years for all of these schemes to be incorporated and properly engineered. This work was prompted by a predicted shortage in petroleum which
naturally would severely alter the operations of the gas companies. This fear of the loss of a supply of oil has passed, but during its presence it brought out facts and fancies that are now being capitalized upon by many gas manufacturing plants, since it is now admitted that almost any kind of an oil, properly used, will serve as an enricher or as a reforming medium.

There are still quite a few operating disadvantages but these will soon be troubles of the past.

Since utility companies, except in the largest of cities, are seldom competitors, the ideas developed in one are usually passed on gratis to all the others who may be interested, and it is this spirit of co-operation that developed what the gas industry knows as "Heavy Oil Operation."

*Reforming is the name given to the phase of the operation in which oil is sprayed on the top of the generator fire during the back-run, forcing the oil through a bed of incandescent carbon and breaking it up into its constituent parts; carbon and hydrogen.*
HISTORICAL BACKGROUND

The word "Gas," a Flemish word meaning spirit, was first applied to the "air" that burned, by the Flemish Chemist Van Helmot about 1609. This was by no means the earliest that the commodity had been used but seems to be the first use of it under the name as we know it today. There are records that point to its use by the Chinese as early as 900 A.D. at which time they piped it through bamboo tubes and used it for lighting. The first record of coal gas appears in the writings of Dr. John Clayton, a Yorkshire minister, who between 1600 and 1670 distilled coal. He described the gas and a "black oil" obtained by heating coal, but as far as can be ascertained made no practical use of his discovery.

It remained for William Murdock, a Scotch engineer, to make practical application of these discoveries. In 1792 he distilled coal in an iron retort and using some seventy feet of copper and tin pipes lighted his home in Cornwall with the coal gas. Murdock was employed by James Watt, the inventor of the steam engine, and lighted the Soho foundry of Watt's firm with gas. A public exhibition here of the new light in April 1802, at the time of the signing of the peace of Amiens, attracted wide attention. Murdock, however, did not patent his invention and does not seem to have derived much financial reward from it.

In France the great chemist Lavoisier paved the way for the practical use of gas by the invention in 1781 of the water sealed gas holder. Here also, Minckelers, a professor in the University of Louvain in 1784 lighted gas distilled from coal, in a demonstration to his class. Finally in 1799, Phillippe Lebon in Paris obtained
a patent for making gas from the distillation of coal or wood and in 1801 he lighted his home and gardens with gas.

Since these men were all scientists and not promoters as is usually necessary to get the ball rolling, it remained for a German by the name of Frederick Albert Winsor to start the gas business and take it out of the laboratories exclusively. Winsor learned all that he could from Lebon, and in 1804 went to London and obtained the first English patent for the manufacture of gas. By his lectures and demonstrations he did much to overcome public prejudice and in 1807 he lighted Pall Mall in London with coal gas. This was the first successful public street lighting. The charter for the first gas company, the London and Westminster Gaslight and Coke Company, was granted to Winsor and others in April 1812. A year later Westminster Bridge was lighted with gas, and from that time the use of the new light gradually spread. Many of the earlier developments were due to Samuel Clegg, an engineer associated with Winsor, but Winsor was the man with the first vision of the future of the gas industry.

Early Gas Lighting in the United States. There are claims of early experiments with gas lighting in Philadelphia in 1796 and at Richmond in 1803, but it is generally conceded that gas was really introduced into this country by David Melville, who lighted his home at Newport, Rhode Island, with gas in 1806. The first gas company in the United States was organized in Baltimore by Rembrandt Peale in 1816. In Boston, gas lighting began in 1822 and in New York a year later.

While it is interesting to follow in detail the history of development of so important an industry, space does not permit this,
if this paper is to fully cover the more recent developments; but it should be stated here that the carbureted water-gas set which forms the nucleus of the discussion to follow, did not come into being until around 1875.

Blue gas, known to the gas man as the result of passing steam through an incandescent bed of carbon, was discovered in 1870 by Fontanna, and his invention antedates many years, Murdock's invention of the coal gas process. Although there were many attempts to use blue gas enriched by light oil vapors, or by the gases resulting from the cracking of heavier oils, or from the destructive distillation of rosin cannel coal, etc., it was not until Lowe's invention of the carbureted blue gas process in 1875 that blue gas really became a factor in the manufacture of city gas.

The blue gas process is rapidly becoming more and more important to the manufactured gas industry both as a source of low B.t.u. gas for mixing with coal gas, and as a heating gas for coke ovens as well as diluting agent for natural gas, where it is desired to utilize natural gas in a vicinity in which all the consumers' equipment is designed for a lower B.t.u. gas.

Blue gas forms the basis of the gas made by the heavy oil process as it does in straight carbureted water gas, as it is generally known.

The carbureted blue gas set as invented by Professor T. S. C. Lowe at Norristown, Pennsylvania, has come up through the years with innumerable improvements and variations until today there is a machine that stacks up with the best mechanical contrivances, and is well in step with this advanced age.

Since it is predicted that gas will come more and more into general use, the time should come when practically everyone should
be able to do all of his heating with it, and also utilize it for the many other uses to which it may be put economically.

It seems as though the Gas Industry is not on the way out but headed in a direction that should gain back for it the prominence that it once held.
Difference Between Light and Heavy Oil

Since the bulk of the discussion in this paper is primarily concerned with the utilization of different kinds of oils around the carbureted water gas plant, it seems fitting that some space be taken here to make clear just what is considered light oil and what heavy oil.

In a very few words the main difference between the light and heavy products is that the light oil has passed out of the crude in the process of refining as a vapor and been condensed; whereas the heavy oil has never been vaporized and represents the residue left after all the gasoline, kerosene, gas oil, etc. has passed off.

Until the introduction of the Heavy Oil Process in recent years the oil companies were not at all concerned about the still residue, which in their trade is known as Bunker "A", "B," or "C," the classification depending on the gravity mainly. Their indifference was due to the fact that the bulk of it was used for fuel oil, and as long as it could be pumped and handled at all, that was all that was necessary. Now that the gas industry is a large purchaser of this still residue these companies have had to change their policy and purchase their stocks or crude, in order that this residue will meet the specifications of these customers. This enables the refiner to dispose of this portion, which happens to be a large percentage of the charge, to the gas companies at a rate above the price for fuel oil of the same grade.

The gas manufacturer is primarily interested in an oil that will give him the greatest recoverable B.t.u. in the form of gas,
and the least amount of water-gas tar. The main item in this direction is the "split" of the oil into its different fractions. It is the usual practice to assume that the higher the paraffins and naphthalenes, and the lower the aromatics, the greater will be the carbureting value of the oil. The presence of comparatively large percentages of aromatics usually indicates large proportions of cracking-plant tars. Cracking-plant tars have some value as a carbureting medium but it is much less than that of a straight run residue, even though the residue may be so viscous that it has to be highly heated in order to be handled easily.

The above statement relative to the value of the different fractions, is in quite a contrast for oils that are to be used for motor fuels. The value of a motor fuel as far as its anti-knock properties are concerned, is greater with the smallest amount of paraffin and go in the following order:

The paraffins are the worst knocking as a general rule; the unsaturated hydrocarbons being next, with the naphthalenes being less liable to cause trouble from this standpoint; whereas the aromatics are considered as anti-knocking and demand a premium from the consumer for this quality.

Besides the above mentioned requirements an oil for use in gas making must be reasonably low in its sulphur as well as its coke content; the flash and fire points being of little importance except as far as storage is concerned.

It should be pointed out here that in several plants throughout the country two grades of oil are used simultaneously in the same set where the reforming process is used. This is made possible by the fact that the oil that is to be reformed need not meet the requirements
of the carburetor oil. This oil can be of a much cheaper grade with a higher sulphur content, and also be higher by far in aromatics without effecting its value as a reforming medium. Since this oil is sprayed on the fire and the petroleum fractions are broken up into hydrogen and carbon, and the carbon being filtered out to a great extent in the fuel bed and replacing coke, it matters little whether the coke content is one or twenty percent, except that the value of carbon per pound is less by about 4,000 B.t.u. than oil. Likewise, an oil of high sulphur when reformed will not produce anywhere near the amount of hydrogen sulphide as though that same oil were used in the carburetor on account of the fact that in passing through the high temperature bed of carbon, this undesirable constituent is changed into other forms of sulphur which are not quite as objectionable as the sulphide of hydrogen. The oil that is to be reformed can be most anything within reason as long as its value on a B.t.u. basis is greater than the generator fuel.

**LIGHT OR GAS OIL.**

Oils in this category will vary in gravity between 28 and 36 degrees Baume with characteristics somewhat as follows:

<table>
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<tr>
<th>Component</th>
<th>Range</th>
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<tr>
<td>Unsaturates</td>
<td>5% to 12%</td>
</tr>
<tr>
<td>Aromatics</td>
<td>15% to 25%</td>
</tr>
<tr>
<td>Naphthalenes</td>
<td>5% to 20%</td>
</tr>
<tr>
<td>Paraffins</td>
<td>50% to 70%</td>
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Probable Heat per Gallon from 130,000 to 140,000 B.t.u.
Probable B.t.u. per Gal. per M. Cu. Ft. 95,000 to 105,000

Sulphur by weight less than 1.0%
Coke Content by weight less than 1.0%

Under good operating conditions using 100% coke as a generator fuel and oil falling in the above limits, the following results may be expected:
Generator Coke - Lbs. per M. Cu. Ft. 27.00 to 30.00
Oil Gals. " " " " 2.75 to 3.2

Hydrogen Sulphide Grains per 100 Cu. Ft. 80 to 150

Oils of this type are ideal for carbureting water gas, but in the last few years due to the hydrogenation process along with many cracking still improvements that have come to the front, it is possible for the refiners to convert this fraction to gasoline and realize a greater profit. In view of the natural scarcity that would accompany such procedure, this portion of the crude will demand a much higher price than the average gas company which is fighting real competition, can afford to pay. It was mainly for this reason that the use of the still residues met with such quick acceptance.

The use of the light oils is considerably simpler but in many instances this simplicity must be disregarded on account of the economy that is possible with the cruder products.

HEAVY OIL

Heavy Oil for gas making, as stated in the preceding pages, is nothing more than refining still residue that may or may not contain some cracking-plant tar or other mucky products. The quality depends on the specifications as given by the purchaser.

These oils vary in gravity from 10 to 25 degrees Baume, and with characteristics as follows:

<table>
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<th>Characteristic</th>
<th>Range</th>
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<tr>
<td>Viscosity</td>
<td>About 20 to Several Hundred Seconds</td>
</tr>
<tr>
<td>Saybolt-Furol</td>
<td></td>
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<tr>
<td>Pour Point</td>
<td>Seldom less than 30 degrees F</td>
</tr>
<tr>
<td>Usually between 60 and 100 degrees F</td>
<td></td>
</tr>
<tr>
<td>Flash Point</td>
<td>From 200 to 350 degrees F</td>
</tr>
<tr>
<td>Fire Point</td>
<td>From 250 to 450 degrees F</td>
</tr>
<tr>
<td>Conradson Carbon</td>
<td>From 3% to 15%</td>
</tr>
<tr>
<td>Sulphur</td>
<td>From 5% to 4.0%</td>
</tr>
<tr>
<td>Asphalt</td>
<td>From 2% to 20%</td>
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In the purchasing of oils in this class the foregoing specifications are about all that any oil company will follow. It is impracticable to make series analyses that could be relied upon for any length of time and for this reason they are left out of the specifications.

In view of the higher specific gravity and weight per gallon these oils will run considerably higher in B.t.u. per gallon, ranging from 140,000 to 150,000 depending upon the coke content.

Oils purchased under fuel oil specifications may, and probably will be a mixture of various still residues and waste oils of various kinds. These may contain a large percentage of tar or residue from cracking stills. It is therefore most important that tests to determine the value as a carbureting agent be run on a given oil before it is purchased or contracted for in large quantities. Likewise some assurance should be given by the seller that the oil offered will not vary appreciably from the sample supplied for test. Test under plant operating conditions is the only safe way to determine the value of an oil as a carbureting agent.

In general, the physical properties of straight run residues which go to make up fuel oils are; high viscosity, high coke content, high carbureting value with gravities as low as ten degrees Baumé. Crack-plant tars, on the other hand, are characterized by low viscosity, high gravity, high coke content and low carbureting value. In general, the gravity of an oil has no relation to the value of the product as a carbureting agent.

Practically all known oils contain sulphur in amounts varying from traces to four percent or more. As a rule, the lighter oils contain less than the heavier. The sulphur in a crude oil distributes
itself in all the fractions and even in the coke. It should be noted that high sulphur crudes usually have high carbon residue. The coke residue runs as high as fifteen percent in some oils and must be given due consideration when purchasing. The percentage of free water in any oil must be necessarily low. The pour point along with the viscosity gives an indication of how the oil will handle.

The methods employed by oil refineries are determined by local conditions and the local market over which the refinery has little control. There is no assurance that an oil purchased under "Bunker" specifications will remain constant in carbureting quality; therefore, it becomes necessary to restrict these specifications to limit the amount of coke, sulphur, and cracking still residue, if any degree of uniformity in its gas enriching value is to be expected. Fuel Oil of "Bunker" "C" type occasionally has its viscosity reduced to meet the purchaser's requirements by the addition of a low viscosity gas oil fraction. At other times the same product will have the viscosity altered by the addition of cracking-still residuum. A cracking-still residuum has a high gravity, a low viscosity and a low value as a carbureting agent. A straight run reduced crude has a high coke content but a high value as a carbureting agent.
CHRONOLOGY

Through an elaborate and comprehensive series of tests covering a period of ten years, the engineers of the Philadelphia Gas Works and the Public Service Gas and Electric Co. of New Jersey, working in one group, and the engineers of several of the gas engineering firms, namely; the United Gas Improvement Company and the Semet Solvay Engineering Corporation, working separately, developed several ways and means of using the heavy still residues from the oil refineries, to supplant the more costly gas oil.

The substitution has proven highly successful from an operating viewpoint, enabling the above mentioned operating companies to head off the problem of the ever increasing price of gas oil. It has also enabled the gas engineering companies to keep going during this period of depression, by affording them a new outlet for their talents and engineering services. This being accomplished by these companies designing and installing equipment for the utilization of these heavier products for those companies which are not able to do their own experimenting or constructing.

In the United States today, (as there has been for the last few years) there is an ever increasing demand for gasoline. This condition, aided by the improvements made in the processing of oils, has made it more profitable for the oil producing companies to convert those fractions in the lower grades to motor fuels. As a consequence the price of the product known as gas oil has steadily increased and the limit to which this rise may reach is anyone's guess. The price of gas oil is linked
with the price of motor fuels and subject to fluctuations accordingly. On the other hand the price of fuel oils is linked with the price of coal and fluctuates with this commodity, since it is a competitor of this fuel. It is therefore reasonable to assume that the price of the heavier oils will be more stable, with less likelihood of sharp advances than the lighter products. For this reason it seems advisable as well as logical that manufacturers of carbureted water gas resort to this type of oil for enriching.

The first actual work in the line of heavy oil operation was carried on with a high coke Mexican fuel oil in Philadelphia. The experimenters quite naturally tried to use the oil in the usual way for gas oil, namely; by spraying the product on the top of the checkerbrick of the carburetor and relying upon the secondary air during the blast to burn off the deposited carbon. Considerable difficulty was encountered with this scheme and it was soon abandoned.

Among the numerous schemes tried were efforts to admit the oil in the middle of the superheater, and scouring the carbon off by allowing the secondary air to remain on a few seconds after the generator air had been shut off. The main trouble with such a system was the rapid disintegration of the checkerbrick, and the reduction in the capacity of the set due to the time required for burning off the carbon. It soon became quite apparent that the entire problem hinged on the fact that the oil must be vaporized before it comes into contact with hot checkerwork. Also this vaporizing must be done in such a place and in such a manner that the free carbon which has a tendency to drop out, will do so at a point where it may be easily removed. This is the arrangement that is utilized in present day practice.

The engineers of the Philadelphia Gas Works Co. after study and numerous experiments came to the conclusion that there was an excess
of heat available in the walls, crown and floor of the carburator, even after the checkerwork had been removed, to completely volatilize the amount of oil necessary for average enrichment requirements. To supplement this theory the use of the nebulizing spray was resorted to, and with such an arrangement with the oil being injected in such finely dispersed particles, the chance of it striking hot checkerwork was greatly reduced. It is for this plan that one of the equipment manufacturers sells apparatus for using heavy oil at present.

Shortly after the work in the Philadelphia region had proved successful, other equipment manufacturers began work developing ways and means of doing the same things in different ways, with the result that the basic process was improved upon considerably.

The Western Gas Construction Co. of Fort Wayne, Indiana, developed a system which they called the "Reverse Blast Process". In this arrangement a portion of the total generator air is blown through the machine from the top of the superheater and out the bottom of the generator. The passage of this air through the highly heated chambers burns off the deposited carbon on the checkerwork. In this system all of the oil is injected into the generator.

The Semet-Solvay Engineering Corporation, after much experimenting brought out their "Ignition Arch Process". This was a departure from the conventional system of using oil sprays in the top of one or more of the units as their arrangement used four small sprays mounted in the side walls of the carburator. These sprays have an inclined head that directs the stream of oil in an upward direction. The oil in being sprayed upward is travelling countercurrent to the flow of gas, and it is claimed that this feature utilizes a large percentage of the sensible heat of the blue gas coming from the generator, in the cracking of the oil.
Along with these patented changes and the empty carburetor, they also incorporate a form of tertiary air introduction at the bottom of the carburetor to burn the carbon that deposits on the floor of that unit. Also: a change in the introduction of the secondary air is made, for which an increase in combustion efficiency is claimed.

By any one of the above mentioned systems it has been demonstrated that Bunker Oils of almost any grade can be utilized in the manufacture of carbureted water gas, with advantages in several directions.
CONDITIONS UNDER WHICH HEAVY OIL INSTALLATIONS ARE ADVANTAGEOUS

As in most every improvement in any line, there are those places and localities in which the new arrangement can not be called suitable or worth the cost of the change, although such new procedure may make an old outfit more flexible. If there is not a substantial financial gain to be realized from such expenditure, during these days and times when the operator's convenience is secondary, there is small likelihood that the management of the average company would consider such a change.

It is generally agreed though, that the use of heavy oil can be made to justify moderate expenditure in most any plant that uses 100% coke for generator fuel, unless the plant be a combination coal and water gas plant that does not have an outlet for its surplus coke. Even under this condition, if it is not planned to reform oil, it is possible to show a sizeable saving in fuel cost. This all hinges though, on whether or not coke is higher than oil in price, as to whether the financial outlay for equipment will be economical.

Those plants using soft coal as generator fuel will not find the use of heavy oil as promising as those using all coke. The use of the reforming feature with soft coal operation is not at all desirable. Where coal must be used as a fuel it is difficult to justify a change to heavy oil.

Combination coal and water gas plants find the new method advantageous in the regulation of gravity, it affords a much more flexible arrangement. Plants of this type that are compelled to burn their coke breeze and pea sized coke in their water gas generators, find the reforming operation very desirable because a fine sized fuel makes the best carbon filter.
FINANCIAL STUDY

The operator intending to use fuel oil will learn very quickly from the character of the fuel that numerous changes of various natures will have to be made in existing equipment. He will find that practically his entire oil handling system is inadequate, lines too small or not built to withstand the pressures that sometimes are used in the new systems; that the pumps are not built to furnish the pressure that may be needed; that his heaters are too small and not built for the higher pressures; that his oil lines as well as all lines carrying tar emulsion or dry tar are not large enough, or are not heated; as well as numerous other changes that will be necessary.

Each plant represents a definite problem which may be met in different ways and the outline given here will of necessity have to be general.

In view of the fact that there may be considered two separate parts to an installation of this type; namely, the changes and additions to be made exclusive of the water gas set, and the changes to the set proper, this set-up will consider them separately in order to differentiate between the several methods available.

The outline given herewith should enable the plant management to analyze his problem correctly, exclusive of course, of conditions that are local and not general. As there are to be investments for new equipment, economies effected by the use of this equipment and additional expenses in operation as a result of the process, the outline is divided into three headings.

1. Investments
2. Savings
3. Expenses and Debits
The installation in a plant will require the following equipment and piping changes. Some of this equipment may already be available at a plant and would therefore reduce the cost of the installation.

INVESTMENTS

(a) Equipment for unloading heavy oil.
(b) Heavy oil storage tank.
(c) Primary oil heater at outlet of storage tank.
(d) Necessary pumps for supplying heavy oil to the machine.
(e) Secondary oil heater with temperature regulator.
(f) Temperature equalizer tank.
(g) Heavy oil pipe lines and valves.
(h) New meters suitable for medium high pressure; one for carburetor oil, one for generator oil.
(i) Heavy oil equipment at the water gas set.  
   Note: this item will be given at the end of this section where all three systems will be described separately.
(j) Changes to the back-run three way valve, such as new water cooling sprays or a new valve especially designed for heavy oil, and now on the market.
(k) Optional installation of the back-run system.
(l) Tar emulsion handling equipment including pumps, lines, emulsion storage tanks, tar storage tanks, and dehydrator.
(m) Tar burning equipment installed on boilers including pumps, lines, heaters, regulators and burners, and revamping of furnace to burn tar.
(n) Emulsion separator pit of ample size.
(o) Changes to existing tar emulsion lines to take care of the much heavier product.
(p) Additional purifying capacity, if existing units are at present working up to their hourly capacity.
SAVINGS AND CREDITS

(a) Reduction in quantity of fuel used in the solid state (supplanting it with liquid fuel in cases where reforming is economical.)

(b) Proportional saving due to differential in the price of gas oil and heavy oil.

(c) Increased quantity of tar produced.

(d) Elimination of checkerbrick replacements in two of the systems and theoretically reducing this expense in the third system.

(e) Reduction in the expense of handling generator fuel.

(f) Possibility of extending time between clinkering, or reducing clinkering time.

(g) Possible saving in reduction of investment in fuel storage.

(h) Reduction in boiler fuel costs if heavy oil tar is to be used under the boilers as a fuel.

(i) Elimination of labor for handling solid boiler fuel.

EXPENSES AND DEBITS

(a) Labor for unloading heavy oil above that required for light oil.

(b) Additional cost of dehydrating tar.

(c) Additional cost of purification.

(d) Cost of steam for heating oil, both unloading and heating for use.

(e) Cost of pumping additional oil required.

(f) Cost of tar as a boiler fuel.

(g) Cost of operation of tar burning equipment.

(h) Additional labor for cleaning water gas sets.

(i) Cost of additional water for cooling.

(j) Interest on the investment.

In the average installation where too large an expenditure does not have to be made (as in the case of extremely old plants) the savings that can be realized with good operation will pay for the necessary equipment in from two to three years.
INVESTMENTS

(a) Equipment for unloading heavy oils.

The oils in this class quite naturally require much larger unloading lines in case that the unloading is by gravity. In view of the fact that the railroad cars have 3" and 4" outlet connections, it has been the practice in the northern part of the country to make the unloading line at least 4". This line should be lagged with some insulating material and the steam line for heating the cars usually can be run along side of the line and insulated with the oil line, in order that there be no possibility of the oil in the line solidifying in the cold months. In case a pressure system is used for unloading, this line should not be less than three inches but smaller ones will suffice if the existing line is insulated and a steam line run with it.

Since most plants desire to maintain a storage of gas oil for emergencies, the calculations for this line should include valves in order that gas oil may be unloaded through the same line.

(b) Heavy oil storage tank.

In view of the fact that most plants desire to maintain a storage of light oil as stated above, it is more economical to construct a new tank to accommodate only the emergency fuel, using the existing gas oil tank for the storage of the heavy oil.

(c) Primary oil heater.

Although the heavy oil storage tank will maintain a fairly constant temperature over several days when a heated tank car of oil is emptied occasionally, this heat, especially in the winter time, is not sufficient to keep the oil fluid enough to flow freely from the tank. It is for this reason that a primary heater is
installed at the outlet of the tank. There are two types of primary heaters available; the injection type and the exterior shell type. The choice depends upon local conditions, space being a prime consideration. The injection type will be found to be somewhat cheaper and has operating advantages worth considering.

This heater should be purchased under specifications derived from a study of the particular oil to be used. It is considered good practice to buy a heater capable of heating the heaviest oil commercially obtainable since it would be sufficient under the worst conditions. The size of the unit should, if of the injection type, be small enough to fit into an existing manhole in the tank, and should be capable of heating at least twice the peak demand up to at least 150°F. If the unit is bought under such specifications it will be large enough under normal conditions to operate on exhaust steam, requiring live steam only during peak demands. Live steam heaters are considerably cheaper than exhaust heaters.

(d) Necessary pumps for supplying heavy oil to the machines.

While many plants will have pumps that are large enough to supply the required amount of gas oil to the water gas sets, a thorough investigation should be made to make certain these pumps will furnish the required pressure at the set, operating with the more viscous and heated liquid.

Whatever the status of the pumping facilities may be it should be remembered that long pulls against a suction head with heated oil are very likely to pull a vapor. In case there is not sufficient static head to insure pressure at the suction side of the pump while working at its maximum load, the supply lines to the pump should be increased so that such a condition of pressure does exist.
In nearly every installation in New England new pump houses have been built adjacent to the storage tanks in order that the above condition may not cause trouble, since it is a gamble and not too true to calculations. A certain set-up may work out on paper but if the temperature of the oil should happen to rise considerably above those calculated for, then trouble would show up quickly. It is quite possible that existing pumps so placed near the storage tank will be entirely adequate unless a substantial increase in output is expected.

A reliable governor should be installed on the heavy oil pumps in order that constant pressure be maintained at the oil sprays. Since time is quite a factor in gas making, alterations to the operating cycle should not have to be made to accommodate irregularities in the oil system.

(e) There are several advantages to be gained by injecting oil into the carburetor of a water gas machine as hot as it is economical to heat the fluid. It takes a shorter time in which to put in a given amount of the fuel; the oil line purges cleaner, and much better atomization is realized. The latter reason is much more advantageous when operating with the heavy liquids than with the light ones on account of the much higher distillation range of the heavy oils. It is for these reasons that a secondary heater becomes essential. It is common practice to purchase one of these units under the same specifications (excepting pressure) as the primary heater, only that the secondary heater should be required to take the oil from the first unit, minus line losses, and boost the temperature to at least 250°F. This heater should be designed for at least 250 lbs. maximum working pressure and should be of a reliable make. A temperature regulator should be installed in conjunction with the secondary heater to insure
oil of a uniform temperature being supplied the sets. This regulator should be controlled from a temperature equalizing tank such as described in the next paragraph. The exhaust steam from this unit can be fed to the exhaust system or to the boiler feed system.

(f) A small tank built to withstand 250 lbs. maximum working pressure should be purchased. The capacity of this unit should be equal to approximately one-half hour's requirements under peak load. The object of this tank is to facilitate a uniform temperature of oil to the sets and smooth out the fluctuations that would occur without such a unit. At least two hand-holes should be incorporated in the design of this tank and they should be of the type that require a ring to be welded in for them, as almost any of the type that fit the curvature of the shell will leak with hot oil under pressure.

The equalizer tank should be lagged with a least 2 inch magnesia covering and the connections designed to suit the best piping arrangement. A one-half inch welded connection for purging should be made in the top and welded connections made in the side for the bulb of the temperature regulator and for a stem-type thermometer. It is advisable to have all connections of the flanged type for convenience.

(g) Heavy oil lines and valves.

It is almost essential that all lines carrying hot oil under pressure be welded and those places where welding is not practicable, forged fittings should be used if the plant is to be kept tidy at all. Cast iron fittings can not be relied upon and it is cheaper to put in well made and reliable fittings on the first job than to have the whole line to take down again. As stated in paragraph "e" the unloading line is well insulated and also carries the steam line for car heating; this same scheme must be carried out throughout the entire system. For the
suction line from the pumps to the primary heater, the steam lines to the heater should be carried alongside this line, (an exhaust and a live line). From the pumps to the secondary heater the live steam lines to the pumps, as well as an exhaust line connecting the main plant exhaust system, can be run with the heavy oil line. Incorporated in the pipe bundles from the secondary heater to the storage tank should be a 2 inch line to take care of the hot oil return; this line feeding the very hot liquid back to the storage tank, allows a continuous flow of oil through the system and also aids the primary heater, for it is general practice to put this connection near the inlet to the primary heater. It is not so essential that this line be welded since the pressure is very low. This line should extend to a relief valve located near the meters mentioned in the following paragraph.

Necessary by-passes should be installed around each piece of equipment exclusive of pumps when there should be at least one spare of these, and all valves on the pressure side of the pumps should be of the 250 lb. variety, and all of those on the suction side standard.

The line from the primary heater to the pumps should be at least as large as the inlet connection to the pump, and likewise so for the pressure line from the pumps to the secondary heater, it should be as large as the outlet connection of the pump to be used. Larger lines are expensive and smaller ones doubtful, although in many cases it is economical to have the lines carrying heavy oil one size oversize.

The pressure line from the equalizer tank to the set or sets can be reduced considerably in size due to the reduced viscosity of the oil resulting from higher temperatures past this point. Ordinarily a two-inch line up to two hundred feet will amply supply as large as an eleven foot set. For plants where two or more sets are in operation at the same time, a line serving as a manifold should be run, making
individual set connections from such manifold.

There should be installed in the hot oil line before the secondary heater either two separate or one duplex pressure strainer with the necessary by-passes, in order that operations may not be stopped in case of a clogged strainer. Such strainers are essential and save considerable maintenance, preventing foreign matter from clogging the secondary heater, ruining the expensive meters or clogging the oil sprays.

A spring type relief valve should be incorporated in the hot oil line just before the meters with relief connection joining the two inch line from the storage tank.

Diagrams of typical overhead and underground construction for the long hot oil lines are given on page 61.

A flow diagram of a typical plant layout is given on page 112.

(h) New meters suitable for medium high pressure.

The oil meters ordinarily found around the gas plant for use with gas oil are not entirely suitable for the heavier oils at 250° F. and from 100 to 200 lbs. gage pressure. For this reason it is usually good practice to purchase meters designed for these conditions.

The size of the meters will depend upon the size of the set on which they are to be used. In view of the fact that considerably less generator oil, as a rule, will be used than carburetor oil, this meter can be at least one size smaller than the one for the carburetor.

In the piping arrangement, by-passes should, of course, be installed around each meter and outlets should be left for the bulbs of either a recording thermometer and pressure gage or indicating instruments. These should be convenient to the operating controls.
An example of oil meter sizes suitable for sets of various sizes is as follows:

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<td>6.0</td>
<td>4.0</td>
<td>( \frac{1}{8} ) in</td>
<td>( \frac{1}{2} ) in</td>
</tr>
<tr>
<td>6.0</td>
<td>10.0</td>
<td>7.0</td>
<td>( \frac{3}{4} ) in</td>
<td>( \frac{1}{2} ) in</td>
</tr>
<tr>
<td>7.0</td>
<td>15.0</td>
<td>10.0</td>
<td>1&quot;</td>
<td>( \frac{1}{2} ) in</td>
</tr>
<tr>
<td>8.0</td>
<td>22.0</td>
<td>15.0</td>
<td>1&quot;</td>
<td>( \frac{1}{2} ) in</td>
</tr>
<tr>
<td>9.0</td>
<td>29.0</td>
<td>19.0</td>
<td>( \frac{1}{2} )&quot;</td>
<td>1&quot;</td>
</tr>
<tr>
<td>10.0</td>
<td>35.0</td>
<td>23.0</td>
<td>2&quot;</td>
<td>( \frac{1}{2} )&quot;</td>
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<td>45.0</td>
<td>30.0</td>
<td>2&quot;</td>
<td>( \frac{1}{2} )&quot;</td>
</tr>
<tr>
<td>12.0</td>
<td>56.0</td>
<td>38.0</td>
<td>2&quot;</td>
<td>( \frac{1}{2} )&quot;</td>
</tr>
</tbody>
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These figures are computed for average conditions using 40.0% of the total oil in the generator.

An examination should be made of the hydraulic valves in the gas oil set up, and these checked against the manufacturer's rating for these particular valves, to make certain that they will be satisfactory for the more exacting operating conditions.

(i) Heavy Oil equipment at the water gas set.

This item will be included at the end of this section to avoid errors that may result from dealing with the several different systems.

(j) Changes to the back-run, three way valve, in the form of additional sprays, etc.

There is formed in the heavy oil operation a considerable amount of lamp black. This formation is a direct result of reforming, being formed by the complete breaking down of the oil sprayed on the top of the generator fire. This fluffy product finds its way through the fuel bed and into the back-run pipe, which connects the bottom of the generator.
As a result of this condition a small part of this lamp black adheres to the walls of the pipe and the large valve. In an effort to prevent this accumulation, additional water sprays are built into the three way valve. This additional water will not as a rule overtax the present circulating water system, and will take the place of any water that at present is being fed to the wash box. The bottom outlet of the large valve connects directly on top of the wash box.

It is also necessary to install in the three way valve box, a quick opening door to facilitate daily cleaning of this unit, as well as the connecting lines.

The manufacturers of the three way valve have designed a new model especially for heavy oil operation. This piece of equipment incorporates some new features that are worth consideration even for light oil operation.

(k) Optional installation of the Back-run system.

While the patented back-run system is in no way essential in heavy oil operation, nevertheless it offers many advantages. In practically every installation of this system it can be made to pay for itself in a short period of time. Among the many benefits of such a system are:

- Increase in the thermal efficiency of the machine.
- Replaces old troublesome hot valves.
- Increases life of checkercwork.
- Makes a more flexible machine.
- Affords a unique disposal for plant effluent.
- Allows better temperature control of the set.
- Increases the capacity of the set.
(1) Tar emulsion handling equipment, including pumps, lines, emulsion and dry tar storage tanks and dehydrator.

Beginning with the water gas set and working in the direction of the dry tar storage, it should be pointed out that the drain lines from the wash box seal pot as well as the primary scrubber, (in case that there is one connected to the set) should all be increased in size to a minimum of three inches for sets smaller than eight feet and a minimum of four inches for sets larger than that size. Since these lines must be free at all times they must have ample pitch to insure proper flow of the water to the separators. If possible these lines should not be run in the open, and under no circumstances should there be any pockets in cool places, as the tar emulsion will freeze in these places and block up the line. Any of these lines that are pressure fed can, of course, be smaller in size than those relying entirely upon gravity. The pump supplying any lines in this portion of the plant should be placed as close to the source as possible if good and reliable operation is to be expected. As a rule it is not necessary to insulate these drain lines from the set, on account of the large volume of water and emulsion and its comparatively warm condition.

All drain lines from the seal pots of the various pieces of equipment such as, condensers, tar extractors, scrubbers, etc. that depend upon gravity for their flow, should be enlarged, and insulated in places that are subject to temperatures below 60° F.

It has been found quite satisfactory to store heavy oil tar emulsion in the pits of relief holders, both those below and above ground. There is the possibility of sometime or other producing pitch in the machine and causing the relief holder, (if a two or more lift holder is used) to catch, but this is the exception and not the rule.
It is imperative that the pumps that are to handle the heavy tar emulsion be located the relief holder, and amply protected against the lower temperatures. Both suction and pressure lines to these pumps should be insulated with steam lines. A live steam line should be connected directly into the suction line in order that this line may be blown out whenever needed.

Following the tar emulsion along through the plant, from the relief holder as a storage pit we come next to the dehydrating system. This portion of the apparatus for the sake of economy must be designed to suit each individual case. It should be determined if possible, whether or not the tar has a market value in the particular locality and how this value compares with the present disposal of light oil tar. From this study it will readily be determinable whether or not the tar emulsion will have to be processed to dry tar. Tar that is to be sold on the market usually must be dehydrated to two percent moisture. Tar that is to be used for reforming or boiler fuel need not be lower than ten percent moisture.

As the tar emulsion is recovered with its water percentage as high as 75% and seldom less than 50% (with reforming operation), it is obvious that to remove all this water by distillation would consume (in fuel cost) a considerable portion of the credit that could otherwise be credited against residuals.

There are several methods in use at the present time for removing this water without cooking it out. One of the simplest of these methods happened to be developed by the writer. A complete description of this system will be given in a later section, allowing this space to be devoted to the physical characteristics of the apparatus.

A steel shell capable of operation under fifty pounds gage pressure, and large enough to accommodate four days' production of emulsion should be
A conservative estimate of the tar emulsion production will be fifty per cent of the total number of gallons of oil used. As 65% of this is water and only 35% tar, this figures out to be about 17.5% of the oil used recovered as dry tar. These figures are actual, being the average of two years operation for a plant making four million feet of gas per day.

Steam coils should be built into this unit. The amount of this radiation should be calculated either from the amount of water that will be available for condensing, or from an arbitrary speed at which the unit is to be operated.

Quite often there are old condensers around a plant that may be put to work on this unit very conveniently, this would save a few dollars in the cost of the installation.

In case that there is no condenser available one will have to be purchased, and from the characteristics of this piece of apparatus and other known factors the speed of the unit can be determined. A set of curves giving the radiation possible for three different metals is given on page 60. These curves will enable rapid calculation for either the condenser or the radiating surface.

A sketch showing a typical dehydrator as used at the present time is given on page 134.

A pump of arbitrary size should be located in close proximity to the tar dehydrator, for pumping the finished product to storage.

All lines carrying dehydrated tar should be well insulated along with a steam line. Every time a tar line is used it should be blown out with steam afterward.

Any tank used for the storage of this tar should include a small amount of radiation, in order to keep the tar in a condition to be pumped
when it is needed. It has not been found necessary to insulate storage tanks containing this tar.

A pump will have to be located very near to the dry tar storage tank with extra large suction line, and this line insulated with a steam line. It will be found convenient to insulate the steam line supplying the heating coils of the tank with the suction line to the pump.

(m) Tar burning equipment installed on boilers, including pumps, lines, heaters, regulators and burners. (This should also include the revamping of the furnaces to accommodate the burning of tar.)

A separate study should be made (provided that tar is to be used for boiler fuel) of the equipment necessary and also the changes that will be required for the burning of tar.

A pump for supplying tar to the boilers should be located very near the storage tank, and all lines connecting it with other component parts of the system well insulated.

The pump should supply the tar to a secondary heater capable of heating twice the normal load to at least 250°F. This pump should be controlled by a pressure regulator, in order that constant pressure be supplied the burners.

The burners will have to be those especially designed for burning this heavy product.

The furnace, (if coal burning) will have to be changed over to the conventional arrangement for such operation. The burning of tar is practically identical with the burning of oil, using steam atomized burners.

A set of curves for arriving at the theoretical value of fuels for constant steam costs are included between pages 154 and 157.

A detailed section on the burning of tar is given later on in this paper.
(n) Emulsion separator pit of ample size.

Since the quantity of tar emulsion to be produced using heavy oil is approximately three times the volume produced for the same gas output operating with light oil, it is evident that a study should be made of this very important link in the chain. Quite often the present separators will be adequate for the new type of operation, but this should be made certain of before it is too late.

In case that the existing unit is of the cement type and below the ground level, it will more than likely be necessary to relocate the pump serving this well to a new position nearer the pit.

(o) Changes to the existing tar emulsion lines to take care of the heavier product.

All lines that are to convey tar emulsion should be studied from the angle of capacity and those that are deemed sufficiently large may be used as with gas oil tar emulsion.

Any existing dry tar lines should be insulated with a steam line.

(p) Additional purifying capacity, if existing units are at present operating up to their hourly capacity.

On account of the fact that the heavier oils as a rule contain a much larger quantity of sulphur, and also that this constituent is passed on to the gas partly as hydrogen sulphide in proportion to the quantity of sulphur in the oil; it can readily be seen that this objectionable gas might increase beyond the point where the existing facilities would take care of it. A study should be made to determine the limit of the amount of sulphur that the oil should contain. The theoretical increase in frequency of change of the oxide in the purifying boxes may be calculated from the above information.
In case that new purification capacity is needed this will quite naturally have to be charged up in the investments against heavy oil. As this type of equipment at present is very expensive, it is very unlikely that the utilization of heavy oil could be made to prove its worth.

There are oil companies selling a medium heavy oil that falls under the heading of heavy oil as used by the gas companies, in which the sulphur content is very low. Operating with oil of this type (and reforming) the hydrogen sulphide content of the gas made is actually lower than when using light oil. This is due to the fact that the hydrogen sulphide content of the gas made by reforming is considerably lower than that made by the oil that is carbureted. The sulphur in passing through the fire of the generator (which may be as high as 2500°F) is transformed into several of its other constituent compounds.

SAVINGS AND CREDITS.

(a) Reduction in quantity of fuel used in the solid state, supplanting it with liquid fuel.

In case that the practice of reforming can be resorted to economically it is possible to cut the consumption of the solid fuel about in half. This reduction or replacement of one fuel for the other is primarily responsible for the popularity of the entire system. This phase of the operation makes for unusual flexibility. The type of operation to be used during any particular period of time can be regulated to sacrifice the cheaper fuel for the more expensive.

(b) Proportional saving due to the differential in the price of gas oil and heavy oil.

Due to the fact that heavy oil is a much cheaper grade of fuel than gas oil there is a substantial savings possible even if this type of oil is used only for carbureting.
While the price per gallon for the heavy oil is only about seventy percent of the gas oil price, there is another differential due to the higher gravity of the former that is worth considering. Although the oils classed in the lower bracket are not as high in recoverable B.t.u. (as gas) the savings possible on account of the B.t.u. differential is substantial.

In a complete analysis of the heavy oil systems the amount of the oil that goes into tar must be taken into consideration and the price differentials on a B.t.u. basis computed, in order to get a true picture.

A group of curves for predicting the theoretical amount of tar that can be expected to be recovered is given on page 114.

There is as far as is known no difference in the quality of the gas made with heavy oil and that made with light oil.

(c) Increased quantity of tar produced.

The writer has proven to his own satisfaction that there is practically no tar produced in the reforming operation. It is during this portion of the cycle that as high as 40% of the total oil is used. There is, as has been stated before, a considerable amount of lamp black formed in this operation which finds its way into the tar. In attempting to arrive at the amount of tar that will be produced it is very difficult to make any accurate rule as to the effect upon the volume, that the lamp black that will be blown through, will have. For a conservative estimate this factor can be disregarded.

Due to the lower efficiency of the heavy oil as a carbureting medium it is reasonable to assume that this portion that did not go into a gas came out as either a tar or as solid carbon. From the Conradson carbon factor it is possible to determine the amount of the oil that will be changed to carbon and knowing two of the three variables a rough idea as to the extent of the third can be made.
(d) Elimination of checkerbrick replacements. (This can be considered for the Semet-Solvay and U.S.I. processes)

Since the checkerbrick of the carburetor are removed in the two systems mentioned above there is at least two fifths of the total checkerwork entirely out of the set. This should reduce the expense chargeable to this part of the set by the same ratio.

In the Western Gas "Reverse Blast System" the replacements are supposed to be reduced considerably.

(e) Reduction in expense of handling generator fuel.

As the consumption of generator coke is cut in half, the handling charges for this fuel should be cut in a like proportion.

(f) Possibility of extending time between clinkering periods or reducing total clinkering time.

With certain types of generator coke, it is possible to lengthen the operating period between clinkering time. This reduces the labor chargeable to the water gas set, and is an asset in other ways that may not show up on a financial study of the system.

(g) Possible saving in reduction of investment in fuel storage.

Since the consumption of solid fuel is cut in half, only half as much of this need be carried in storage for the same safety factor as with gas oil.

(h) Reduction in boiler fuel costs, (if heavy oil tar is to be used under the boilers as a fuel).

This possibility depends quite naturally upon the value of the boiler fuel being used and the value of the tar (based on the market value with allowance for dehydrating differences). The heating value of heavy oil tar will average better than 160,000 B.t.u. per gallon. This high value is due to its high specific gravity which will run
in the neighborhood of 1.20. The carbon content of this tar is a
determining factor of the heating value. The heating value of the oily
constituent of tar will average 17,000 B.t.u. per pound whereas carbon
is only 14,600.

(i) Elimination of labor for handling solid fuel.

In case that tar is substituted for coal as boiler fuel, any labor
chargeable to the handling of the coal could be shifted to other accounts
or eliminated.

EXPENSES AND DEBITS.

(a) Labor for unloading heavy oil, above that required for light
oil.

Heavy oil is shipped in tank cars equipped with steam coils. As a
rule this oil must be heated to about 100° F. before it will flow very
easily. Several hours are required in the colder months to heat a car
up to the above mentioned temperature. There is additional labor invol-
volved in this heating and this must be charged up against the system.

(b) Additional cost of dehydrating tar.

With a dehydrator properly arranged and cared for, the steam charge
for processing the fluid should not exceed two tenths of a cent per gallon.
The labor charge for this operation will quite naturally be variable, but
for ordinary plants this can be conservatively put at three tenths of a
cent per gallon. These two figures are actual, being used by a plant
making two million cubic feet of gas per day.

(c) Additional cost of purification.

This item at its best is only a guess, for there are many variables
that affect the purifying qualities of a given set up. The operation of
the plant has a great deal to do with whether or not an increase in the
charges apportioned to the purification system should be allowed.
The purification system of the average plant usually offers a wide opportunity for study. The way in which the gas is delivered to the boxes for purification is the prime factor of their ability. If too low temperatures are carried the activity of the oxide is reduced, and likewise if the other extreme is allowed the light oils will carry through the proceeding apparatus and foul the oxide. It can readily be seen that a study of the temperature limits is imperative for the best results from the oxide is to be obtained.

As stated before, unless the sulphur content of the oil is more than twice the amount usually encountered in gas oil, there should be no increase in purification costs.

(d) Cost of steam for heating oil, both unloading and heating for use.

The cost of steam for heating the oil in tank cars is of course dependent upon the outside temperature and any cost chargeable to this phase of the operation would be subject to wide variations. In many instances exhaust steam is used for this purpose, this procedure would quite naturally reduce the cost to a figure that would hardly be worth consideration.

Based on an efficiency of 70% in the heat inter-changers, four pounds of steam are necessary to heat the oil used per thousand cubic feet of gas made. The specific heat of the oil being considered as four tenths, thus making 4 B.t.u. per pound per degree Fahrenheit.

(e) Cost of pumping additional oil required.

This cost is so small that it hardly deserves consideration, being only several hundredths of a cent per thousand cubic feet made.

(f) Cost of tar as a boiler fuel.

Although the heavy oil tar will average better than 160,000 B.t.u. per gallon, and will go as high as 170,000, it is old time practice to
consider this product worth only two cents per gallon, when it is used as a boiler fuel.

There is another use to which this tar may be put economically and that is the use of it as a reforming fuel to supplant a portion of the oil that would be so used. It has been proven in several large plants in the East that tar will serve nicely as a reforming medium. This of course depends upon its value on the market and the value of the coke that is being used. Since when it is used as such it replaces coke, for the average plant this is the most economical place for it to be consumed.

(g) Cost of operation of tar burning equipment.

If the heavy oil tar is to be burned under the boilers, it should be remembered that only the steam atomizing type of burner may be used. This is due to the fact that this tar will have a free carbon content as high as 20%, which will not permit operation with the mechanical burners. Therefore for calculations in this direction at least ten percent of the steam to be generated should be considered as used by the burner. This figure is somewhat higher than ordinary oil operation, but has been proven in tests. A separate section of this thesis covers the burning of heavy oil tar.

(h) Additional labor for cleaning water gas sets.

Since it requires approximately one hour longer to properly clean the entire set, including the generator, the bottom of the carburetor, the back-run valve, and the connection to the superheater, this time should be charged up against the study. The wash box must be cleaned on an average of once each week.

(i) Cost of additional water for cooling.

The additional water for cooling the back-run valve box is about the only charge in this direction. This amounts to about two hundredths of a cent per thousand feet of gas.
(j) Interest on the investment.

This item should include interest that would have to be paid on all money that was borrowed for the installation of the equipment necessary to utilize heavy oil.

Sample Calculations:

In order to show more explicitly the amount of savings that may be realized from heavy oil operation, a series of different combinations possible with such is given on the following pages.

These estimates were taken from an actual study of a New England plant that quite naturally took advantage of the reduced operating fuel costs and has been able to show a savings approximating 4.0 cents per M. Cu. Ft. which is well within the estimates.

The equipment that was necessary for this installation, which happened to be one of the Semet-Solvay Ignition Arch jobs, is detailed also, in order to give an idea of the extent of the investment.
ESTIMATE of CONSTRUCTION COST
for a
3,000 M.C.F. per DAY NEW ENGLAND PLANT

HEAVY OIL INSTALLATION
CLASSIFICATIONS of CHARGES

WORKS and STATION STRUCTURES

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</tr>
<tr>
<td>Tar Storage Tank, Foundation, etc.</td>
<td>1,450.00</td>
</tr>
<tr>
<td><strong>TOTAL WORKS and STATION STRUCTURES</strong></td>
<td><strong>$4,935.00</strong></td>
</tr>
</tbody>
</table>

BOILER PLANT EQUIPMENT

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line from Storage Tank to Boiler Room</td>
<td>$75.00</td>
</tr>
<tr>
<td>Boiler Pump Foundation, Regulators, Etc.</td>
<td>225.00</td>
</tr>
<tr>
<td>Secondary Heater and Fittings</td>
<td>200.00</td>
</tr>
<tr>
<td>Line from Heater to Boilers</td>
<td>15.00</td>
</tr>
<tr>
<td>Burners and Furnace Changes</td>
<td>300.00</td>
</tr>
<tr>
<td>Two Meters and By-Passes</td>
<td>150.00</td>
</tr>
<tr>
<td><strong>TOTAL BOILER PLANT EQUIPMENT</strong></td>
<td><strong>$965.00</strong></td>
</tr>
</tbody>
</table>

WATER GAS SETS

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Heater Tank Type</td>
<td>$300.00</td>
</tr>
<tr>
<td>Piping Primary Heater to Pumps</td>
<td>190.00</td>
</tr>
<tr>
<td>Pumps and Regulators</td>
<td>1,000.00</td>
</tr>
<tr>
<td>Piping Pumps to Secondary Heater</td>
<td>1,200.00</td>
</tr>
<tr>
<td>Secondary Heater and Regulator</td>
<td>500.00</td>
</tr>
<tr>
<td>Equalizer Tank and Equipment</td>
<td>200.00</td>
</tr>
<tr>
<td>Hot Oil Line Secondary Heater to Meters</td>
<td>100.00</td>
</tr>
<tr>
<td>Hot Oil Line Meters to Set</td>
<td>50.00</td>
</tr>
<tr>
<td>Ignition Arch Installation</td>
<td>8,638.00</td>
</tr>
<tr>
<td>Carburator Control Valve</td>
<td>300.00</td>
</tr>
<tr>
<td>Back-Run 3-Way Valve</td>
<td>800.00</td>
</tr>
<tr>
<td>Back-Run Pipe</td>
<td>400.00</td>
</tr>
<tr>
<td>New Generator</td>
<td>2,500.00</td>
</tr>
<tr>
<td><strong>TOTAL WATER GAS SETS</strong></td>
<td><strong>$16,178.00</strong></td>
</tr>
</tbody>
</table>
HEAVY OIL INSTALLATION - CLASSIFICATION of CHARGES -(continued)

**PURIFICATION APPARATUS**

| Description                                                                 | Cost  
|-----------------------------------------------------------------------------|-------
| New Pump, Foundation, Regulator, Etc.                                      | $ 500.00 |
| 6th Line Settling Basin to Pump                                            | 150.00 |
| 5th Line Pump to Separator                                                 | 150.00 |
| Overflow Line Separator to Relief Holder                                   | 250.00 |
| Changes to Scrubber under Wash Box                                         | 75.00  |

**TOTAL PURIFICATION APPARATUS** $1,125.00

**OTHER EQUIPMENT AT WORKS**

| Description                                                                 | Cost  
|-----------------------------------------------------------------------------|-------
| Connections to Tar Storage Tank                                            | $ 300.00 |
| Line from Storage Tank to Dehydrator                                      | 200.00 |
| Primary Heater Connections Steam Trap                                     | 400.00 |
| New Dehydrating Tank and Supports Complete                                 | 1,200.00 |
| Steam Piping to Dehydrator                                                | 50.00 |
| Foundation and Connections for Tar Pump                                    | 100.00 |
| Changes to Existing Piping                                                | 100.00 |

**TOTAL OTHER EQUIPMENT AT WORKS** $2,350.00

**UNCLASSIFIED**

| Description                                                                 | Cost  
|-----------------------------------------------------------------------------|-------
| Superintendence & Engineering, Local                                        | $2,000.00 |
| Superintendence & Engineering,                                              | 400.00 |
| Stone and Webster                                                           |       |
| Contingency                                                                 | 647.00 |

**TOTAL UNCLASSIFIED** $3,047.00

**TOTAL ALL ACCOUNTS & UNCLASSIFIED** $28,600.00
# Detail of Operations for Gas Oil Fuel Costs

## Typical Year

<table>
<thead>
<tr>
<th>Month</th>
<th>Gas Made M.C.F.</th>
<th>Lbs/MCF.</th>
<th>Total Lbs.</th>
<th>@ .36/lb.</th>
<th>Generator Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lbs/MCF.</td>
</tr>
<tr>
<td>Jan.</td>
<td>60,000</td>
<td>8.70</td>
<td>522,000</td>
<td>$1,566.</td>
<td>28.0</td>
</tr>
<tr>
<td>Feb.</td>
<td>56,000</td>
<td>9.20</td>
<td>515,200</td>
<td>$1,546.</td>
<td>28.0</td>
</tr>
<tr>
<td>Mar.</td>
<td>59,000</td>
<td>9.00</td>
<td>531,000</td>
<td>$1,593.</td>
<td>28.0</td>
</tr>
<tr>
<td>Apr.</td>
<td>49,000</td>
<td>9.50</td>
<td>465,500</td>
<td>$1,397.</td>
<td>28.0</td>
</tr>
<tr>
<td>May</td>
<td>43,000</td>
<td>8.30</td>
<td>356,900</td>
<td>$1,071.</td>
<td>28.0</td>
</tr>
<tr>
<td>June</td>
<td>44,000</td>
<td>10.30</td>
<td>453,200</td>
<td>$1,360.</td>
<td>28.0</td>
</tr>
<tr>
<td>July</td>
<td>44,000</td>
<td>8.70</td>
<td>382,800</td>
<td>$1,148.</td>
<td>28.0</td>
</tr>
<tr>
<td>Aug.</td>
<td>44,000</td>
<td>9.60</td>
<td>422,400</td>
<td>$1,267.</td>
<td>28.0</td>
</tr>
<tr>
<td>Sept.</td>
<td>45,000</td>
<td>9.00</td>
<td>405,000</td>
<td>$1,215.</td>
<td>28.0</td>
</tr>
<tr>
<td>Oct.</td>
<td>48,000</td>
<td>9.80</td>
<td>470,400</td>
<td>$1,411.</td>
<td>28.0</td>
</tr>
<tr>
<td>Nov.</td>
<td>51,000</td>
<td>8.00</td>
<td>408,000</td>
<td>$1,224.</td>
<td>28.0</td>
</tr>
<tr>
<td>Dec.</td>
<td>50,000</td>
<td>9.60</td>
<td>475,000</td>
<td>$1,728.</td>
<td>28.0</td>
</tr>
</tbody>
</table>

|       |                |          |            |           | Total Fuel Cost | $164,886.00 |
|       |                |          |            |           | Tar Residual Credit | $12,060.00 |
|       |                |          |            |           | Net Operating Cost | $152,826.00 |
SET-UP AS SHOWN ON DETAIL PAGE

for

ONE YEAR'S OPERATION

(Gas Oil and Coal for Boiler Fuel - Hand Fired)

Boiler Fuel  5,508,400 lbs. @ .3¢ per lb.  $ 16,526.00

Generator Fuel  16,884,000 lbs. @ .45¢ per lb.  75,978.00

Gas Oil  1,688,400 gals. @ 5.0¢ per gal.  84,420.00
(32° Be. .865 Sp. Gr.)

TOTAL FUEL COST  $176,924.00

TAR

For oil of this grade the tar production will average .5 gallons per M.C.F. of gas made which is approximately 18% of oil used.

Tar .5 gals. per M.C.F. = 301,500 gals.  
@ 4.0 ¢ per gal.  (Credit)  12,060.00

NET OPERATING FUEL COST  $164,864.00
(Excluding Drip Oil)
HEAVY OIL - (Medium) FUEL AND RESIDUAL SET-UP
(Excluding Drip Oil)
FOR ONE YEAR
For Carburetion Only - Coal for Boiler Fuel

Oil 20° Be. 93 Sp. Gr. 145,000 B.t.u. per Gal.
Oil Efficiency 95,000 B.t.u. per Gal. per M.C.F.
Coke Content of Oil 60%

BOILER FUEL
@ 11 lbs. per M.C.F. = 6,633,000 lbs.
@ .3¢ per lb. $19,899.00

GENERATOR FUEL
@ 28 lbs. per M.C.F. = 16,884,000 lbs.
@ .45¢ per lb. $75,978.00

HEAVY OIL
@ 3.1 gals per M.C.F. = 1,869,300 gals.
@ .40¢ per gal. $74,772.00

TOTAL FUEL COST $170,649.00

TAR

From Tar Production Curves for above Conditions production should be 25% of oil used.

.25 x 1,869,300 gals = 467,325 gals. @ .40¢ per gal. $18,693.00

NET OPERATING FUEL COST $151,956.00

*MISCELLANEOUS CHARGES
(Attributable to Heavy Oil Operation.) $10,303.00

NET OPERATION FOR COMPARISON
(Not Including Basic Operating Costs.) $162,259.00

*See following page for detail.
## Detail of Miscellaneous Charges

**Attributable to Heavy Oil Operation**

**For Carburetion Only**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity/Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gas Made</td>
<td>603,000 M.C.F.</td>
</tr>
<tr>
<td>Total Oil Used</td>
<td>1,869,300 Gals.</td>
</tr>
<tr>
<td>Oil Heating Cost</td>
<td></td>
</tr>
<tr>
<td>Unloading @ $.15 per M. Gals.</td>
<td>$280.00</td>
</tr>
<tr>
<td>For Use @ .35 per M. Gals.</td>
<td>$654.00</td>
</tr>
<tr>
<td>Tar Produced</td>
<td>467,325 Gals.</td>
</tr>
<tr>
<td>Tar Dehydrating Cost @ 3.00 per M. Gals. (Steam &amp; Labor)</td>
<td>$1,402.00</td>
</tr>
<tr>
<td>Tar Handling Cost @ 2.00 per M. Gals. (Steam &amp; Labor)</td>
<td>$934.00</td>
</tr>
<tr>
<td>Increase in Pumping Costs @ .02¢ per M.C.F. (Steam Cost)</td>
<td>$121.00</td>
</tr>
<tr>
<td>Increase in Purification Material Cost @ .2¢ per M.C.F.</td>
<td>$1,206.00</td>
</tr>
<tr>
<td>Increase in Purification Labor @ .2¢ per M.C.F.</td>
<td>$1,206.00</td>
</tr>
<tr>
<td>Investment Charge @ 15%* on $30,000.00</td>
<td>$4,500.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$10,303.00</strong></td>
</tr>
</tbody>
</table>

*Includes Interest, Taxes and Retirement.
HEAVY OIL - (Medium) FUEL AND RESIDUAL SET-UP
(Excluding Drip Oil)
For Carburetion and Reforming
Coal for Boiler Fuel

Oil 20° Be. .33 Sp. Gr. 145,000 B.t.u. per Gal.
Oil Efficiency for Carbureted Oil 95,000 B.t.u. per Gal. per M.C.F.
Coke Content of Oil 6.0 % — 40.0 % of Total Oil Reformed.

BOILER FUEL
@ 11 lbs. per M.C.F. = 6,633,000 lbs.
@ .5¢ per lb. $19,399.00

GENERATOR FUEL
@ 15 lbs. per M.C.F. = 9,045,000 lbs.
@ .45¢ per lb. $40,702.00

HEAVY OIL
@ 4.0 gals. per M.C.F. = 2,412,000 gals.
@ 4.0 ¢ per gal. $96,560.00

TOTAL FUEL COST $157,161.00

TAR

From Tar Production Curves for above oil tar production should be 25% of Oil used for carbureting.
Oil for carburetion is 60% of Total Oil

25 x .60 x 2,412,000 = 361,800 gals. @ 4.0¢ per gal.
$ 14,472.00

NET OPERATING FUEL COST $142,689.00

*MISCELLANEOUS CHARGES

(Attributable to Heavy Oil Operation) $ 10,048.00

NET OPERATION FOR COMPARISON (Not Including Basic Operating Cost) $152,737.00

*See Following Page for Detail.
Note;
Boiler Fuel Increased 2.0 lbs. per M.C.F. to Include Additional Heating.
Tar Price given is New England Market Price.
### DETAIL OF MISCELLANEOUS CHARGES

**ATTRIBUTABLE TO HEAVY OIL OPERATION**

**FOR CARBURETION AND REFORMING**

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL GAS MADE</strong></td>
<td>603,000 M.C.F.</td>
</tr>
<tr>
<td><strong>TOTAL OIL USED</strong></td>
<td>2,412,000 Gals.</td>
</tr>
<tr>
<td><strong>OIL HEATING COST</strong></td>
<td></td>
</tr>
<tr>
<td>Unloading @.15 per M. Gals.</td>
<td>$362.00</td>
</tr>
<tr>
<td>For Use @.35 per ? Gals</td>
<td>$844.00</td>
</tr>
<tr>
<td><strong>TAR PRODUCED</strong></td>
<td>361,800 Gals.</td>
</tr>
<tr>
<td><strong>TAR DEHYDRATING COST</strong></td>
<td>@$3.00 per M.Gals. (Steam and Lab)</td>
</tr>
<tr>
<td><strong>TAR HANDLING COST</strong></td>
<td>@$2.00 per M.Gals. (Steam and Lab.)</td>
</tr>
<tr>
<td><strong>INCREASE IN PUMPING COSTS</strong></td>
<td>@.02¢ per M.C.F. (Steam)</td>
</tr>
<tr>
<td><strong>INCREASE IN PURIFICATION MATERIAL</strong></td>
<td>@.2¢ per M.C.F.</td>
</tr>
<tr>
<td><strong>INCREASE IN PURIFICATION LABOR</strong></td>
<td>@.2¢ per M.C.F.</td>
</tr>
<tr>
<td><strong>INVESTMENT CHARGE</strong></td>
<td>@ 15.0 % on $30,000.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
</tr>
</tbody>
</table>

* Includes Interest, Taxes and Retirement.
HEAVY OIL - (Medium) FUEL AND RESIDUAL SET-UP
(Excluding Drip Oil)
For Carburation and Reforming
Tar for Boiler Fuel
Oil Specifications Same as on Previous Pages

BOILER FUEL - TAR

From Calculations on Page 47 the tar production will approximate 361,800 gals.
This Tar will Average 1.18 Sp.Gr. @ 17,000 B.t.u. per lb. = 9.81 lbs. per gal.

Boiler Coal @ 12,500 B.t.u. per lb. = \( \frac{12,500}{17,000} \) = .735 lbs. tar/lb. coal.

361,800 x 9.8 = 3,545,640 lbs. tar produced.

\( \frac{3,545,640}{.735} = 4,840,000 \) Equivalent lbs. Coal.

Assuming no increase in furnace efficiency, the production of tar would not meet the requirements. This deficiency would have to be made up with heavy oil.

Heavy Oil = 18,800 B.t.u. per lb.

\( \frac{12,500}{18,800} = .665 \) lbs oil per lb. coal.

6,633,000 - 4,840,000 = 1,793,000 equivalent lbs. coal to be made up with heavy oil.

1,793,000 x .665 = 1,192,345 lbs oil.

Oil of .93 Sp.Gr. = 7.75 lbs. per gal.

\( \frac{1,192,345}{7.75} = 154,000 \) gals. oil necessary to meet requirements.

If coal is worth .3% per lb. Tar = .3 \( \times \frac{.408}{735} = 4.0 \% \)

Although heavy oil tar is here figured to be worth 4.0% per gal. it will be charged out in this estimate at 3.0

361,800 gals. tar @ 3.0% = $10,254.00

154,000 gals. oil @ 4.0% = $6,160.00

TOTAL BOILER FUEL = $17,014.00

Continued of Following Page
DETAIL OF MISCELLANEOUS CHARGES

ATTRIBUTABLE TO HEAVY OIL OPERATION

TOTAL BOILER FUEL (From Page 49) $17,014.00

GENERATOR FUEL @ 15 lbs per M.C.F. = 9,045,000 lbs.
@ .45 ¢ per lb. $40,703.00

HEAVY OIL @ 4.0 gals. per M.C.F. = 2,412,000 gals.
TOTAL GAS MADS @ 4.0 ¢ per gal. $96,560.00

TOTAL FUEL COST $154,276.00

TAR (CREDIT) Same as for Previous Set-Up
361,900 gals. @ 3.0 ¢ per gal. $10,854.00

NET OPERATING FUEL COST $143,422.00

MISCELLANEOUS CHARGES * (Attributable to Heavy Oil Operation)

TAR HANDLING COST @ 2.00 per M.C.F. $724.00

NET OPERATION FOR COMPARISON (Not Including Basic Operating Costs)

$153,547.00

INCREASE IN PURIFICATION MATERIAL 6.25¢ per M.C.F. $1,206.00

INCREASE IN PURIFICATION LABOR 2.5¢ per M.C.F. $1,206.00

INCREASE CHARGE @15.0% on $30,000 $4,500.00

TOTAL $10,125.00

* Includes 2,412,000 gals. for gas making and 164,000 for boilers.
** Includes Interest, Taxes and Retirement.

* See Following Page for Detail

Note: Unloading heating, and heating for use charges are considered about equal to unloading costs for coal in case where coal is used in place of oil for boiler fuel.
### DETAIL OF MISCELLANEOUS CHARGES

**ATTRIBUTABLE TO HEAVY OIL OPERATION**

**FOR CARBURETION AND REFORMING**

**TAR FOR BOILER FUEL**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity/Details</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Gas Made</td>
<td>603,000 M.C.F.</td>
<td></td>
</tr>
<tr>
<td>Total Oil Used</td>
<td>* 2,566,000 gals. (Oil as Partial Boiler Fuel)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2,412,000 gals. (Coal as Partial Boiler Fuel)</td>
<td></td>
</tr>
<tr>
<td>Oil Heating Cost</td>
<td>Unloading 2,566,000 gals. @ 15¢</td>
<td>$ 385.00</td>
</tr>
<tr>
<td></td>
<td>For Use</td>
<td>$ 898.00</td>
</tr>
<tr>
<td>Tar Produced</td>
<td>361,800 gals.</td>
<td></td>
</tr>
<tr>
<td>Tar Dehydrating Cost</td>
<td>361,800 gals. @ $3.00 per M. Gals.</td>
<td>$ 1,085.00</td>
</tr>
<tr>
<td>Tar Handling Cost</td>
<td>&quot;                                  @ $2.00 per M. Gals.</td>
<td>$ 724.00</td>
</tr>
<tr>
<td>Increase in Pumping Costs</td>
<td>@ .02¢ per M.C.F.</td>
<td>$ 121.00</td>
</tr>
<tr>
<td>Increase in Purification Material</td>
<td>@ .2¢ per M.C.F.</td>
<td>$ 1,206.00</td>
</tr>
<tr>
<td>Increase in Purification Labor</td>
<td>@ .2¢ per M.C.F.</td>
<td>$ 1,206.00</td>
</tr>
<tr>
<td>Investment Charge</td>
<td><strong>15.0 % on $30,000</strong></td>
<td>$ 4,500.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>$10,125.00</td>
</tr>
</tbody>
</table>

* Includes 2,412,000 gals. for gas making and 154,000 for boilers.
** Includes Interest, Taxes and Retirement.

Note: Unloading heating, and heating for use charges are considered about equal to unloading costs for coal in case where coal is used in place of oil for boiler fuel.
HEAVY OIL - (Medium) FUEL AND RESIDUAL SET-UP
(Excluding Drip Oil)
For Carburetion and Reforming
Tar and Coal for Boiler Fuel
Oil Specifications Same as on Previous Pages

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity/Details</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOILER FUEL</td>
<td>4,840,000 equivalent lbs. of coal as tar 361,800 gals. @ 3.0¢ per gal.</td>
<td>$10,854.00</td>
</tr>
<tr>
<td></td>
<td>1,795,000 lbs. coal @ .3¢ per lb.</td>
<td>$5,379.00</td>
</tr>
<tr>
<td>TOTAL BOILER FUEL</td>
<td></td>
<td>$16,233.00</td>
</tr>
<tr>
<td>GENERATOR FUEL</td>
<td>@ 15 lbs. per M.C.F. = 9,045,000 lbs. @ .45¢ per lb.</td>
<td>$40,702.00</td>
</tr>
<tr>
<td>HEAVY OIL</td>
<td>@ 4.0 gals. per M.C.F. = 2,412,000 gals. @ 4.0¢ per gal.</td>
<td>$96,560.00</td>
</tr>
<tr>
<td>TOTAL FUEL COST</td>
<td></td>
<td>$153,495.00</td>
</tr>
<tr>
<td>TAR (CREDIT)</td>
<td>Same as for Previous Set-up. 361,800 gals. @ 3.0¢ per gal.</td>
<td>$10,854.00</td>
</tr>
<tr>
<td>NET OPERATING COST (FUEL)</td>
<td></td>
<td>$142,641.00</td>
</tr>
<tr>
<td>MISCELLANEOUS CHARGES *</td>
<td></td>
<td>$10,125.00</td>
</tr>
<tr>
<td>(Attributable to Heavy Oil Operation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NET OPERATION FOR COMPARISON</td>
<td>(Not Including Basic Operating Costs)</td>
<td>$152,766.00</td>
</tr>
</tbody>
</table>

*Same as for Previous Set-up.
Note: Boiler Fuel Not Corrected for Less Heating of Oil, Since This Expense Would Be Offset by Additional Expense of Unloading Coal.
HEAVY OIL - BUNKER "C" - FUEL AND RESIDUAL SET-UP
(Excluding Drip Oil)
For Carburetion and Reforming
Coal for Boiler Fuel

OIL 15°Be. .965 Sp. Gr. 147,000 B.t.u. per lb.
Oil Efficiency for Carbureted Oil 90,000 B.t.u. per Gal. per M.C.F.
Average Coke Content 12.0 %

.965 x 8.34 = 8.04 lbs per gal. 8.04 x .12 = .965 lbs. carbon per gal.
.965 x 14,800 = 14,400 B.t.u. as Carbon

147,000 - 14,400 = 132,600 B.t.u. available for gas or tar.
132,600 - 90,000 = 42,600 B.t.u. available for tar.

Since 40.0% is about the maximum Reforming Limit
At 4.2 Gals per M.C.F.
4.2 x .60 = 2.52 Gals per M.C.F. in Carburetor.

2.52 x 42,600 = 108,000 B.t.u. as Tar per M.C.F.

The heating value of this tar is about 165,000 B.t.u. per gal.

$ \frac{108,000}{185,000} \times .66 \text{ gals tar per M.C.F.}$

BOILER FUEL 6,633,000 lbs. @ .3¢ per lb. $19,899.00
GENERATOR FUEL 15.5 lbs. per M.C.F. @ .45¢ per lb. $42,059.00
OIL 4.2 Gals per M.C.F. @ 3.5¢ per Gal. $38,641.00

TAR (CREDIT) .66 Gals per M.C.F. = 397,980 gals.
@ 4.0 ¢ per Gal. $15,919.00

NET OPERATING FUEL COST $134,680.00

MISCELLANEOUS CHARGES *
(Attributeable to Heavy Oil) $12,701.00

NET OPERATION FOR COMPARISON
(Not Including Basic Operating Costs)

$147,381.00

* See Following Page for Detail.
DETAIL OF MISCELLANEOUS CHARGES
ATTRIBUTABLE TO HEAVY OIL OPERATION
FOR CARBURETION AND REFORMING
FOR BUNKER "C" OPERATION

TOTAL GAS MADE 603,000 M.C.F.
TOTAL OIL USED 2,532,000 Gals.

OIL HEATING COST
UNLOADING @ .15 ¢ per gal. $ 380.00
FOR USE @ .35 ¢ per gal. $ 386.00

TAR PRODUCED 397,980 Gals.

TAR DEHYDRATING COST @ $3.00 per M. Gals. $ 1,194.00
TAR HANDLING COST @ $2.00 per M. Gals. $ 796.00
INCREASE IN PUMPING COST @ .02¢ per M.C.F. $ 121.00
INCREASE IN PURIFICATION MATERIAL @ .4¢ per M.C.F. $ 2,412.00
INCREASE IN PURIFICATION LABOR @ .4¢ per M.C.F. $ 2,412.00
INVESTMENT CHARGE 15% on $30,000.00 $ 4,500.00

TOTAL $12,701.00

* Includes Interest, Taxes and Retirement.
SUMMARY OF OPERATING FIGURES

In all the foregoing comparisons the fuel and tar prices were considered at the present New England market price. These prices are of course changing from time to time, but since, as stated before the price of heavy oil fluctuates with the price of coal, the differential remains fairly constant. On a per ton and gallon basis these prices are as follows:

- Coke: $9.00 per ton in storage
- Coal: $6.00 per ton
- Gas oil: $0.05 per gallon

Heavy Oils:
- Residuum (medium): $0.04 per gallon
- Bunker"C" (heavy): $0.035 per gallon

Drip and holder oils which will average 2.0% of the total oil used are not included in these calculations. Experience has proven that the recovery of these residuals does not vary appreciably from gas oil operation, and for this reason they are omitted from all consideration.

From a study of the different combinations given, it is obvious that there are substantial savings to be realized on at least three of the arrangements given. There are other possible combinations that may prove even more profitable in certain cases but space does not permit a detail of all of them.

The detail on gas oil operation was given for the sake of comparison. The set-up for heavy oil, (for carburation only) shows savings to the extent of $1,905.00. This sum would not in most cases warrant the change to a different type of operation. This estimate is very
conservative for any plant with reasonably good control of operations. The fuel figures were purposely increased to cover less efficient operating conditions.

Under gas oil operation the "Boiler Fuel" figure represents a per M.C.F. of 9.13 lbs.; this is an actual operating condition at the Haverhill Gas Light Co. of Haverhill, Mass. To take care of extra heating of lines, seal pots, and the like under heavy oil operation, this figure was increased to 11.00 lbs. This increase does not include oil heating which is accounted for under Miscellaneous Charges.

In the third set-up reforming operation is taken into consideration. Under this it will be noted that the generator fuel figure has dropped from 28.00 lbs. per M.C.F. to 15.00 lbs., and likewise the oil has been increased from 3.1 gals. to 4.0. This, at first glance, seems somewhat out of line on a B.t.u. basis, since the input in the form of coke has been reduced 13.00 lbs. - this representing 13 x 13,500 = 176,000 B.t.u., while the oil has increased only .90 gals., which represents .9 x 145,000 = 131,000 - a difference of 45,000 B.t.u. Under these operating conditions it will be found that the difference lies in the fact that the oil fed to the carburetor has been reduced to 2.60 gals. per M.C.F. while the 1.40 gals. represent the oil to the generator. Since the oil reformed does not produce tar, then the tar production has taken a drop from 25% of 3.1 gals. to 25% of 2.60 gals. While this difference represents only .125 gals. tar per M.C.F. which at 165,000 B.t.u. per gal. = 20,600, the difference is made up in less carbon precipitated in parts of the set where it cannot be utilized to gas making advantage. These operating figures are being bettered by several companies in this section of the country at the present time.
The yearly savings under this third set-up are $12,157.00 which is a sizeable cut in operating expenses representing 2.02 cents per M.C.F. Facilities of a plant are sufficient to take care of hydrogen sulphide if the facilities available can take care of it, of the various combinations given is the one in which Bunker "C" oil is used. The utilization of this oil can be accomplished with practically no increase in grief, with one exception; that being the possibility of the purification system taking care of the increase in hydrogen sulphide that will inevitably result. By increase here is not meant merely the doubling of this constituent but possibly quadrupling the amount ordinarily encountered in gas oil operation. For rough calculations between 13 and 15 grains per 100 cu. ft. per .1% by weight of sulphur in the oil, can be used. Taking an

The fourth set-up takes into consideration those plants which would not be able to dispose of their tar production and are compelled to burn it under boilers. (A section covering the burning of tar is given in the following pages.) Under this set-up the boiler fuel takes a considerable rise due to the fact that it is considered that the gas making oil will be used to make up the deficiency in tar. This can be done with practically no outlay of money as compared to a second complete system for handling a cheaper grade of oil. In plants where it is possible, coal may be used in one or more boilers and just enough boiler facilities changed over to accommodate the tar that will be produced. This is shown as a secondary set-up.

Even taking into consideration this large increase in boiler fuel there is still a saving in the first case of $11,317 and in the second of $12,098.00, which should warrant the expenditure as shown. The most profitable combination, if the facilities available can take care of it, of the various combinations given is the one in which
oil of 1.5% sulphur by this rule, it will be seen that this represents about 225 grains of H2S per 100 cu. ft. Therefore, if the purification facilities of a plant are sufficient to take care of hydrogen sulphide contents as high as 300 grains regularly, and as high as 600 grains intermittently, the management can consider itself lucky indeed, for an additional $5,326.00 can be gained by using these very heavy products. Bunker "C" oil, as stated before in this paper, will run as high as 5.0% sulphur. This is above the average but a plant contemplating the use of such oil should be prepared for the worst.

It will be noted that the charges under Purification Labor and Material have been doubled under this type of operation to take care of more frequent changes of oxide.

Operating details concerning the use of this type of oil will be found in the section under "Operation of Set Proper."
Sketch of a Typical Arrangement for Overhead Construction

Magnesia Insulation Roofing Paper Covering

Sketch of the Ric Wil Underground Conduit, with dry pack insulation for filler

Drainage Duct
The first installation of this process was at Pittsfield, Mass., on a 10' 0" water gas machine equipped with back run, in June, 1931. This installation has been in continuous operation since. Experiments were conducted with different grades of oil, and tests run over periods of several months to prove the economy as well as the practicability of the method. A set of results are given at the end of this section with explanatory notes.

The equipment necessary, along with the changes required for this system are as follows:

(a) Ignition arch in top of carburetor.
(b) Oil sprays in carburetor.
(c) Oil sprays in generator.
(d) Air scurfing jets in bottom of carburetor.
(e) Changes in secondary air connection.
(f) Necessary oil piping and valves.
(g) Necessary steam purge piping and valves.
(h) Necessary cooling water piping and valves.
(i) Cleanout doors at bottom of carburetor and superheater.
(j) Inspection door at top of carburetor.
(k) Additional back run steam valve for throttling during oil admission.
(l) Additional sprays in three-way valve; also, enlarged cleaning door of the quick opening type.

A cut of a typical water-gas generator set showing the arrangement of the component parts of this system is given at the end of this section.
A description of the changes and additional equipment outlined on the previous page is as follows:

(a) Ignition arch in top of carburetor.

All checkerbrick and the supporting arches and tile are removed from the carburetor. At the time of doing this it should be ascertained whether or not the refractory lining should be replaced. This will save disturbing the ignition arch in case the replacement need be done within the next four years, which is the average life of one of the arches.

Two arches of specially formed and of special refractory are sprung across the carburetor at right angles to each other. The elevation of the arches is near the top of the carburetor. The wall on top of each arch is built up even with the bottom of the inlet connection from the generator. Special precaution is taken in the installation of one of these arches to compensate for expansion, and for this reason cement binding is not put in the upper section at all.

(b) Oil sprays in carburetor.

Four oil sprays of special design are installed at 90-degree intervals in the shell of the carburetor. These sprays are of the Anthony type and are located at a point about five feet from the bottom of the unit. The head of the spray is cast so that the nozzles direct the oil in a line about 30 degrees up from the horizontal. They are so arranged with respect to the ignition arch that the oil stream should not impinge upon the refractory of the arch; in other words, in between the four arms.

The oil sprays are connected with a common oil manifold, the cut-off valve being in the supply line. A steam manifold supplies
steam for purging each spray. The steam purge is controlled through the Semet-Solvay double piston steam purge valve.

The sprays are constructed so that the head protrudes about two inches beyond the refractory wall of the unit. These sprays are water cooled.

This arrangement of the sprays permits the spraying of the oil into the carburetor, countercurrent to the flow of gas, and therefore, the oil particles are continually travelling in a new atmosphere.

The blue gas coming from the generator, passes through and by the ignition arch. The gas is heated to a much higher temperature before it comes into contact with the oil fog than in the case of the checkered unit when the oil is sprayed from the top. This is due to the fact that during the blow, combustion takes place before the producer gas reaches the carburetor, thereby heating the upper zone that is not heated so highly when the secondary air is admitted in the top.

The sensible heat of the blue gas coming from the generator is sufficient to volatilize the oil, leaving the radiant heat of the walls to be utilized in cracking.

Due to the increased volume of the empty unit over the checkered one, the velocity of the gases passing through the carburetor is very slow, and the time of contact is therefore greatly increased.

Any solid matter drops out in the carburetor, due to the low velocity of the gases. This carbon deposit is mostly burned during the blow period by admitting air through the scurfing slots in the bottom of the unit.

(o) Oil sprays in the generator.

In the top of the generator is installed a spray or sprays, as the case may be, for the reforming operation. These sprays are of the same make as those of the carburetor, but of different design.
They are so designed that the oil should hit the top of the bed of carbon about one foot from the wall of the generator. The reason for this is obvious, since discharging all of it in the middle would cool that part too much, for best results, if any struck the wall it would cause a carbon deposit.

In case tar is to be used as a reforming medium to supplant a portion of the generator oil, it will be necessary to install two sprays. It is not practicable to use oil and tar alternately in any piece of equipment, unless the particular equipment is thoroughly cleaned between each flow. This is because a coagulation takes place when oil and tar are mixed which will cause stoppages that sometimes can be overcome only by removing the congested section from the system.

The generator oil spray nozzles must be so designed, that the required amount of oil to be injected should not consume more than two-fifths of the total back-run period. Since the back-run steam is reduced during the oil admission period to about one-third or one-fourth normal, if the oil consumes too much time, the make per hour from the set will be severely reduced. On account of this reduction in steam, (which is done to allow the carbon from the oil to settle out in the fuel bed, by reducing the velocity) the blue gas made by the total back-run period is reduced about twenty percent. If the full amount of steam is used during the oil admission period, two things take place, namely; the lamp black formed does not replace generator fuel as it is supposed to, and being blown through the fuel bed and into the wash-box, mixes with and excessively pollutes the tar.

The generator oil spray is connected through separate hydraulic valves and meter to the main oil system. In case that a different oil is used for reforming, it of course ties in with that system.
(d) Air scurfing jets in the bottom of the carburetor.

An inspection of the out of this system, at the end of this section will show, in orange coloring, the scurfing air manifold connecting to the different ports in the bottom of the carburetor. This manifold is connected to the blasting main through a hydraulically operated and hand regulated valve. The different ports are connected through the shell of the unit to fantail type nozzles. This type of opening gives a wide spread to the air and allows each one to scurf a maximum amount of space at the bottom of the unit.

Each port has a valve in its line in order that it may be regulated in accordance with the demand for such air.

The main valve, with needle valve regulation, is so adjusted that it does not open rapidly. The proper adjustment has been found to be that one by which this valve reaches full opening at the end of the blow. The hydraulic cylinder of this valve is connected in parallel with the secondary air valve. With proper regulation of this arrangement the bulk of the deposited carbon can be burned during operation, leaving only a small portion to be removed by hand.

One scheme used to aid in the removing of the deposited carbon is to spread sand on the floor of the carburetor after each cleaning. This will prevent the deposit from sticking to the refractory.

(e) Changes in the secondary air connection.

In place of the usual arrangement where the secondary air is admitted directly into the top of the carburetor, the air is admitted in the gas-way between the generator and the carburetor. This theoretically and practically enables a more thorough mixing of the blast gas with the secondary air before it reaches the ignition arch. This system in several ways is superior to the old way. One of the main
advantages is the ease with which a carburetor is lighted after a period of shutdown, or after a coaling.

(f), (g) Necessary oil piping and valves
Necessary steam purge piping and valves.

Quite naturally all the oil steam purge and hydraulic piping will have to be changed to accommodate the new valves and arrangements.

(h) Necessary cooling water piping and valves.

A cooling water manifold is installed around the carburetor. The individual spray connections are made from this line. The outlet connections from the sprays are piped to individual sight drains which are grouped together on the operating floor. This allows a positive check for the operator, as to whether or not each and every spray is receiving sufficient cooling water.

(i) Necessary cleanout doors at bottom of carburetor and superheater.

A quick opening cleanout door of a size large enough to allow ample room to remove the carbon deposits is installed in the bottom of both the carburetor and superheater. The level of these doors is arranged so that the bottom of the door is flush with the floor of the unit. This allows the carbon to be hoed out with a steel instrument. The location of these doors is made to suit the convenience of each set.

(j) Inspection door at top of carburetor.

A small quick opening door about six inches in diameter is installed in the top of the carburetor. This door allows inspection of the wall and ignition arch within the unit from the top. The usual sight glass is moved off center.

(k) Additional back-run steam valve.

An extra hydraulically operated valve is installed in the back-run steam line to facilitate throttling of this steam for the oil admission period. It is an ordinary gate valve, shunted with a small line large
enough to pass the required amount of steam for the oil period. During the oil admission period the large valve is closed and the steam flows through the shunt. The shunt has a hand regulated gate valve. When the oil shuts off the large valve opens, giving full opening, regulation being accomplished by a secondary hand operated gate valve.

(1) Additional sprays in the three way valve.

This additional spraying defeats the accumulation of carbon as well as increases the cooling of this vital piece of equipment. A portion of this cooling water must be on, even when the set is idle (hot) in order that the discs will not warp.

In order to facilitate easy cleaning of this valve, a large quick opening door is installed in this unit.

With a machine equipped as outlined above, the operation is most flexible. High quality gas oil can be used in the carburetor with equal efficiency as with a checkered unit. When using heavy oil, all of it may be sprayed in the carburetor on the up-run, or part during the up-run and part during the back-run (reforming). The type of operation to be used depends upon the costs of the oil and coke, local conditions, the gravity to be carried as well as the quality.

As a general rule the operating temperatures required in the set are reached and maintained with a shorter blow period, with this type of equipment. This feature reduces the fuel consumed during that part of the cycle. (See curves on page 113 for determining the amount of heat lost through the stack for different blowing periods)

The temperatures of the ignition arch carburetor as shown from actual tests do not vary as much, taking the carburetor as a whole, as does the checkered type unit. This insures a much more even cracking condition, reducing the possibility of making naphthalene or lamp black.
Since the carburetor is several hundred degrees hotter than the superheater, in a unit with checkerwork the edges of these brick are exposed to temperatures considerably higher than is best for oil cracking. This condition is necessary in order to properly heat the superheater. As a result it is almost impossible to operate without making some lamp black, since a portion of the oil fog inevitably comes into contact with the very hot edges of these brick. This condition is avoided in the checkerless type carburetor, as there are practically no extremely hot surfaces in this arrangement.

A few statistics on this system from an operating point of view are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Ignition Arch Unit</th>
<th>Checkered Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature at beginning of oil run</td>
<td>1,500°F.</td>
<td>1,935°F.</td>
</tr>
<tr>
<td>Highest Temperature</td>
<td>1,710°F.</td>
<td>1,960°F.</td>
</tr>
<tr>
<td>Temperature at end of oil run</td>
<td>1,565°F.</td>
<td>1,480°F.</td>
</tr>
<tr>
<td>Time in seconds after beginning of oil run that highest temperature is reached</td>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td>Time of oil run in seconds</td>
<td>76</td>
<td>76</td>
</tr>
</tbody>
</table>

As indicated from the above data, at the beginning of the oil run, operating with a checkered unit, the temperature is extremely high and drops down quickly until it reaches the lowest point at the end of the oil run.

With the checkerless unit the conditions are somewhat more favorable. The temperature at the start of the oil run is within the range of efficient oil cracking, it then rises slowly to its high point, which is still below the high point in the checkered unit. This point is not reached until the run is more than half over.
The temperature then drops slowly to the end of the oil run, but is still higher than when the oil run first started. This is a better condition.

Oils as low as 10° Baume have been used with this system. For many reasons the method is somewhat more suitable, especially for the smaller plants, than the other methods described in the following pages. The other systems also have their operating advantages that are not afforded by this one.

**OPERATING RESULTS * SEMET-SOLVAY SYSTEM**

Some typical operating results from a plant making from 1.5 to 3.0 million cubic feet of gas per day are as follows.

<table>
<thead>
<tr>
<th>Oil</th>
<th>Specific Gravity</th>
<th>Deg. A.P.I. @60° F.</th>
<th>22.35</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Viscosity @ 122° F.</td>
<td>37.0 Saybolt Furol Secs.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pour Point @97°OF.</td>
<td>Flash Point @330°F.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fire Point @383°F.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conradson Carbon</td>
<td>4.65%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sulphur</td>
<td>.51%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Asphalt</td>
<td>9.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B.t.u. per gal.</td>
<td>145,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recoverable B.t.u.</td>
<td>95,000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heavy Oil</th>
<th>Oil</th>
<th>Gas Oil</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator Fuel</td>
<td>4.01 gals.</td>
<td>26.91 lbs.</td>
<td>2.86 gals.</td>
</tr>
<tr>
<td>January</td>
<td>17.47 lbs.</td>
<td>3.20 &quot;</td>
<td>27.49 &quot;</td>
</tr>
<tr>
<td>February</td>
<td>18.36 &quot;</td>
<td>3.10 &quot;</td>
<td>27.67 &quot;</td>
</tr>
<tr>
<td>March</td>
<td>23.23 &quot;</td>
<td>3.10 &quot;</td>
<td>27.67 &quot;</td>
</tr>
<tr>
<td>April</td>
<td>16.97 &quot;</td>
<td>3.21 &quot;</td>
<td>25.85 &quot;</td>
</tr>
<tr>
<td>May</td>
<td>16.86 &quot;</td>
<td>3.50 &quot;</td>
<td>26.11 &quot;</td>
</tr>
<tr>
<td>June</td>
<td>16.38 &quot;</td>
<td>3.59 &quot;</td>
<td>26.27 &quot;</td>
</tr>
<tr>
<td>July</td>
<td>15.44 &quot;</td>
<td>3.71 &quot;</td>
<td>25.31 &quot;</td>
</tr>
<tr>
<td>August</td>
<td>16.34 &quot;</td>
<td>3.75 &quot;</td>
<td>26.88 &quot;</td>
</tr>
<tr>
<td>September</td>
<td>14.30 &quot;</td>
<td>3.94 &quot;</td>
<td>26.71 &quot;</td>
</tr>
<tr>
<td>October</td>
<td>16.17 &quot;</td>
<td>3.79 &quot;</td>
<td>26.19 &quot;</td>
</tr>
<tr>
<td>November</td>
<td>14.59 &quot;</td>
<td>3.95 &quot;</td>
<td>25.04 &quot;</td>
</tr>
<tr>
<td>December</td>
<td>15.71 &quot;</td>
<td>4.01 &quot;</td>
<td>25.16 &quot;</td>
</tr>
</tbody>
</table>
Fig. 2—One Inch Hydraulic Operated
Double Piston Valve

Fig. 3—Diagram for Connections to Oil and Steam Purge Valve
THE UNITED GAS IMPROVEMENT METHOD

This method has been in use by some of the largest gas plants in the United States for ten or more years, and for such continued operation must have been successful and entirely satisfactory. There are one or two features of the system that are similar to the Semet-Solvay arrangement but the main advantages of each system are somewhat different.

It might be said that this method is more applicable to plants that are so situated geographically that they can utilize refinery wastes and the heaviest of oils, regardless of their carbon content.

The equipment necessary, along with the changes, required for this system, is as follows:

(a) Terzian pier in carburetor in place of checkerbrick.
(b) Oil Spray in generator.
(c) Changes to existing oil spray in carburetor.
(d) Marginal Blast system.
(e) Cleanout doors at bottom of carburetor and superheater.
(f) Necessary oil piping and valves.
(g) Necessary steam purge piping and valves.
(h) Necessary hydraulic piping.
(i) Enlargement of cleanout door on three-way valve.

A sketch of a typical generator with Marginal Blast bustle pipe is shown at the end of this description.
A detailed description of the changes and new equipment outlined on the previous page is as follows:

(a) Terzian Pier in carburetor.

All checkerbrick are removed with their supporting arches, and in the center of the carburetor is installed a cylindrical pier in proportion to the diameter of the unit, which is about seven feet high. This pier quite naturally gets hotter than the walls of the unit on account of it being in the direct path of the blast gases. This piece of refractory serves as an igniter to the blast gases and performs the same function as the Ignition Arch of the Semet-Solvay method. Since the carburetor is an empty shell exclusive of the pier, the operation should be quite similar to the Semet-Solvay arrangement with minor advantages or disadvantages one way or the other.

(b) Oil spray in the generator.

This system uses a patented, horizontal type, hydraulically operated oil spray that disappears into the sides of the unit when it is not injecting oil. When the oil is being injected it pushes itself out so that the nozzles are approximately over the center of the fuel bed. This sprays a conical spray of oil so that none will impinge upon the walls of the unit, and not all go on the center of the fire. This injector is installed directly under the operating floor, for ease of repair, and maintenance.

(c) Changes to existing oil spray in carburetor.

The present oil spray in the carburetor if of a reliable design will be converted to a nebulizing type and left in the top of the unit spraying down, so that none of the oil will impinge, if possible, upon the walls of the unit or on the pier.
(d) Marginal Blast system.

The heart of the entire U.G.I. system is the marginal blast, which is a patented feature. In this arrangement a large bustle pipe is installed around the outside of the generator shell. Connections or ports are run through the shell and lining in an inclined fashion. (See sketch at end of this description). The bustle pipe is connected through a hydraulically operated gate valve of the conventional type to the blast main. The air that is fed through the marginal blast ports, is supposed to pass into the fuel bed just below the top. This air takes the place of the secondary or carburetor air and in being blown in below the top of the fuel bed tends to give much greater combustion in this zone, causing the top of the fire to be much hotter than with the conventional system of just blasting through the bottom. This very hot condition of the top of the fuel bed enables the carburetion as well as the reforming of oil on the fire, and none in the carburetor. The oil spray is available in the top of the carburetor and can be used if necessary.

It is usual practice for all the oil to be put on top of the fire when operating with extra high coke content oil, and the carburetor used only when using a light or low carbon oil.

The admission of the air near the top of the fire does not necessarily burn all of the oxygen or completely react with the carbon, some of this air is available for burning the producer gas later on in the set for heating the next two units, the carburetor and superheater. It also serves to keep the gas-way scurfed of deposited carbon, and by so doing allows the carbureting of the oil on the top of the fire. Without some means of burning off carbon in the gas-way it would soon reduce in size to a point that would severely affect the operation of the set.
(e) Cleanout doors at the bottom of the carburetor and superheater. With the pier obstructing the center of the carburetor it is necessary to install two quick opening cleanout doors in the bottom of this unit. These are installed opposite each other if possible and are flush with the floor as in the Semet-Solvay system. Only one such door is installed in the superheater.

(f) Necessary oil piping and valves. It is usual practice to install all new valves including the hydraulically operated ones when a new system is installed. All piping has to be changed to accommodate the new arrangement.

(g) Necessary steam purge piping and valves. Steam purge lines are installed for all equipment needing such. A low pressure steam purge, is so arranged with hydraulically operated valve, that the bustle pipe of the marginal blast system is flooded with steam each run. This keeps this part of the equipment free of oil vapors, and acts as a purge to prevent explosive mixtures being in the pipe. This valve is connected with the stack valve, and operates when that valve is closed.

(h) Necessary hydraulic piping. Change will have to be made in the hydraulic control system to accommodate the new equipment.

(i) Enlargement of the cleanout doors on the three-way valve. As with the Semet-Solvay system this change must be made if a lot of time is to be saved in the cleaning of this valve. It is usual practice to clean this valve each day.
A sketch showing the arrangement of an average set-up for using heavy oil with the U.G.I. system, along with several pages of typical operating results furnished by the United Gas Improvement Company are included on the following pages. A cross-section sketch of a generator with the Marginal Blast arrangement is also included.
## APPENDIX A

**August 15, 1930**

<table>
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<tr>
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<th>50-Gr. Direct</th>
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## U. S. I. MARGINAL BLAST

### PLANT RESULTS

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<th></th>
<th>Marginal Blast, on fire</th>
<th>Marginal Blast, on fire</th>
<th>Marginal Blast, on fire</th>
<th>All oil on Car-</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
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<tr>
<td>Size, internal diameter, and type of Generator</td>
<td>9 ft. Self- Clinkered</td>
<td>5 ft. Hand- Clinkered</td>
<td>9 ft. Hand- Clinkered</td>
<td>9 ft. Self- Clinkered</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Number of days</td>
<td>16 Full time</td>
<td>18 Part time</td>
<td>6 Full time</td>
<td>61 Full time</td>
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<tr>
<td>Operating time</td>
<td>(16 to 18 hrs./day)</td>
<td>(16 to 18 hrs./day)</td>
<td>(16 to 18 hrs./day)</td>
<td>(16 to 18 hrs./day)</td>
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<tr>
<td>Total make during period, M. cu. ft.</td>
<td>176,692</td>
<td>13,593</td>
<td>17,400</td>
<td>306,769</td>
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<td>Make per set day, M. cu. ft.</td>
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<td>1,010</td>
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<td>0.675</td>
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<td>27.2</td>
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<tr>
<td>Oil to 170⁰</td>
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<td>3%</td>
<td>1%</td>
<td>2.6%</td>
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<td>200⁰</td>
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<td>235⁰</td>
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Sketch of a Typical Generator with Marginal Blast Arrangement for Heavy Oil
APPENDIX B

NO.1

Above is shown an arrangement of tank pumps, heaters, and connections to water gas set, which is in use in a plant capable of making 80,000,000 cu ft of gas per day. The oil is of high viscosity and is handled at 200°F. The oil is heated in the tank by circulation through heater B (external to the tank) by pump B. Pressure at atomizer is 100 psi. Temperature of oil in tank 155°F. Temperature of oil at outlet heater D 180°F. Pressure at atomizer 190°F to 200°F.

NO.2

Another arrangement of external heater for tankage, with provision for recirculation of oil back to the tank from generator house main system.

NO.3

NO.4

An arrangement for heating oil in the tank by means of steam coils within the tank and secondary heater on inlet to pressure pumps. Same pressures and temperatures maintained as in NO.1 capacity of plant using this - 15000 M per day.
THE WESTERN GAS CONSTRUCTION CO.

HEAVY OIL SYSTEM

Of the three systems available for the utilization of heavy oils at the present time, the one offered by the Western Gas Construction Co. requires the least amount of new equipment, for the set proper. The oil handling equipment for supplying the set with oil is the same for any one of the different methods.

The equipment necessary, along with the changes required for this system is as follows:

(a) Installation of "Reverse Blast" line to superheater offtake.

(b) Installation of "Reverse Blast" stack off back-run pipe.

(c) Installation of oil spray in generator.

These are all the major changes necessary to the average water gas to bring the "Reverse Blast" system into operation.

The empty carburetor is not used with this system on account of the fact that all the oil is sprayed in the generator, and any carbon that has a tendency to settle out, will do so in that unit and be consumed, either in the form of blue gas or blast gas.

(a) Installation of the "Reverse Blast" line to the superheater offtake.

A line from the blast main is connected through a hydraulically operated gate valve to the top of the superheater. This allows a portion of the air that is fed to the generator fire to be passed through the hot superheater and carburetor, thereby scouring off any deposited carbon that may have been left by the oil vapors in the gas. This air after passing through the aforementioned units then passes down through the fire and out the "Reverse Blast" stack. This stack is run out of the vertical section of the back-run pipe, or from the bottom of the generator.
(b) Installation of "Reverse Blast" stack off back-run pipe.

As mentioned in the foregoing paragraph the gases from the bottom of the generator during the Reverse Blasting must be cared for by an additional stack. For this purpose a new stack must be erected coming directly from the bottom of the generator or off the back-run pipe.

The old type of set using plain up-run and down-run must be further changed by adding another valve between the superheater and the wash-box in order that the blast air will not have a tendency to relieve itself to the relief holder through this piece of equipment.

(c) Installation of an oil spray in the generator.

Any type of spray suitable for installation in a generator will serve the purpose.

These are all the major changes necessary to the average water gas set in order to utilize the "Reverse Blast" arrangement.

The "Reverse Blast" system is patented by the Western Gas Constructing Co.
Since the underlying principles are the same for all three methods of water gas operation with heavy oil, this discussion will be generalized in order to cover the fundamentals and peculiarities of each of the three under one heading.

In the operation of any of the arrangements it should be kept in mind at all times just what one wishes to accomplish with his heavy oil installation, for there are many factors to be considered in each direction. Under the average condition in New England, the purpose of such an installation has been to sacrifice oil for solid fuel to the economic limit. This may not be true for any other section, and companies operating elsewhere may have to operate entirely differently. Doubtless some companies will find it more profitable to utilize such products only for carburetion purposes, and still others may have entirely different schemes in mind.

The operating estimates on a yearly basis given between pages 444 and 58 give an idea of how the utilization of heavy oil appeared to a medium sized New England gas company. In view of the fact that the purification facilities of that company were not adequate to take care of Bunker "C" oil with its usual high sulphur content, it can readily be seen that it was to the advantage of that company to install equipment to use medium heavy oil of low sulphur content. This type of oil happened to be available on the market. The equipment to handle this oil would very easily handle Bunker "C" oil when the expenditure for new purification is warranted.
As coke was the premium fuel in the gas making process with this company, the reforming process was of prime consideration since with it cheap oil could be made to replace much higher priced coke.

A group of curves entitled "Comparison Curves" is given on page 59. This series of curves enables quick determination of operating procedure under heavy oil. Knowing the delivered price per gallon of oil of any of several gravities, and the delivered price of coke, whether or not reforming should be resorted to is easily determined. An example of such a determination is as follows:

Consider an oil of 22° A. P. I. selling (delivered) at 4.0 cents per gal. By following the 4.0% line until it strikes the line of gravity it will be seen when read on the scale to the left that this represents a value of 34,400 B. t. u per cent. The coke value corresponding to this figure is approximately $7.85 per net ton delivered. Any coke price below this level of course means no reforming, any above represents a potential saving.

In order that the operating procedure be taken up in the logical order and least confusing form, the discussion of the various observations and variables, relating to the set proper, will be considered in the following order:

THE BLASTING PERIOD
THE BLOW-RUN PERIOD
THE UP-RUN PERIOD
THE BACK-RUN PERIOD
THE FINAL UP-RUN PERIOD
THE BLOW-PURGE PERIOD.

The set being ready for operation, it is assumed that a fire has been going in the generator for a number of hours. The unit has had a
THE BLASTING PERIOD.

After the water gas generating equipment has been converted to use heavy oil and the set is ready to be put back into service, there are many considerations to be taken care of. These are very much the same as those in putting a boiler back on the line. All complementary equipment is to be checked for operation, all valves operated several times to make sure there are no tight places, and the equipment checked from every conceivable angle.

In starting up a new set, it is general practice to bring the unit up to temperature gradually in order to avoid undue strains in any portion of the different sections. Some of the larger gas companies do not follow this procedure as closely as do the smaller plants, on account of the idle time involved. A gas set in one of these large plants will only run a predetermined length of time, regardless of the condition of the refractory. It will then be taken out of service and relined again.

In the smaller plants, the operating period of a lining is an important factor, so much so that in recent years a carborundum lining has been developed that allows many times the number of operating hours as do the clay and firebrick type. It is not uncommon for one of these linings to run 10,000 operating hours, against 1,500 to 2,000 hours for a firebrick lining. After the fire in the unit is burning evenly the set is turned on.

These carborundum linings cost several times as much as the cheaper ones but their cost is in most cases offset by the cost of renewing the latter type several times. During the peak load season it is not best to have a set out of service for a new lining if possible, and the carborundum linings permit a better timing of such jobs.

The set being ready for operation, it is assumed that a fire has been going in the generator for a number of hours. The unit has had a
chance to heat up to three or four hundred degrees in the preheating period, depending upon the length of that period. The temperature in the generator will run as high as 2,500° F. in the carburetor 1,900° F., and the superheater 1,500° F. in operation. From these it will be seen that the unit is still comparatively cold at the time of starting it.

The set should be idled in starting and the allowed to approach its optimum operating temperature after several hours.

The turbo-blower is started, and the generator blast valve opened, the regulating valve for the generator air is adjusted to give about half the amount of air ordinarily used for maximum capacity. This blasting is allowed to continue for at least one and one half minutes, after which time the secondary air valve is opened. Through the sight-cook on the top of the carburetor it can be ascertained when the blast gas in the unit has been ignited. In case that the gases show no signs of burning the steam purge line to the base of the generator should be turned on, thus admitting a small quantity of steam for the generation of blue gas. This blue gas is about three times as rich as the blast gas, (300 B.t.u. per cu.ft., against 100 for blast gas) Very quickly the gases in the carburetor should ignite, and when they burn steadily the set is then well on its way toward doing useful work.

After the flame in the unit is burning evenly the steam to the base of the generator should be turned off and the carburetor watched closely to make certain that it does not go out again, in which case the procedure is repeated.

In view of the fact that the rapid combustion of the coke in the generator produces very high temperatures in this portion of the set, it is considered good practice to blast the unit not more than four minutes during any single cycle. This practice will prevent the formation of considerable clinker, and serve to get the set started.
properly.

If a stubborn clinker is formed in the first few runs, it will greatly hinder the operation of the set for the rest of the day, or until the next cleaning period.

After the allotted time for the first blasting period, the up-run is begun. It is customary to operate the set by hand control for the first three or four runs after starting up, even if the set was idle only a few hours. The operation of the set during the different parts of the cycle are taken up later in their logical order.

On the second blasting period the generator air should be increased slightly, the same procedure followed in lighting the carburetor as during the first blow or blasting period. After the second run the blast gases will usually ignite without any attention whatever.

It is usual practice to start up a set, after a long period of idleness, without a waste-heat boiler, as it is easier in several respects to get the set properly regulated without this unit.

After several runs have been made and the temperature of the set is increasing gradually, the amount of generator air should be increased little by little, until the maximum ordinarily used is reached. This should require about three or four hours, after which time the set may be operated as though it had never been out of service.

When the proper balance is reached, an Oresit analysis should be made of the blast gases at the top of the superheater. The carburetor air should be adjusted to give the best condition, from these analyses. A good condition is reached when the blast gas will show 19.0% CO₂, 0.0% CO and a very low percentage of excess oxygen. This condition is not at all hard to attain, and when once reached will remain fairly constant, until operating conditions shift.

The test of the blast gases should not be made before the third run
after a cooling, thereby giving the new fuel sufficient time to heat up to the generator temperature.

The first few seconds of a blasting period finds the fuel bed in a much colder condition than at the end of the blast. When this period begins, as a result of this chilled condition, the quantity of combustible blast gas leaving the generator is much less than at the end of the blow. For this reason the admission of secondary air is regulated to reach maximum opening about fifteen seconds after the valve begins to move.

With the admission of the secondary air graduated, only enough is passed to burn that quantity of gas generated. This prevents the cooling effect that excess air would have. As the blast progresses the quantity of carbon monoxide liberated by the fuel bed increases, and the increase in secondary air should be just enough to burn this amount. It is very easy to fulfill this condition if the air valve was designed to be so operated.

In case that the valve does not contain an adjustment it is very easy to install a needle valve in the line, shunted with a check valve that will serve the purpose very nicely.

In heavy oil operation with the Semet-Solvay system, there is installed, as shown in sketch of a water-gas generator, so equipped, that which is known as the carburetor scouring arrangement. As described in the detail of this arrangement, it comprises a manifold near the bottom of the unit which is connected through a gate valve, with graduating mechanism, to the blasting main and the bottom of the carburetor. The connection to the interior of the shell is made through a special quick opening port. In order to burn off the deposited carbon, a small amount of air is admitted through these ports during the blasting period. This is usually delayed for half an hour after starting a set up to allow the
bottom of the unit to get hot enough to burn when air is supplied. After this period the scouring air valve should be regulated to rise slowly and reach its full opening about the end of the blasting period.

If this air is allowed to introduce an excess of air it will cause a lengthening of the blast period, because this cooling is very near the control thermocouples.

A group of sensible heat curves is given on page 113. These curves enable rapid calculation of the amount of heat saved or lost by the blows becoming too long or short.

A definite amount of heat is required each blasting period to bring the temperature of the refractory of the cracking units up to their proper level. There is an economical time in which this phase of the operation should be done. With the proper regulation of the generator, carburetor and scouring air (in the case of the Semet-Solvay system) it should be possible to replace the heat absorbed in the gas making portion of the cycle in one minute and thirty seconds.

From the Sensible Heat curves, if the usual one and one half minute blow happens to increase to two minutes, we have a sample calculation such as the following.

Assume that the waste heat boiler is in service and that the stack temperature is 450° F. and that the atmospheric temperature is 70° F. giving a differential of 380° F. Assume also that the unit is a 10" set, then the total blast gas leaving the stack will average about 15,000 cu.ft. per minute, (generator plus carburetor air). From the curves, for a temperature differential of 380° and at 15,000 cu.ft. per min. the heat loss is 115,000 B.t.u per minute.

\[
\text{then } \frac{15 \times 115,000}{24 \times 115,000} = \frac{172,500}{230,000} = 75,000 \text{ B.t.u.}
\]

This represents a loss of 57,500 B.t.u. per run. Over a period of one day fuel cost...
when as many as two hundred or more runs will be made this amounts to about 900 lbs. of coke per day, which is quite a waste. In one year's time this would with coke at $8.00 per ton amount to about $1,300.00.

With the United Gas Improvement system, the operation is quite similar to regular operation and that just described, although this arrangement does not use scouring air in the bottom of the carburetor.

The Marginal Blast manifold takes the place of the carburetor air admission. The regulation of the system is somewhat different from the case where the air is admitted in the connection between the carburetor and generator, or where it is admitted in the top of the first mentioned unit.

The Western Gas Construction Company's "Reverse Blast" system whereby the air is admitted from one end of the set to the other and then reversed, quite naturally operates unlike the other two methods. The reverse blast can be so arranged as to come after the regular up-blast or before it. This period usually comprises about one third of the total blasting period. The reverse blast gases are taken from the set by a stack coming out of the bottom of the generator.

There is a peculiarity about the reverse blast system that seems somewhat against reason, but which is proven in practice. With the blast of air passing through the carburetor and superheater and becoming highly superheated and then from the top of the fuel bed downward, it would seem offhand that an intensely hot condition would be created in the bottom of the fuel bed. This it would seem would soon burn out the grates, but such is not the case. About the only explanation available is that the carbon dioxide formed near the top of the bed of coke is reconverted in passing through this intensely hot mass of carbon to carbon monoxide, and in so doing absorbs heat from the bottom of the fuel bed.
If this be the case then there are obviously two objections to such a system, the first being that the reverse blast gases are not available for heating the carburetor, superheater and waste heat boiler and, secondly the potential heat that is lost in the form of carbon monoxide.

All of these factors must be taken into consideration if a true picture of the situation is to be had. For example, if 30% of the waste heat steam is lost on a ten foot set, and if 45 lbs. per M.C.F. is considered average generation by the waste heat boiler, we have the following:

\[ 0.30 \times 45 = 13.5 \text{ lbs. per M.C.F.} \]

For 600,000 M.C.F.:

\[ 13.5 \times 600,000 = 8,100,000 \text{ lbs. steam.} \]

\[ @ 50\text{f} \text{ per M. lbs. 8,100,000 lbs.} = \$4,050 \text{ per year.} \]

Such a loss in steam would severely handicap a financial set-up under these conditions.

Since the blasting period is that period in which there is the greatest chance for loss in efficiency, it deserves very close checking at frequent intervals in order to realize the greatest economy from a water gas set.

The reactions taking place during the blasting period as given by Jerome J. Morgan in his Vol. No. 1 of Manufactured Gas are as follows:

\[ \text{C} + \text{O}_2 = \text{CO}_2 + 174.530 \text{ B.t.u.} \]

\[ \text{C} + \text{CO}_2 = 2 \text{CO} - 70.910 " \]

\[ 2 \text{C} + \text{O}_2 = 2 \text{CO} + 103.620 " \]

\[ 2 \text{CO} + \text{O}_2 = 2 \text{CO}_2 + 245.440 " \]
THE BLOW-RUN PERIOD.

In water-gas operation with the light oils the blow-run operation is resorted to at times for any one of several reasons that may tend to make for better economy, or in some cases for mechanical or thermo-dynamic reasons. In heavy oil operation where reforming is resorted to, if it is important to maintain a definite gravity, as is the case of the company making only water gas, the blow-run, or blow-purge or both must be used, in order to keep the gravity of the gas within the allowable limits.

In companies making only water gas, the gravity of the distributed gas will run about .65, this is in contrast with a coal gas company which will send out .65 spgr. gas. The combination company usually depends upon coal gas for its base load, taking care of the peak demands with water gas. Under such conditions the gravity of the water gas is of little consequence since it represents such a small portion of the total gas.

As mentioned elsewhere in this paper, when oil is injected into the generator during the back-run and its vapors forced through the incandescent bed of carbon, these vapors have a strong tendency to completely break down into their constituent parts, hydrogen and carbon. During this portion of the cycle and for several seconds after full back-run steam is on the hydrogen content of the gas will run as high as 70%. The specific gravity of hydrogen is .0696 and it can be seen that such a quantity of such a light constituent will reduce considerably the gravity of the gas as a whole.

There are three ways by which this unbalanced condition may be compensated for, namely; Blow-run, Blow-purge and with purification air. The blow-run will be taken up here, the blow-purge in its logical order and under chemical control will be discussed purification air.

As mentioned under the discussion of the blasting period of the operating cycle, as the blow progresses and the generator fire becomes
hotter and hotter, the liberation of carbon monoxide increases. Advantage is taken of this condition by allowing the generator blast valve to remain open with full blasting pressure, and forcing these lean gases into the foul gas main and the relief holder. This blast gas will average 100 B.t.u. per cu. ft. Its main advantage is in gravity regulation.

The heating value of the blow-run gas was derived from the coke of the generator fuel bed. Since the heavy oil operation, as has been said before, is primarily a means of sacrificing oil for solid fuel for greater economies, the blow-run alternative is not the most logical means of rectifying gravity differences.

In case that coke happened to be the cheaper fuel, with heavy or light oil used solely for carburation, then the blow-run would be the most advantageous.

The duration of the blow-run is very seldom over twenty seconds under any kind of operation.

When the price of oil on a B.t.u. basis is higher than coke or coal for generator fuel, the blow-run operation becomes uneconomical, since for a gas of 530 B.t.u. per cu.ft. and only 100 B.t.u. being supplied by the blow-run gas, 450 B.t.u. must be supplied in the form of oil gas, the higher of the two.
THE UP-RUN PERIOD.

After the blow-run, if such is used, comes the up-run, which is that portion of the cycle wherein steam is admitted (usually low pressure accumulator steam) at the base of the generator. This passes in an upward direction through the incandescent bed of carbon, allowing maximum opportunity for the steam to combine with the carbon in the formation of blue gas.

The reactions taking place during the up-run according to Morgan are as follows:

\[
\begin{align*}
C + H_2O &= CO + H_2 \\
C + 2H_2O &= CO_2 + 2H_2 \\
CO + H_2O &= CO_2 + H_2 \\
C + CO_2 &= 2 CO = 70,910 \text{ Btu} 
\end{align*}
\]

The theories underlying these reactions are discussed in Mr. Morgan's Volume 1, pages 211 and 212.

The gas being formed in these reactions, in light oil regular operation passes from the generator to the carburetor, where oil is injected in the form of a mist from a spray located in the top of the unit. The oil vapors along with the blue gas passes down through the carburetor, which partially cracks the vapors in their travel to the superheater. The amount of cracking done in the carburetor depends upon the heat available in the unit. There is doubtless considerable cracking done in the case of the checkered type of carburetor, but much less with the empty type.

The advantages and disadvantages of the two types of carburetors are as follows:

The Checkered Unit.

A checkered carburetor can be used as such with light or gas oil only. (The Western Gas heavy oil system uses such a carburetor
but sprays all the oil in the generator, in which case the carburetor becomes a primary superheater.) There is no disputing the contention that a properly checkered unit has minor advantages over the empty type in light oil operation. This statement has been the source of argument for many years, and since there are so many variables in the manufacture of gas it will possibly never be proved conclusively.

The checkered unit offers considerably more cracking surface, and should theoretically give better transformation of the oil to gas, were it not for the feature detailed before concerning the fact that the bricks in this unit having sharp edges will be found to expose a portion of their surface, for a limited time, at temperatures above those most suitable for oil cracking. This has a tendency to form a small amount of lamp black under the best regulation.

The above condition is unavoidable under present conditions, since the temperature of the carburetor is secondary to the superheater temperature in importance.

With heavy oil operation if any of the oil is injected into the checkered carburetor the unit will become clogged beyond further use in several days.

The Empty Unit.

The empty carburetor does not offer but a very small percentage of the amount of cracking surface as the checkered unit, nor does it contain the potential heat at the beginning of the oil run. Nevertheless, there is sufficient heat in the wall of the unit to volatilize the oil. The cracking is left to be done by the superheater, wherein the temperature is more suited for such work. Such an arrangement creates the least amount of lamp black. There is less naphthalene made in a set using an empty unit on account of the fact that the formation of this constituent
is fostered to a greater extent in the temperature range in which lamp black is formed. This high temperature is not as prevalent in an empty unit as in the checkered type.

The up-run period varies in length in accordance with the length of the steam cycle, and with different conditions. It is sometimes necessary to regulate the length of a particular portion of the cycle in accordance with conditions rather than efficiency. On account of the clinker forming tendencies of some fuels an operating cycle will have to be changed considerably in order that the fires may be cleaned with any ease.

It is usual practice to begin the injection of the oil to the carburetor just as soon as the up-run has begun. This is done in order to take advantage of the stored heat in the wall and elsewhere in the volatilization of the oil, before the blue gas from the generator has a chance to cool it.

The up-run will consume about 50% of the total time allotted for the steam portion of the complete cycle, but the rate of admission of the steam is not as high as for the back-run. The rate of steam flow will average between 2 and 3 lbs. per sq. ft. of grate area per minute.

As mentioned elsewhere in this paper the rate of oil injection is to be considered and regulated for the best operating condition of each plant.

The analysis of the blue gas made during the up-run is the most reliable guide for the regulation of this part of the cycle, the interpretation of an analysis is covered under Chemical Control of the Set a later section.
THE DOWN-RUN — THE BACK-RUN

The old conventional water-gas generating set employed what is known to the gas operator as the down-run. This was merely the reversing of the flow of steam to the generator from the bottom upward, to the top and downward. To do this necessitated the synchronization of three valves, a three-way steam valve, and two valves connecting the top and the bottom of the generator (hot valves as they are usually called). These two valves are usually connected together mechanically, the steam valve being a separately operated unit. The steam on the up-run is introduced in the conventional way and then the hot valve at the bottom of the generator opens and the steam valve reverses, sending the steam to the top and forcing the gas out the bottom.

In this arrangement the blue gas generated must pass through the carburetor and superheater in getting out of the set, on both up and down runs.

The Back-Run.

It occurred to a Mr. D. J. Young of Tacoma, Washington, several years ago that the stored heat of the superheater could be used to advantage in transforming the saturated and very moist steam ordinarily fed to the generator, to highly superheated steam. In doing so considerable heat would be spared the top of the generator fuel bed that could be used to advantage in making gas. To do this he introduced the steam at the top of the superheater. It then had to traverse this unit and the carburetor before getting to the fuel bed of the generator. By the time it reached this spot it was highly superheated steam and did not absorb from the bed of carbon nearly the amount of heat absorbed by the up-run. The result of this allowed a large increase in the flow of steam to the generator on the back-run
without causing additional cooling effect. This naturally resulted in increased capacity and also thermal efficiency.

Before this patented scheme was commercialized to any extent numerous experiments were conducted to determine the effects upon the machine of this operation and some of the interesting facts established were as follows:

The steam is highly superheated in the course of its travel through the first three or four feet of the superheater, absorbing very little heat after that distance.

Water may be substituted for steam by installing sprays in the top of the superheater. This, of course, absorbs more heat than does steam operation but is entirely feasible and practicable.

Plant effluent may be disposed of by injecting it as water in the top of the superheater.

The passage of the steam through the checkerbrick has a tendency to scurf a portion of the carbon, thereby lengthening the life of these brick and reducing time lost replacing them, since they will last considerably longer.

The thermal efficiency of the set had been increased.

The capacity of the set had been increased roughly twenty-five percent.

The formation of naphthalene was reduced in the finished gas.

The back-run apparatus consists of a steam line to the top of the superheater, a three-way valve with the common connection coming out the bottom of the valve box for connection on top of the wash box and the two other connections, connecting the offtake from the superheater and the bottom of the generator. A special gas-way must be constructed from the bottom of the generator to the three-way valve.
Since this valve carries no blast gases it is not subjected to the
high temperatures and accompanying troubles of the old hot valves.
The valve is water cooled; the water from the sprays supplying the
make-up water for the wash box.

The back-run will ordinarily comprise about 45% of the total
steam cycle time, but the steam flow being between 4 and 5 lbs. per
sq. ft. per minute, will run the percentage of total steam through
this course above fifty per cent.

The chemical limitations upon the back-run are given under the
heading of "Chemical Control."

It is during the back-run portion of the cycle that the reforming
process is carried on.

As the back-run and steam valves change for this portion of the
cycle, through a connection in the hydraulic system that may be
worked in any one of several ways, a secondary steam valve remains
closed as long as the generator oil is being injected. The secondary
valve is by-passed by a two-inch line with a hand-control valve.
Throttling of the steam through this small line during the oil
admission period reduces considerably the velocity of the gases
through the fuel bed. As stated before, this gives the carbon or
lampblack formed by the contact of the oil with the extremely hot bed
of carbon, more time to adhere to the coke or settle out as the case
may be.

After the oil has been injected, the secondary steam valve opens
and allows full flow during the remainder of the back-run period. In
view of the fact that the time for the high rate of flow of steam has
been reduced by the time for oil admission, it is possible to still
further increase this flow and partially compensate for the loss.
The upper limit of 5 lbs. per sq. ft. of grate area per minute can be carried with ease, with reforming.

THE FINAL UP-RUN

After the back-run is over, the base of the generator as well as the back-run pipe connecting the base of the generator and the three-way valve are both full of gas. It would not be safe to start the blasting period from this point since the air enters the bottom of the generator and works in the opposite direction to the flow of steam during the back-run. It is for this reason that a final up-run is made, being nothing more than a purge-run to free the bottom of the generator of gas.

This portion of the steam cycle will amount to about five percent of the total time and the steam flow will be the same as for the regular up-run; namely, between 2 and 3 lbs. per sq. ft. of grate area per minute.

THE BLOW PURGE

The spraying of the oil on the generator fire reduces very quickly the temperature of the carbon in the upper foot or so of its depth, and as a result, the last few gallons that are sprayed come into contact not with white-hot carbon, but in most cases a black area of coke. This condition only exists of course in the center of the fire where the bulk of this oil is directed. As a result, a good portion of the last oil is not entirely cracked or removed from the fuel bed.

Along with the condition mentioned in the preceding paragraph, is the fact that a portion of the carburetor oil invariably finds its way to the floor of that unit. As this is in reality, a tarry portion, it does not encounter temperatures at that point high enough
to volatilize it and allow it to pass away as a gas. From this condition with the condition of the residual oil in the top layer of the generator fuel bed, there is a tendency for these two to cause smoking at the stack during the first few seconds of the blasting period.

In an effort to defeat this smoking each run, advantage is taken of what is known as the blow-purge, wherein the generator blast valve is opened a few seconds prior to the opening of the stack valve. This has the same tendency as the blow-run; that of forcing these tarry vapors that constitute the smoke into the wash-box and to the relief holder.

The blow-purge is more advantageous with heavy oil on account of the fact that it recovers these tarry vapors which would have been lost, and at the same time relieves the smoke nuisance, which is a very important factor to those gas plants unlucky enough to be located in thickly settled communities. It does not relieve the fuel bed of as much potential heat as does the blow-run and allows the heating value of the lean gas to be compensated for by oil which is usually the cheaper fuel, in heavy oil operation.

The blow-purge serves as a gravity compensating medium just as does the blow-run. The length of the blow-purge depends entirely upon local conditions, but on a five minute cycle which is most commonly used, it will not exceed twenty seconds, and sometimes as short as three seconds.

Purification AIR

As mentioned under the heading of the Blow-Run, purification air is a third means of compensating for gravity. This is merely the admitting of air to the suction side of the exhauster. This air will in its course with the gas, pass through the purifying boxes and act
as a revivifying agent to the oxide in the boxes. This scheme is worked in most plants and considerably aids the purification facilities. It will enable a much longer period between cleans, and cut down purifying costs. It requires additional enrichment in the form of oil in the set but usually can justify itself. Three per cent is about as high as this feature can economically be used, the lower limit being 1.8%. Oxide does not respond to revivification in atmospheres containing less than 1.8% by volume of oxygen.

Things have been properly planned and installed, the operation of this equipment is nothing to with gas oil.

For several years after the introduction of many types of equipment, most everyone, from the retailer to those behind the scenes, were afraid that they would not go to see the results. In automatic conditions, gas로서의 석유 [(Gas Engine)] could operate, while the gas supplier finally had to admit that the utilization of this class of raw material was limited. In the gas company's losses parts of the engines were to operate with the oil companies for the heating business.

Since the operation of the equipment and experience, development of the same has only been practically the same for each of the new systems. Upon things moving to light-oil operation to be liquid fuel, and the new phases that have been developed, the time has decreased. The peculiarities of the system will be described in an effort to possibly signify that, which to the younger man, it almost sounds.

In the average plant, only that equipment having worked on oil system exists with the oxygen revivification, as used to any appreciable extent. In some cases, this is being tried,
Operation with heavy oil in a water-gas plant is in every respect like a good workman: with a good set of tools and in his best mind he can make most anything in his line with ease, and do a finished job. But if he is poorly equipped it is a different story; so with this type of water-gas manufacture, if things have been properly planned and installed, the operation of this equipment is as simple as with gas oil.

For several years after the introduction of this type of procedure most everyone, for some reason or other avoided it, excepting those who were rather hard pushed to find new ways and means of cutting expenses. As economic conditions grew darker and oil prices started upward again, some of the gas executives finally had to admit that the utilization of this class of raw material was inevitable if the gas companies in these parts (New England) were to compete with the oil companies for the heating business.

Since the operation of the apparatus and equipment, exclusive of the water-gas set, is practically the same for each of the three systems, those things uncommon to light-oil operation to be watched for, and the new phases that have been developed so far are detailed. The peculiarities of the systems will be described in an effort to possibly clarify that, which to the non-gas man, is almost meaningless.

In the average plant only that equipment dealing with the oil system and with the emulsion handling should be effected to any appreciable extent with heavy oil. In order that everything be given,
each piece of apparatus will be taken in the order that the particular contraption appears in the flow diagram of the plant. See page 112.

A list of the various pieces of apparatus, with comments on each are as follows:

(a) Relief Holder
(b) Condensers or Washer Coolers
(c) Exhausters
(d) Tar Extractor
(e) Scrubber
(f) Purifiers
(g) Meters
(h) Storage Holders.

(a) Relief Holder

One of the hardest worked pieces of equipment in the average gas plant that makes carburized water-gas is the relief holder. This somewhat flimsy structure must serve as a buffer between the intermittent manufacture of the gas and the constant pumping of the exhauster. In the duration of a day's time such a holder may travel many times its height in serving its purpose. Its job does not under ordinary circumstances demand rapid motion, nevertheless it is on the go from the time that manufacture begins until it ends. It is a very vital cog in the wheel and severely alters the operating procedure when it is out of service.

Heavy oil operation does not add any work to the relief holder in the average plant, nor as far as is known effect this structure at all. As a matter of fact the heavy oil fog in leaking through loose rivet holes or other small places of escape, does a very good
job of sealing them up and thereby saves many a cubic foot of gas in a year's time.

(b) Condensers or Washer Coolers

In most plants it will be found that the condensers represent one of the weakest spots in the entire system. They are the source of a lot of trouble and expense but cannot be substituted, for without a considerable outlay of money, the condensing equipment is a vital link in the chain and should be properly overhauled before the installation of heavy oil.

Since it is general practice for the condensers to follow the relief holder in the flow of the gas through the plant, it is quite natural for a portion of the tarry vapors to pass through the relief holder and on to these units. As a result, a considerable part of the tar is recovered here. With light oil operation the vapors that were condensed at this point were very light in nature, and all drain lines or seal lines could be quite small. This is quite the contrary with the heavier tar and such small lines will have to be enlarged and run the shortest path possible to the larger lines of the emulsion system.

It must be remembered that condensers so placed in a system will have only relief holder pressure (minus line loss) at their inlet, and may have several inches vacuum at the outlet. Under those conditions any leaking tubes will allow water into the gas line. Since this water is considerably lower in temperature than the gas, this water will chill the heavy liquid, and in doing so stand a very good chance to plug up the drain line. This would then allow the leakage to fill up the low spot nearest its entrance and in very short time block off the flow of gas to the exhauster, stalling that
unit and causing a shutdown.

As far as is known, it does not require any more cooling water to the condensers with this type of operation.

(c) Exhausters

There are several types of exhausters in common usage these days; namely, the positive displacement type, fan type, and blower type.

It would seem that having to pass through as many as three or four condensers the lighter fractions of the tar would be precipitated, but with the average condensing equipment found in gas plants, this condition is seldom found. Tar then finds its way to the exhauster and still farther into the system.

In the case of the positive displacement exhauster heavy oil tar has practically no different effect than with light oil tar. Due to the higher consistency of this tar it is thought that it affords a better seal and reduces somewhat, slippage at the lower capacities, but this is of trivial consequence. The seals from this unit will have to be enlarged, if the room in which the unit is installed, at any time goes below sixty degrees Fahrenheit. If the exhauster is well protected from low temperatures and the drain lines do not pass through a cold area, the chances are good that nothing need be done and it should operate as smoothly as with light oil.

A multiple stage fan type exhauster is a more fragile piece of equipment by far than the one mentioned above but there are advantages to this type that make it very popular.

Among the advantages of this type of exhauster are as follows:
It is turbine driven.
Occupies less space.
Quieter in operation.
It is direct driven.
Can be overloaded with greater safety.

The outstanding advantage of this type of exhauster as far as heavy oil operation is concerned is its ability to remove a considerable amount of the tarry matter from the gas by its centrifugal action. This tar would ordinarily pass on through the positive displacement type and have to be removed by the next apparatus in line, namely the tar extractor.

This relieves the tar extractor of considerable work and allows it a better chance to remove the still lighter fractions.

In several plants operating with heavy oil and using the positive displacement type of exhauster, the tar extractor becomes plugged so frequently that it is by-passed completely. One plant using the fan type and with a very similar arrangement of apparatus, has not had a bit of trouble with their tar extractor. The cleaning period for this piece of equipment is exactly the same as with light oil operation.

The same suggestions regarding the lines, seals etc. for the positive type of exhauster quite naturally hold for this type.

The blower type of exhauster is the simplest of the three and possibly the cheaper but is not so popular due to its high operating speed and the accompanying troubles of such. It is usually found in the larger plants. This type of exhauster is not as efficient a tar remover as the fan type (multiple) but is much more so than the impeller type.

(d) Tar Extractor.

About the most common type of tar extractor in use in the average water gas plant is the F. and A. type (Pelouse and Audouin). This unit consists of a series of perforated cylinders immersed in water and free to rise with increasing pressure to allow more surface to be exposed.

The gas passes through alternately a cylinder perforated with small
holes and then one of a larger diameter with larger holes. This arrange-
ment affects a velocity change that serves very efficiently to remove the
tarry matter and oil vapors.

As stated in the paragraph under Exhausters these units are quite
frequently by-passed with heavy oil operation, on account of the clogging
of the perforated cylinders.

Electrical precipitators operate as efficiently and trouble free
under heavy oil operation as with light oil.

(e) Scrubbers.

The most common type of scrubber used in the water gas plant is
the shavings scrubber. This is in the true sense an empty shell, thirty
or forty feet in height, with a cross-section ten to twenty times the area
of the gas main connecting it. In this unit is placed a series of slat
type shelves on which is dumped very coarse hard wood shavings.

The gas in passing into this unit reduces its velocity in proportion
to the ratio of the cross-section area of the unit and the main, and under
this reduced velocity passes through the coarse shavings. This allows a
maximum of opportunity for the light oil particles to collide with the
shavings and coalesce into a liquid. There is no perceptible change in
the operation of this unit with the change of oils.

(f) Purifiers.

The operation of the purifiers is in all respects the same with
heavier oil operation, with gas of the same hydrogen sulphide content.
This condition is entirely possible with the medium heavy oils, but out
of the question with those of the Bunker"C" grade.

The frequency of change can be predicted somewhat by an idea of the
sulphide content of the gas that is to be made, but individual cases are
so different in respect to this phase of the operation that it simmers
down as to whether or not adequate facilities existed before the
installation of heavy oil.

As is commonly known the study of gas purification could occupy a considerable portion of a man's life without divulging all of its secrets. Although with close scrutiny and systematic operation regarding purification air and revivification of the boxes in situ, a considerable increase in the hydrogen sulphide content of the gas can be handled with little or no increase of purification costs.

(g) Meters.

Since the purified outlet gas is in most respects identical to gas made with light oil operation there should be no variation in operation of the metering equipment.

(h) Holders, (Storage)

There is one item that possibly should be mentioned with respect to storage holders and that is the accumulation of the distillate commonly known as holder oil. This precipitate appears slightly greater with heavy oil operation and should be watched more closely. It should not be allowed to accumulate where facilities are available to keep it moving.

This product will with a sudden change in temperature re-evaporate and pass off with the gas and condense again in some cool low spot, where it will accumulate and quickly cause a blocked main or service. The blocking is caused by the resinous gum left after the light fractions have disappeared. The seriousness of the above mentioned possibility depends entirely upon local conditions, but is to be watched for.

The most reliable preventative is to keep the storage holders free of this oil.
Blast Air and Stack Temperatures.

SENSIBLE HEAT CURVES
For Determining the Sensible Heat of Blast Gates for Differential Temperatures from 300°F to 500°F.

Haverhill, Mass. May 24, 1933.
J.L.B.
CHEMICAL CONTROL OF WATER GAS MANUFACTURE

The efficiency and economy of most any manufacturing process depends to a large extent upon the intelligent supervision exercised by those in charge. The manufacture of carbureted water gas is a very good example of a process involving a large number of variables that demand the constant attention of someone very familiar with the eccentricities of such units, and one who is able to interpret from chemical analyses just what is going on at most any time during the operating cycle.

The management of the average small gas plant occasionally knows very little of the technical side of the manufacture of the gas that he sells and the sad part of such a situation is that it is very difficult to prove to these men that close supervision of the manufacture as a rule pays handsome dividends.

There are numerous ways and means of cutting corners so to speak in the average plant and sizeable savings are at times staring the unexperienced operator in the face and he is unable to see them.

It is the policy of all the large companies to maintain an elaborate check on practically everything that goes on in the plant from the raw material storage to the outlet of the storage holders and at times even farther.

The management companies operating in the United States have found it very profitable to maintain graduate chemists in their plants, even to the very small ones. In many cases close supervision of the manufacture of the gas has been the means of one of these organizations being able to take over an unprofitable plant and in short order have it on a money making basis.

The chemist of the medium sized gas plant can as a rule secure from the management a sizeable sum each year for research work, and since quite
a bit of his time is more or less his own, with a spark of ingenuity and a little work he should be able to accomplish a great deal in his particular choice or branch of his training.

The extent to which pure chemistry is put in the gas plant depends upon the man, for there are countless problems that are still a mystery and the solving of some of these should bring sizeable rewards.

CHEMICAL CONTROL.

The manufacture of water gas consists of a series of chemical reactions, all of which take place under very high temperature. The regulation of these reactions requires a knowledge of these intricate and variable changes of the elements from one form to another. The numerical accuracy or certainty of these changes will possibly never be known on account of the high temperatures under which they take place.

It is essential of course to have an idea of what is happening and what will happen should conditions shift to another operating plane, which can and does happen on very short notice, not allowing time for lengthy deliberation, as to their cause and remedy.

The chemical control of the manufacture of this gas can be divided into several headings, namely:

The regulation of the blasting period.

The steam admission period, (both up-run and down-run).

The carbureting oil period, (heating value function)

The reforming period and its effects in general.

The purification of the gas.

The finished gas.

Miscellaneous laboratory work.
The regulation of the blasting period.

A close check must be kept on the flue gases from the set in order to minimize these losses. An orat apparatus is sufficient for this work and should be used frequently. The manipulation of the generator and carburetor blast valves will usually give the desired regulation. The presence of any carbon monoxide in the blast gases at the top of the superheater is not desirable, the burning of the last trace of this gas with the least amount of free oxygen possible is naturally the ideal condition. A series of samples taken one after another during one blasting period serves very well for a complete study of the individual blast.

Such a group of tests should be taken for several different runs during a coaling period.

The steam admission period.

The blue gas generated is the same quality for both light and heavy oil operation. About the best guide as to the regulation of the steam input to the set is the percentage of carbon dioxide of the blue gas of the up-run and back-run. It is considered good practice to carry a CO₂ in the up-run gas below 6.0% and that of the back-run below 7.0%. The carbon dioxide content can be increased by increasing the steam rate to the set and may be lowered by the reverse.

It is usually more accurate to base any changes to be made in the operation, as far as the steam admission is concerned, upon a composite sample of several runs rather than a snap sample from any one run.

For the best results the carbon dioxide content of the gases should closely approach the maximum limit. A typical blue gas analysis is given on the following page.
Composite sample of up-run and back-run gas, (blue gas)

<table>
<thead>
<tr>
<th>Gas</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>52%</td>
</tr>
<tr>
<td>CO</td>
<td>4%</td>
</tr>
<tr>
<td>CH₄</td>
<td>39%</td>
</tr>
<tr>
<td>N₂</td>
<td>18%</td>
</tr>
<tr>
<td>H₂O</td>
<td>51.5%</td>
</tr>
<tr>
<td>H₂</td>
<td>2%</td>
</tr>
</tbody>
</table>

100.0%

These constituents will naturally vary from one run to the next but will not change radically except when the balance of the set is altered.

A group of rules for quick interpretation of a blue gas analysis is as follows:

An excess of carbon dioxide shows an excess of steam, poor fuel or an overloaded machine, a cold fire or a shallow uneven fuel bed with dead spots. An excess may also be due to a steam leak in the valves, or incomplete purging of the machine of the blast gas.

A deficit or absence of carbon dioxide, while being an advantage in the finished gas is evidence of too little steam for the temperature of the fuel bed and shows an uneconomical condition of operation on account of the machine being underloaded and not giving its proper output. Very low carbon dioxide is evidence of conditions which produce naphthalene. While dioxide is an impurity and should be kept low, it is not well to crowd it to extinction.

Illuminants or unsaturated hydrocarbons should not appear in the blue gas analysis. If there is a trace of such gases it indicates that there is uncracked oil in the unit and conditions should be checked.

The oxygen content will vary from one or two tenths of one percent to one percent depending upon conditions. Any excess above 1.0% warrants a check-up of the set, although check analyses should be run before becoming alarmed to make certain that the analysis apparatus was not to blame.
From 30% to 40% is the range of the carbon monoxide content. An excess or an amount in the neighborhood of the upper limit mentioned above means a good fire condition. When accompanied with an excess of hydrogen (in the enriched gas, not including the gas made from reforming) it indicates steam mixed with the oil gas. A deficit of monoxide when accompanied with an excess of dioxide and especially an excess of nitrogen, shows an air leak while the gas is still hot.

The hydrogen content will vary from 35% to 55% of the blue gas.

An excess of hydrogen or a percentage in the neighborhood of 55% indicates that a portion is being given off from uncracked oil which is broken up into hydrogen and lampblack. A deficit of hydrogen in the blue gas shows insufficient steam or too little fire; or if accompanied with excess nitrogen indicates an air leak while the gas is still hot.

The nitrogen content of the blue gas should not exceed 10% on a sample taken during the entire duration of the run. An excess of this constituent indicates insufficient purging of the machine, leaky valves, or if accompanied with an excess of oxygen indicates possible leaks in the sampling apparatus.

In obtaining samples of hot gases it should be remembered that as these gases cool they contract and will pull air in the sampling vessel from the water escapement and if care is not taken to prevent such.

There, of course, is no such thing as a deficit of nitrogen.

Theoretically the presence of methane is unlikely in blue gas but due to the errors that will creep in, in a chemical analysis as carried on in the gas plant laboratory, this constituent may appear. With the use of reforming it is possible to get several per cent of methane from the hydrocarbons that remain after the blasting period from the oil.
sprayed on the generator fire.

Blue gas forms the base of carbureted water gas and the close control of its manufacture is imperative for economy.

The Carbureting Oil Period.

The spraying of oil into a carburetor of a water-gas machine containing an atmosphere of blue gas between 1500° F. and 1900° F. is the means of enriching the comparatively lean blue gas to the standard required by the particular state in which the set is operating. The state standard for Massachusetts is 528 B.t.u. per cu. ft. for saturated gas.

This oil being subjected to such high temperatures breaks up into several constituents such as methane, ethane, free hydrogen, the unsaturated hydrocarbons (which in gas plant practice are classified as a group as illuminants) and free carbon. The percentage of these different constituents formed depends upon the operating condition of the set, the temperatures carried, the time of contact with the checkerwork and numerous other variables.

The amount of oil gas formed per gallon of oil injected will vary for different oils and for different conditions. This figure will vary from as low as 45 or 50 to 75 cubic feet per gallon. The heating value of the methane constituent which will run as high as 15% of the finished gas is taken as 1,009 B.t.u. per cu. ft. The value of the illuminant portion is a variable and is usually calculated from a particular analysis. Knowing the percentages of the other constituents of a gas and their heating values and the heating value of the gas, it is simple arithmetic to find the value of the illuminants as a whole. This value will vary from 2,000 to 2,600 B.t.u. per cu. ft.

For the best control of operations a recording calorimeter is
essential, and from this instrument signal lights can be arranged to
give the operator an idea at all times, just how to regulate his oil
for the proper heating value.

The regulation of the heating value of a manufactured gas that is
to be supplied to a town or city is somewhat of a puzzle at times.
The B.t.u. of the gas leaving the plant must at all times be carried
at least five above standard, if standard is to be maintained. This
regulation is quite a guess since it is entirely dependent upon the
atmospheric temperature, operating factors remaining the same. This
loss in B.t.u. is accountable for in the unsaturated hydrocarbon con-
stituent of the gas made. These portions are recovered in the form of
what is known as drip oil or holder oil, depending upon whether it con-
denses out in the pipe lines or in the holders. These oils are amber
colored liquids of approximately .85 sp. gr., very volatile with a
very disagreeable odor. A distillation of a sample of fresh drip oil
(specified fresh because this oil changes its state on standing by a
tendency of the higher temperature fractions increasing) is given
below. The residue or gummy constituent increases considerably on
standing, even sealed from the air or any gas.

| First Drop | 175° F. |
| Boiling Point | 180° F. |
| From 175 to 275° F. | 23.0% |
| 275 to 302 | 17.9 |
| 302 to 347 | 18.3 |
| 347 to 363 | 4.5 |
| 363 to 413 | 21.3 |
| 413 to 423 | 2.6 |
| 423 to 437 | 1.3 |
| 437 to 458 | 3.0 |
| Residue | 2.2 |
| 100.0% |

This oil is used principally in the blending of tars for road
materials and the other processes in which tar is used.
Heavy oil operation does not appreciably affect the production of drip oil nor does it change its physical characteristics. For these reasons drip oil is left out of all calculations concerning the benefits or troubles of operation with heavy oil.

As stated before in this paper, when oil is sprayed into a cracking chamber such as the carburetor it breaks down into gas, vapors that condense in the form of drip oil, and tar, along with a certain portion of free carbon. The quantity of the latter depends upon the type of oil being used and the way in which it is handled.

The amount of an oil expressed in B.t.u. per gallon per M. Cu. Ft. that finds its way into a fixed gas is known as the Oil Efficiency and is the guide used to determine the cracking efficiency of the unit and also as a check on the oil that is being used.

In light oil operation from 98,000 to 108,000 B.t.u. per gal. per M. cu. ft. is considered average and should the results fall below the figure of 98,000 it is reasonable to assume that trouble is at hand or that the oil supplied is falling in quality.

The formula quite often used for calculating the above figure is as follows:

\[
\text{Average B.t.u. of Gas for Day} = \frac{500}{\text{Oil per M. Cu. Ft.}}
\]

This formula is a contraction of the formula:

\[
\frac{\text{Avg. B.t.u.} \times 1,000 - (1,000 - (\text{Gals. Oil per M} \times 70))}{\text{Gals. Oil per M} \times 1,000} = \frac{500}{\text{Oil per M. Cu. Ft.}}
\]

Where 70 represents the cubic feet of oil gas per gal. of oil. Where 300 represents the heating value of the blue gas.

With heavy oil operation, due to the high carbon content of the oil ordinarily used as well as the poor carbureting possibilities of some of the constituents, such as cracking plant tars and the like, it is not usually possible to attain as high oil efficiencies. The
average recovery or percentage will run from 85,000 B.t.u. per gal. per M cu. ft. to 100,000, there being instances of much higher with the selected grades of heavy oil.

This arbitrary factor used mainly for comparison does not hold with heavy oil operation when reforming is done. This is obvious on account of the B.t.u. recovered from the oil sprayed on the generator fire. There are several similar factors used by various operators to give a similar comparison under heavy oil operation; one of these is as follows:

\[
\frac{\text{Gals. Oil per M Cu. Ft.} \times 1,000 + \text{No. of Lbs. Gen. Fuel} \times 100}{\text{Average B.t.u. of Gas}} = X
\]

Any quantity for X below 102 is considered good operation under this formula.

The above formula is based on one gallon of oil being equivalent to 10 lbs. generator fuel, and is purely arbitrary, the result of the calculation being expressed only as a number.

Other companies prefer to use a formula based upon the ratio of the B.t.u. input to the set in the form of coke and oil, and the recovered products of gas and tar expressed as follows:

\[
\frac{\text{Avg. B.t.u. Gas} \times 1,000}{\text{Gals. Oil per M} \times 140,000 + \text{Lbs. Gen. Fuel} \times 15,000} - \text{(RP x Gals. Oil per M x 165,000)}
\]

RP being the percentage of the oil recovered as tar,
165,000 being the B.t.u. of the tar per gallon.

The above formula is a rough fuel efficiency figure and values above 85.0% are considered good operation.

The amounts of two constituents found in the gas resulting from the carburation of oil; namely, methane and illuminants, will vary from day to day. The quantity of methane in carbureted water gas (of a B.t.u. content in the neighborhood of 525 B.t.u. per cu. ft.), will vary from 8.0% to 16.0% while the illuminant portion will range
between 7.0% and 10.0%. The higher the methane content the more stable the gas will be found to be and the higher the illuminant fraction the more unstable.

An excess of methane is the result of a low or dirty fire, too little steam or dirty checkwork, or an overloaded machine. A deficit of methane indicates that the temperatures are too high in the cracking chambers, this being especially so when this condition is accompanied with excess hydrogen.

When a company maintains high pressure distribution or transmission systems of carbureted water-gas it is considered good practice to keep the ratio of methane to illuminants equal to or above 1.65, the higher the better up to the limit of excess methane, which will show up in the operating figures in other ways than as an excess of methane.

The Reforming Period.

From the chemical standpoint about all that the reforming of oil does in the way of changing the gas is in increasing its hydrogen content and its methane content slightly. The illuminant constituents, or unsaturated hydrocarbons, are broken down in their passage through the fuel bed, and in the average analysis of gas made during the oil admission to the back-run, only a small percentage of this constituent will be found. Immediately after the oil has been injected and the back-run steam is on full force, the amount of illuminants will increase slightly. This is due to the fact that a portion of the oil near the end of the injection period, found a black-top fuel bed and was not reformed. Being forced rapidly through the fuel bed by the increase in velocity of the back-run gas, when the full amount of steam was allowed to the unit, the time of contact of this small portion of gas with the high temperature zone, was greatly decreased
preventing reformation.

The percentage of methane also increases when the full steam is allowed to flow through the fire, the explanation of this condition is not exactly clear since it does not follow the logic of methane made during the oil admission period.

The analysis of two typical samples of back-run gas are as follows, one taken during the oil admission period and one immediately after:

<table>
<thead>
<tr>
<th></th>
<th>During Oil Adm.</th>
<th>After Oil Adm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_2H_6</td>
<td>2.6%</td>
<td>3.4%</td>
</tr>
<tr>
<td>CH_4</td>
<td>4.4</td>
<td>1.1</td>
</tr>
<tr>
<td>CH_3</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>CO</td>
<td>24.6</td>
<td>28.0</td>
</tr>
<tr>
<td>CO_2</td>
<td>3.4</td>
<td>7.8</td>
</tr>
<tr>
<td>H_2</td>
<td>61.3</td>
<td>51.7</td>
</tr>
<tr>
<td>N_2</td>
<td>6.7</td>
<td>7.1</td>
</tr>
<tr>
<td><strong>100.0%</strong></td>
<td><strong>100.0%</strong></td>
<td></td>
</tr>
</tbody>
</table>

The gravity of the oil made during the back-run oil admission period is much lower than that made during other portions of the cycle. It will vary between .35 and .45 depending principally upon the ability of the fuel bed to completely reform the oil.

The Purification of the Gas.

The purification of gas under heavy oil operation as under any other type of gas manufacture depends upon the amount of hydrogen sulphide contained in the gas. The frequency of box change is directly proportional to the increase of this constituent. As mentioned elsewhere, there are oils in the heavy class that are very low in sulphur and operation with these oils will result in no increase in purification troubles. Those plants not equipped with ample purification facilities should not consider the use of Bunker "C" oil if the local statutes require the distribution of sulphide free gas.

It is claimed that some of the very light oil fractions that will
carry through the plant equipment are increased with heavy oil operation, these light oils will foul theoxide and render it inactive in a very short period of time. This condition is a function of the condensing facilities and operating temperatures of these units rather than of the oil used.

The Finished Gas.

The finished product is of course the aim of any manufacturing process and whether or not one system or another is better depends first of all as to whether or not the result is the same. The quality of the finished product is of prime importance and the effect upon the utilization is also a determining factor.

There has never been any doubt but that the gas made with these heavier oils would fulfill all the requirements of the gas being made with the more refined enrichers. This has been borne out by several years of operation in a number of plants, the majority of which are comparatively large ones.

There are advantages to the use of heavy oil that do not present themselves as prominently with light oil, among these is the very flexible control of the gravity of the finished gas as well as the possibility of better regulation of the percentages of the different constituents.

There is no noticeable difference in any way between the gas made with either type of oil, as far as the distribution and transmission systems of a company are concerned.

Miscellaneous Laboratory Work.

The use of heavy oil does not make the work of the laboratory staff any more tedious or laborious. The routine tests made with light oil operation are the same in nearly every respect with the cruder raw material.
HEAVY OIL TAR AND EMULSION

The handling and disposition of the tar made has from the beginning been a problem to the gas manufacturing plant. This burden has been somewhat amplified by the use of heavy oils, as can very easily be surmised from the foregoing pages.

The characteristics of a tar follow closely in line with the oil from which it was made. A light oil tar produces a light tar and likewise a heavy oil results in a much heavier tar.

A discussion of the different phases of the production and the disposition of such tars can be divided into several headings, namely:

1. The effect of set balance and operations in general upon the quality of the tar produced.
2. The recovery and dehydration of the emulsion.
3. The marketing of the tar.

The effect of set balance and operations in general upon the quality of the tar produced.

While the quality of the oil used in the manufacture of the gas is a prime factor in predicting the quality of the tar that will result it is by no means the sole item. Among the many variables that present themselves along these lines are: The temperatures carried in the cracking chambers. The type of checkerbrick. The cycle of manufacture. The way that the oil is sprayed and where. The operation of the condensing equipment and the other equipment used in conjunction with it, and many other considerations that would be of a local character.

A duplicate sample of oil could be supplied two operating companies
for a trial run and the chances are several to one that the tar that will be produced by each will vary considerably in several directions. This is due to the different conditions under which it had been produced, such as those in the preceding paragraph.

When oil is being injected into a carburetting chamber it should be so directed and regulated that none of the oil will have a chance to come into contact with the walls of the unit. This condition in some cases is almost impossible to prevent, (as in the case of the very small water gas sets where the internal diameter of the carburetor may not be more than two or three feet in diameter). In the larger units it is possible to prevent this and in the design of present day units much care is exercised in this direction. In theory, the radiant heat of the refractory of the unit is ample to completely vaporize, as well as partially gasify the oil necessary for normal conditions.

There is usually sufficient time in which to inject the required amount of oil for each run. This phase of the operation should not be rushed and should consume the greater part of the up-run period time. The reason for this may not be obvious but is due to the fact that a gallon of oil will produce in the neighborhood of 200 cu. ft. of oil gas, which quantity coming into being in a very short time, increases the pressure in the carburetor and considerably increases the flow of the gas through the superheater. This severely cuts down the time of contact of the oil vapors with the checkerwork of this unit, which after all, is the most critical of the three sections of the set. In so lessening this contact time a portion of the vapors are never completely cracked and come out at the wash box as an oil emulsion.

The above condition can readily be caught by observation of the seal pot from the wash box, and provided the set is properly checkerened
it may be remedied in one of two ways. The oil may be injected slower, or the superheater temperature may be increased a few degrees. The first effort should be the slowing down of the oil rate, and if this does not clear up the trouble then change the temperature. In the second alternative mentioned above the wash box should be watched closely to make sure that lampblack is not being made. In the carbonation of the average oil there is only about fifty degrees between the temperatures at which emulsion will appear and when lampblack will be made. Oil emulsion makes the tar very difficult to dehydrate and lampblack increases its viscosity.

The quality of the tar produced from a given set is so readily affected by temperature in the checker chambers that, other things being equal, the analysis of composite tar samples could be used as a guide for determining the operating temperature of a set. In determining the most favorable operating temperature it is customary among other things to choose that temperature whereby the largest percentage of the oil is cracked into gas, suitable for carbonating purposes without the formation of excessive amounts of naphthalene.

In the larger plants where several sets are operated at the same time it is not always so easy to say which set is producing an excessive amount of naphthalene, or which can be operated advantageously with higher temperatures without causing naphthalene difficulties. The analysis of the tars from each set will show which one is cracking the oil to the best advantage and which one is producing naphthalene. The kind of analysis referred to here is merely the distillation of the water-free tar, wherein the specific gravity, quantity and physical character of each fraction is noted, as well as
the specific gravity of the composite tar. The sulphonation residue of the distillation fractions shows very closely the percentage of paraffins in them and collectively indicates the relative amounts of uncracked oil in the different tars. However, the specific gravity of the corresponding distillation fractions is lower as the percent of uncracked oil increases, and hence it is not always necessary to make the sulphonation test to determine approximately the relative cracking efficiency of the different sets.

Relative to the checkering of the carburator and superheater, it may be said that the type of checkering used affects the linear velocity of the gas, the time of contact of the gas and vapors with the hot bricks, the intimacy of contact with the bricks and the amount of heating surface available for oil cracking. A prolonged time of contact at one temperature produces in a general way, much the same cracking effect as a higher temperature with a shorter time of contact. It follows then that two similar sets operated alike and with the same operating temperatures may produce different qualities of gas as well as tar, if the checkering is not the same in both. It goes without saying that changes in a checkering system should be made with a definite purpose in mind and only then after due consideration has been given the other important variables. When such changes are made, an analysis of the tar made will serve about the best means of arriving at a new operating temperature.

After a set has been in operation for a long period of time, the volume of free space decreases because of the formation of carbonaceous deposits on the checkerwork as well as between the bricks. This formation may be accounted for partially by the material blown over from the generator fuel and ash, and in part by the carbonization of oil or
products therefore. Carbon from carbonization of oil tends to form over the exposed surface of the bricks a hard film that grows thicker as the set continues in use. As the checkerwork becomes clogged and the linear velocity of the gases is increased, the efficiency of combustion decreases considerably and the quality of the tar suffers at the same time. The physical properties of the carbon coated checkerwork change, and while it is not possible to assign numerical values as to the change in cracking efficiency of a clean and a coated brick, nevertheless much better conditions prevail with clean ones than with the carboned-over ones.

The tar formed when the brickwork is "dirty" contains more uncracked oil, saturated hydrocarbons, less solids in the distillation fractions and has a lower specific gravity.

The type of tar produced in a plant should be watched closely, since it is a very good guide as to whether the set is in proper balance and whether or not the quality of the tar produced matters much as far as the tar is concerned. It should be kept in mind that when good tar is being recovered the maximum amount of the oil is being transformed into gas and this is the prime consideration.

Among other factors that make good operation is the quantity of steam used in the manufacture of the blue gas with which the oil gas is to be mixed. On the assumption that the fuel in the generator is carbon the theoretical amount of steam required according to the equation:

\[ 12 \text{ lbs. } C + 18 \text{ lbs. } H_2O = 28 \text{ lbs. } CO + 2 \text{ lbs. } H_2 \]

is 18 pounds of steam per 756 cubic feet of blue gas made. This is in accordance with the assumed values for the quantity of blue gas in 1,000 cubic feet of finished gas. It is evident that when 35 lbs. of steam are used per 1,000 cu. ft. of finished gas made, 100% more is
used than is theoretically required. Also, an appreciable amount of gas is made according to the equation:

$$12 \text{ lbs. C} + 36 \text{ lbs. } H_2O = 44 \text{ lbs. } CO_2 + 4 \text{ lbs. } H_2$$

The actual amount of steam required to satisfy the chemical reactions in the production of 1,000 cu. ft. of gas made is 20 lbs. Thus 35 - 20 or 15 lbs. excess steam are used. Assuming a tar production of one-half gallon of tar per 1,000 cu. ft. of gas, and using a weight per gallon of 8.5 lbs., then for every volume of tar in the gas there are 3.53 volumes of water from the calculation.

$$\frac{15}{0.5 \times 8.5} = 3.53$$

It is obvious from the above deductions that the tar is condensed in an atmosphere highly saturated with water vapor and that when condensing does take place the chances are for the formation of a high water content emulsion, especially in those sections of the system above 212° F. As the gas passes through the condensers and the temperature is reduced, the precipitation contains less and less water vapor until it reaches the purifiers where it is almost impossible for tar to go any farther.

It follows then that even the steam fed to the set has a considerable effect upon the emulsion produced, and only that quantity to give the required balance as far as the CO₂ content is concerned and to control the formation of clinker (which must be considered at times to the disadvantage of the gas quality) should be used.

With the use of heavy oil there is another consideration that must be balanced to keep the quality of the tar within reason, this being the amount of reforming that is carried on.

In the reforming operation as has been stated before, the oil is sprayed on top of the generator fire during the back-run operation or when the steam is being admitted through the top of the superheater
and passes down through this unit, up through the carburetor and down through the generator passing out through the back-run pipe to the wash box. With the admission of this oil during this period the gas that is formed is forced through the very hot bed of generator fuel and in so doing is changed in state considerably from that portion of the oil that is fed to the carburetor and which is only subjected to approximately 1450°F.

The quantity of the different constituents formed during this operation is as much a variable as most of the other operations in the manufacture of water gas. It is quite evident that the bulk of the hydrogen passes off as hydrogen with a very small quantity of ethane and methane, with only a very small quantity of unsaturated hydrocarbons getting through. It is sufficient here to say that a large part of the carbon portion of the different constituents that may have been in the oil is transformed to its free state, most of this being deposited in the pores of the coke in the generator and a small portion being blown through as lampblack. It is this lampblack that so concerns the quality of the tar.

Several experimenters working with tar emulsions have concluded that lampblack is one of the determining factors in the formation of an emulsion. In a study made by W. W. Odell in plants of the Peoples Gas Light and Coke Co., of Chicago, many experiments were made along this line and although it is not definitely established why lampblack does promote the formation of an emulsion, the fact remains that it is so. There are other factors to be considered such as the naphthalene, paraffin and anthracene content, but about the only control that the operating man has along these lines is the percentage of lampblack present.
The percentage of reforming carried on is a factor of the amount of this lampblack that will be carried forward to the emulsion, but this quantity is also a variable depending upon the type, size and porosity of the coke used and the depth of the fuel bed.

A discussion of this phase of the operations could be carried on page after page, with the views of one operator varying considerably from those of another. It should suffice here to say that it is the general opinion of the majority of those using this type of operation that for reforming a light, porous vertical retort coke is the ideal fuel. This type offers the greatest filtering action to the fluffy lampblack. The ideal size for maximum capacity is either stove or furnace. The very dense, coke oven coke, while wonderful fuel for straight operation is very inferior to the type mentioned above. This is due to its very dense structure which defeats the possibility of the fluffy carbon becoming lodged in the pores, as is the ideal condition.
THE RECOVERY AND DEHYDRATION OF THE TAR EMULSION

Very few water gas plants are equipped to take care of their residuals as experiments have proven that they should be cared for, for a minimum of emulsion trouble. It is very easily seen that the tar condensed just as the gas leaves the set in a highly superheated state will be quite different in character from that portion of it that settles out in the shavings scrubber. Quite naturally the tar from the wash-box will contain a large portion of the high temperature fractions upon distillation and that tar from the shavings scrubber should contain a larger portion of the lower fractions. Experiments have proven that the emulsifying tendencies of any of the fractions are quite often increased when these different fractions are mixed together. This is a condition that in practice can not be avoided without a lot of extra equipment and care.

In nearly every plant of this type all drain lines empty into one basin which may be a baffle type separator or a catch basin from which the emulsion will be pumped to a separator, or a settling well. Any one of these arrangements allows the tar emulsion to settle out and be removed to storage for processing.

The arrangement in use at the Haverhill Gas Light Co., where the writer has spent several years is given in the Flow Diagram on page 112.

From this sketch it will be seen that all emulsion lines drain to the catch basin marked "Sump" and from which they are pumped to the baffle type separator. This separator is a steel shell (rectangular) 6\(\frac{1}{2}\) ft. x 6\(\frac{1}{2}\) ft. x 30 ft. supported by steel work about fifteen feet above ground level. This elevation allows the overflow from the last section to drain to the relief holder by gravity.

The water overflow from the relief holder goes into a large settling
well, (formerly a relief holder pit) where further separation takes place. From the settling well the circulating water pump takes this water for its trip again through the different pieces of equipment.

The tar emulsion which settles out in the separator is allowed to flow by gravity to the same relief holder pit (marked emulsion storage on diagram) only that it is fed to the bottom and not allowed to pass through the layer of water. Since this relief holder pit is below ground level the emulsion maintains a very constant temperature and no difficulty is encountered in raising it for processing.

With heavy oil tar, settling has practically no effect upon the emulsion, at temperatures below 150°F. although at temperatures in the neighborhood of 200°F. a portion of the water will rise to the surface in time.

The pre-heating tank shown in the Flow Diagram is a supplementary unit to the tar dehydrating system used in Haverhill and is not entirely necessary. It is used here because it was available and helps increase the output of dry tar. In this tank a batch of the emulsion is placed and allowed to simmer or boil slowly for about eighteen hours after which time the steam is turned off, and the mass allowed to cool. This cooling will cause partial separation. It is transferred from this tank to the dehydrator and given another simmering and decanted under pressure. A complete description of the operation of the tar dehydrator, designed by the writer for the Haverhill Gas Light Co., is given herewith.

A very interesting study was completed last year by Jerome J. Morgan, Associate Professor of Chemical Engineering of Columbia University, working in conjunction with Charles F. Stolzenbach on the "Heavy Oil Tar Emulsions in the Water Gas Process;" this dissertation
appeared in the American Gas Association Monthly for July and August, 1934. This treatise gives for the first time, definite proof that the formation of these very stubborn emulsions encountered in the water gas plant with heavy oil, are not entirely promoted by lampblack.

A method for dehydrating heavy oil tar emulsion very economically was developed in the early part of 1934 at the plant of the Haverhill Gas Light Co. and since it has been adopted by several companies in this part of the country, it will be described here.

A sketch of the tar dehydrator is given on page 134.

A steel shell built to withstand 50 lbs. working pressure was purchased from a local boiler works and mounted on "I" beam legs on cement piers as shown in sketch. This unit is 3' 6" in diameter and 22' long with a 30" dome six feet from the end. It was built under Massachusetts Specifications and complies with the Hartford Steam Boiler Regulations, with which company it is fully insured.

The working capacity of this unit is 9,000 gallons of emulsion every 48 hours giving approximately 3,000 gallons of dry tar in that time.

At one end of the shell twenty \( \frac{3}{4} \)" level cocks were welded in, these being aligned and so arranged that they could be used as drain cocks as well. A slotted three-inch pipe serves as the drain for the upper tier of these and this ties in with a four-inch slotted drain from the lower group. This drain empties into the plant catch basin.

On top of the shell is mounted a brass tube, (water tube type) condenser that was available at the plant. This condenser contains 72 - \( \frac{3}{4} \) OD brass tubes 11 ft. in length. The emulsion chamber is connected through the dome and a four-inch pipe with a gate valve to one end of this condenser. Cooling water is supplied from the river
water system. The condenser is a four-pass water and four-pass vapor with a condensing area of approximately 155 sq. ft., which is roughly equivalent to twice the same amount of surface of steel or wrought iron. Since this condenser does not work under but several pounds pressure at any time, almost any such unit lying around a plant will suffice. The valve in the vapor line is connected to a long 2" steel rod running the length of the unit from the valve to the operating end of the shell; this is in turn equipped with a sprocket and chain. A dead weight relief valve is installed as shown in sketch with the relief line connecting to the drain line from the drain cocks. A steam coil made of 2" wrought iron pipe, consisting of a series section of eight - 20 ft. lengths in series with a parallel section of ten such lengths of the pipe, is placed as shown in the sketch; the parallel section being about eighteen inches from the bottom of the shell and the series section about sixteen inches above the lower section. This coil is connected through globe valves to the live as well as the exhaust steam systems and all control is manual.

There is also installed about four feet above the heating coil another group of 2" pipes that are connected to the cooling water system. This coil can also be used for heating and is so connected to the steam lines.

Manholes are provided at each end of the shell for internal examination and cleaning.

The outlet or condensate connection of the condenser is connected through a 2" pipe and a sight glass to two 500 gallon tanks, which act as separators for the light oil and water that cooks out the emulsion. The overflow lines from these tanks are so arranged that the water on the bottom is forced out by the oil above it, so when oil appears at
the overflow the condensate line can be changed to the other tank and
the light oil emptied to the storage tank provided for this product.
This oil is entirely different from drip oil and will not pass as such.
In most plants it is pumped back and mixed with the dry tar to reduce
the consistency of the latter. The small condensate tanks are elevated
to allow gravity flow to the storage tank. The overflow line from
these tanks as well as connections from the vapor line between the dome
and the condenser, and the condensate line are brought down to a funnel
at the operating end of the unit. This enables the operator to ascertain
conditions in any one of these lines at any time. This arrangement
is especially handy when the emulsion primes, boiling over through
the condenser,

A steel platform constructed of small angle iron and grating was
installed at the operating end of the shell. The operator has within
an easy reach, control of the various valves for the operation of the
dehydrator.

A live steam connection shown about one foot from the top of the
shell is connected directly into the emulsion chamber. This enables
the pressure in the unit to be increased rapidly for decanting.

An opening is left in the operating end of the shell for the
bulb of a recording thermometer which is mounted in the adjacent
building.

Connections are provided at each end in order that the unit may
be filled or emptied from either end.
The operation of the dehydrator is as follows:

The emulsion is pumped into the dehydrator from the pit of the reheat holder at a temperature around 100°F, and only space for expansion is allowed. The steam valve to the heating coils is opened slightly and the mass is allowed to simmer or boil slowly, (so that a stream of condensate about the size of a pencil is noticed in the sight-glass) for from 16 to 24 hours; the temperature during this period is in the neighborhood of 220°F. This cooking period is done at atmospheric pressure, the valve between the dome and the condenser being wide open. The period of from 16 to 24 hours can be reduced but to the disadvantage of the desalting operation.

At the end of this simmering period the steam to the heating coils is turned off and the vapor valve to the condenser closed. Live steam is now admitted through the connection in the top of the tank and the pressure in the emulsion chamber brought up to about 10 lbs. (A regulator to maintain the maximum pressure established is quite a help during this phase of the operation). The mass is allowed to stand under this pressure for a period of fifteen minutes, during which time about a foot of clear water will rise to the surface. This separated water is drawn off through the drain cocks from the top down. It usually takes nearly two hours for complete separation to take place. During this time the water can be continuously drawn off following the line of separation right down from one cock to the next. During the drawing off process it should be kept in mind that the pressure on the liquid should not be allowed to drop, in which case separation ceases.

The usual charge of emulsion will average 65% water and 35% tar.

After all the water that will separate has been drained off, it
has been found economical to drain off the next level (one cock) of very high water content emulsion. At this point the pressure is released on the unit and the steam turned on the heating coils for the final cooking.

The percentage of water to which emulsion of this type can be brought down to by the above simmering and decanting method depends upon the carbon content of the emulsion, its stability in other ways, and the period allowed for simmering. It is possible in some cases to break an emulsion after only eight hours simmering, but it will be found that it will, under average conditions, break only to about thirty per cent. With from sixteen to twenty-four hours it is easy to reduce this to ten or fifteen per cent.

It will be found that the tar at the very bottom of the vessel will approach dry tar and that the water content will increase to about 20% at the upper level after the watery emulsion layer, just below the free water, has been drained off.

In case that the tar is to be used for boiler fuel or for use in the water-gas generator for reforming fuel, it can be removed after the decanting has been completed and all free water, etc., has been drained off, since emulsion of this type can be used as such fuel. The expense in the cost of steam to remove the remaining 10% is several times the amount consumed in the simmering period.

In the Haverhill unit the steam consumption will average:

Simmering period
16 to 24 hours @ 250 lbs. per hour = 4,000 to 6,000 lbs.

final Cooking
1,200 lbs. per hour @ a reduction of approximately 1% of the water content per hour

For 10% to be reduced to 2% equals a reduction of 13% 
13 x 1,200 = 15,600 lbs.
At 50¢ per 1,000 lbs., this represents from $2.00 to $5.00 for removing 50% of the water, and $7.80 for bringing the percentage from 15% to 2%.

Where the tar is to be sold it usually must be brought down to 2% water content, and at present there is no option as to how this is to be done, for the only way known at the present time is to cook it down to that level. As can be seen from the above calculations this represents the greater part of the expense in processing the product.

In case it were not possible to deoact the water from the tar emulsion it can be very easily seen that the cost of removing the water and getting the tar in condition to sell or use would be almost prohibitive.

There, of course, is room for argument in the statement relative to the use of tar for reforming or boiler fuel since any water fed in tar as boiler fuel must extract from that fuel sufficient heat to change it to steam and then superheat it to stack temperature, and in the case of reforming it is to be taken into consideration that the same amount of heat must be extracted from the fuel bed of the generator to change the state of the water. Since this is the most expensive fuel (coke) around the average water-gas plant it seems to be a question of the efficiency of the steam generating and distribution system of the plant as to which of the two lines of reasoning is the more economical.

Consider for example an emulsion charge of 3,000 gallons from which water will have to be extracted by distillation. Assume the average condition of 45% water content product.

\[ 3,000 \times 0.45 = 1,350 \text{ gals. water} \]
\[ 5,850 \times 0.34 = 2,001 \text{ lbs. water} \]

Assume that 80% of the total of 85% could be removed with an
efficiency of 80% for the unit. Then we would have:

Total heat of 120 lb. (gas) steam = 1192 B.t.u. per lb.
970 B.t.u. = Latent Heat of Evaporation of Atmospheric Steam

Assume outlet steam is water of 260°F.
Heat of Liquid = 220 B.t.u. per lb.

1192 - 220 = 972 B.t.u. available per lb. of 120 lb. steam used.
This would be an efficiency of 81.5%.

Since the Latent heat is 970 B.t.u., then 1.0 lb. of 120 lb. steam will evaporate 1.0 lbs. water from and at 212°F.

Then 80 x 48.789 = 3905 lb. steam would be necessary to get the solution down to 15.0%

Then 15.0 - 2.0 = 11.0% at a rate of 1,200 lbs, steam per one per cent moisture removed.
11.0 x 1,200 = 13,200 lbs., additional

Then 39,051 + 13,200 = 52,251 lbs., steam necessary at 50% per 11 lbs. — This equals roughly $25,00 for a recovery of 37% of the total 9,000 gals. = 3,300 gals. (37% equals 37% dry tar plus 3% water).

\[
\frac{25,000}{3,300} = 7.583 \text{ cents per gallon}
\]

This cost is in contrast with the maximum of $11.00 by being able to decant off 50% of the water.

After the tar has been processed according to the requirements it is without further processing pumped to storage to await disposition.

During the process of dehydration a portion of the tar oils is cooked over. From tests run in New York it seems as though this oil is brought over mechanically for its boiling point on re-distillation was found to be around 290°F. The amount of this oil recovered will be approximately 10% as much as the dry tar recovered. From the processing of 3,000 gals. of tar about 300 gals. of this oil will be obtained.

This oil differs considerably from the line distillates commonly known as drip oil and under most specifications for the latter type this oil will not pass, mainly on account of its higher boiling point.
and the low percentage passed over in the range of the distillation
temperature of drip oil. The oil is usually put back into the tar and
serves to make it considerably more workable.

There are gas plants in New England of the combination type, coal
and water gas, that do their own blending of their tars and sell direct
to the states of commodities, but as a rule the crude product is disposed
of to the companies in that line of business.
Sketch of

PEABODY ENGINEERING CORP.
STEAM ATOMIZING BURNER
FOR OIL OR TAR

J.L.E.
Water gas tar dehydrated to a fairly low water content makes an excellent fuel for power boilers. With the proper type of burner and furnace arrangement along with sensible control it equals the heavier oils in ease of operation as well as flexibility. The efficiency of burners suitable for using the heaviest of tars is not as high as the same burner for utilizing oil.

Tar has a comparatively high heating value on a volume basis varying from 150,000 B.t.u. to 175,000 B.t.u. per gallon, depending upon its gravity. The light oil tar will range in gravity from 1.04 to 1.12, while the heavy oil tars will vary from 1.12 to 1.25 sp.gr. The average heating value used for calculations is 17,700 B.t.u. per lb.

It seems from off-hand calculations that a liquid with a heating value as high as tar would be ideal for boiler fuel, and were it not for physical characteristics such would be the case. But there are other considerations than the heating value that determine whether or not a fuel will be economical to use.

The light water gas tar as a rule has a market value slightly above its value as a fuel ordinarily, and it is for this reason that this type of tar is usually sold by the gas companies. This type is quite easy to dehydrate and in most cases if there is ample storage space for this product to lay idle for a short while it will dehydrate itself. After which time tar with as little as 2.0 % water content can be removed from the bottom of the storage tank, provided that the mass has been kept comparatively warm and not agitated. In case that storage facilities are not adequate, this tar can be processed by centrifuging through special tar centrifuges or it may be dehydrated by cooking.
Only those companies that are not able to sell their light oil tar within a reasonable limit of its value as a fuel will burn it. Most companies will sacrifice several tenths of a cent per gallon in order to sell it on the open market.

With the introduction of the heavy oil process in the gas industry and its rapid expansion, especially with the larger companies, the tar consumers were not in a position to absorb this large amount of a new product of which they were not entirely familiar. Since these same tar companies blended their products according to long established rules with coal tars and other light tars there was very little advantage in it for them to change over to the heavier tars, as long as they could get the required amounts of the other types.

It was for this reason mainly that several of the larger gas companies were compelled to burn under their boilers this heavy tar. These same gas companies had (as a rule) much rather sell their tar than bother with burning it, within reasonable price differentials.

There is the possibility that had the introduction of the use of heavy oil been made several years previous to its introduction these companies (tar companies) would have been in a better condition to absorb the greater portion of such tar. In the last few years the specifications on road materials have been made more rigid on account of heavier traffic. Likewise the rapid strides that have been made in cement highways, (making obsolete many a tarred road) has reduced to a certain extent the use of these materials. It is predicted that the time is not far distant when most of the gas companies will be compelled to burn their tars.

As stated previously there are several drawbacks to the use of tar as a boiler fuel, especially the heavy tars.
Among the several kinks in the burning of tar are:

- The difficulty of handling dry tar.
- The difficulty of burning high water content tar.
- The high steam consumption of a burner that will do a good job with the heaviest tars.

This heavy oil tar, (especially that recovered from operation involving reforming) when dehydrated becomes one of the most viscous liquids that any plant is called upon to handle. It is a solid at 50°F, and must be kept above 120°F if it is to be moved at all. It is imperative that a pump that is to handle this type of tar be placed within several feet of the storage tank and that the suction line be as large as it is economically possible to run. The storage tank must be kept at a temperature of at least 150°F. The tank need not be insulated since the heat flow through this tar is comparatively low, and the outer portions in contact with the tank will solidify to a certain extent and act as an insulator.

It is bad practice to install lines of less than one inch in size to handle this tar. Even the recirculating line back to the tank should not be less than that size. All lines leading to the storage tank, namely the live steam, exhaust steam, tar and recirculating lines should be bunched and insulated together, for maximum heating of the tar lines.

It is general practice to dehydrate tar that is to be used for boiler fuel no lower than 10.0% water content. This extra moisture lowers the viscosity considerably and makes the handling of this product much easier and safer, (by safer is meant the reduction of the possibility of the tar freezing at an exposed joint, etc.) The average burner will handle 10% emulsion easier than dry tar, this being especially true of the heaviest tar.

In the lighter tars the water particles are not as finely dispersed as in the heavier products and for this reason the moisture content of
heavy oil tar that is to be burned may be several percent higher than for the light tars. In the light products the globules of water will coalesce and form large droplets that will cause sputtering of the burner, this is not so likely with the heavy tars.

As near to the boilers as is convenient should be placed the secondary heater. This unit should be similar to the secondary oil heater and capable of heating at least twice the normal demand from 150° F. to 250° F. All lines from this unit to the burners should be insulated with steam lines. In the case of the steam atomizing burner, which is the only practicable type for this tar, the atomizing steam line can be run with the tar line, this makes a comparatively neat arrangement.

There are numerous steam atomizing burners on the market and the choice of one will depend a lot upon the individual. One of the most successful burners of this type is the Peabody Burner, a product of the Peabody Engineering Co. of Boston, Mass. Another is the Campbell burner made by the Atlas Valve Co. of Newark, New Jersey.

A primary steam mixing arrangement used in Haverhill in conjunction with a Peabody burner for utilizing the heaviest of tar is given in sketch form on page 147.

The revamping of the furnace for the utilization of tar as a boiler fuel is identical to the changes necessary for using heavy oil. These changes may be found in numerous papers dealing with the burning of oil under boilers.

The efficiency of tar burning is slightly lower than oil burning with the same burner, on account of the increase in the amount of steam necessary for atomization, and in the case of the heavier tars an additional increase in steam for the primary mixing or breaking up.

Some operators will burn tar (heavy oil tar) with water contents as high as forth percent, but this is due in most cases to a lack of equipment
to dehydrate the emulsion. Theoretically it is more economical to remove the water by dehydration than to allow it to be passed up the stack as highly superheated vapor.

The Peabody Steam Atomizing Oil or Tar Burner.

Several of the larger gas companies in the East who have had to burn a portion of their tar production have found the Peabody Steam Atomizing Burner about as simple and fool proof as such a unit could be. It is very difficult unless the proper instruments are available to check the operation of one burner against another; but it is reasonable to assume that the steam consumption of a well designed unit will be closely comparable to the most economical available. In the case of burning tar, efficiency is of secondary importance. The primary consideration is to get a burner that will handle almost any kind of tar from the worst to the best. The Peabody Burner fulfills this last specification very nicely with a minimum of trouble.

As can be seen from the sketch on the page 147, the burner is a very compact affair with a minimum of operating drawbacks. The burner proper consists of the body of bronze, a removable steam jet and a removable nozzle. The body is designed for high velocity and has two slotted orifices at right angles to each other as part of the body casting. These slots tend to increase the atomizing action of the burner. The nozzle has a slotted opening allowing the flame to be shot in fan shape either vertical or horizontal.

When the average regulating cock is used with liquids with a large percentage of dirt and free matter, due to the fact that these cocks are only open a small fraction of their total opening, the cocks will very quickly become clogged and stop the action of the burner. As a remedy to this condition a mixing or breaking-up jet is installed as shown in the sketch. The steam passing through the small orifice,
built into the tee, breaks up the liquid to a considerable extent, reducing its viscosity and affords much better regulation of the burner. This jet is ordinarily used only for dehydrated tar that is too thick to operate in the burner without such a system. With heavy oil tar emulsion of 10% water this jet is not used.
START COST CURVES

Showing Cost of Steam per 1000
Pounds for Various (Boiler plus
Furnace) Efficiencies when Fired
with Heavy Oil
Specific Gravity of Oil .95
Per Oil Costs 1.5¢ - 5.0¢ per Cal.

Boiler Pressure 120 lbs.

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</table>

ASSUMPTIONS

1. Heating Value of Heavy Oil 18,400 B.T.U. per Pound
2. Feedwater Temperature 200°F.
3. Laburnum Steam used for Feedwater Heater

May 1, 1939 G.E. Light Co.
March 5, 1935 J.L.B.
STEAM COST CURVES

Showing Cost of Steam per 10,000
Pounds for Various (Boiler plus
Furnace) Efficiencies when Fired
with Gas Oil Tar. of 1.00 sp. gr.

For Tar Costs 3.0¢ - 5.0¢ per Gal.

Boiler Pressure 120 lbs.

Assumptions
Heating Value of Tar 17,000 B.T.U. per Pound.
Feedwater Temperature: 200°F.
Exhaust Steam used for Feedwater Heaters.

Haverhill Gas Light Co.
March 7, 1933 - J.J.C.
The chief outlet for nearly all tar made in New England is in road materials; a small amount of it finds its way into roofing materials, tar papers and the like. Some of the plants along the Atlantic seaboard have found a market for these products in Europe where considerable business is done in briquetting. The tar distillates from the production of road materials go into wood preserving and disinfectants, or are selectively used in the blending of other road materials.

As a general rule the tar market in any state is governed more or less by the requirements of the particular state, its counties and municipalities. The specifications for the materials used by them are based upon the experience in construction of tar macadam roads over a period of years, and the requirements are changed from time to time as data gathered from far and wide deems it advisable. The specifications undergo study and revisions annually by the American Association of State Highway Officials, and New England comes under the division known as the North Atlantic Group.

These specifications are devised to cover all types of road materials for all types of road construction and maintenance. They range from the thin tars for surface treatment to the soft pitch road binders used in the construction of penetration tar macadam roads. Between 80% and 90% of the tar used in New England road work at the present time goes into two classes of materials; tar for surface treatment and tar for homeing, and tar for mixed-in-place construction and mulch homeing.

The specifications for these two classes of materials are illustrated by the 1933 Massachusetts requirements known as #14 and #14A shown on the following page.
Water
Specific Gravity at 25° C.  1.10  1.10
Specific Viscosity (50ccs. at 40° C)  8 35  16 36

Bitumen (Soluable in Carbon Bisulphic) 88%  88%

Distillation
Total Distillation by weight
Up to 170° C.  5.0%  5.0%
Up to 270° C.  30.0%  25.0%
Up to 300° C.  40.0%  30.0%
Softening point of residue  38° C.  65°C.  40°C.  70°C.

These tars are subdivided by their specific viscosities into different grades according to the type of work for which they are to be used.

The Massachusetts specifications are typical of the others in the New England Group and serve to show the general characteristics that are required.

Crude heavy oil tar as it is produced in several plants in New England assays within the following limits:

Water
Specific Viscosity (50ccs. at 80° C.)  18 to 169
Bitumen (soluable in carbon bisulphide)  76 to 92%

Distillation
Total distillates by weight
Up to 170° C.  4.2 to 4.4%
Up to 235° C.  6.0 to 8.0%
Up to 270° C.  14.0 to 19.0%
Up to 300° C.  20.0 to 25.0%
Softening point of residue (B and R)  67° to 85°

How the dehydrated heavy oil tar fits into those limits depends upon the kind of oil used and the percentage of it that is reformed. Some of the companies are governed in their selection of the oil to be used by the character of the tar it will produce.

From a comparison of the characteristics of the dehydrated heavy
oil tar and the Massachusetts specifications, it is obvious that the tar cannot be used straight, but must be blended with other tars in order to meet these requirements. The four methods that are used consist of either dehydration and blending, dehydration and blending and cutting back, dehydration and blending and distilling, or dehydration and cutting back.

The choice of the method will depend upon the materials available for blending and the specification for road tar that has to be met. It is easily appreciated that the combining of tars is primarily a mathematical problem and variables governed by the characteristics of the tars that are used. It can be shown that 30% to 75% of heavy oil tar may be used, although this latter high percentage is dependent upon using a specially fractionated fluxing oil for blending with the heavy oil tar.

Roads constructed from materials made with heavy oil tars are being kept under close observation and (with the exception of some of the first produced), these tars have proven entirely satisfactory when kept within these specifications. The construction of tar roads is being pushed farther and farther into the country districts of New England and it is this prospect in view that the tar companies look for their livelihood in the future.

This description concerning the marketing of heavy oil tar is from a paper given before the New England Gas Association, Operating Division, in 1934 by Mr. H. I. Thornton, Chief Chemical Engineer of Charles H. Tenney Co. of Boston, Mass. and is included in this paper to give an idea as to how the heavy oil tars fit into the picture of road materials.
CONCLUSIONS

It is regretted by the writer that many small details that have come to his attention in the line of this thesis, on account of space, are not included. To do so would take a paper almost as lengthy again and at the same time many of these details are more or less local in character and would serve to clutter up and increase the difficulty of presenting a few thoughts in a clear and concise manner. Those who are familiar with gas plant practice and operation, it is believed, will not have any great difficulty in interpreting most of the ideas and thoughts contained herein.

The writer was sent to a gas plant from the head office of a large operating and engineering firm much against his will, since his endeavors had been in an entirely different field. After several years of curiosity as to "what it was all about" so to speak, the job became more and more interesting and more fascinating since it offers an almost unlimited field for research and study.

It is not feasible to draw conclusions from such a general study as this paper happens to be, that would in the end mean very much on account of that fact that "What will kill one will fatten another." It is evident, however, that there are savings and economies to be realized in the use of heavy oil, provided one is so situated that these oils are available to him.

Although Natural Gas has been piped in recent years long distances to the large centers, this commodity is still not available to a large part of the people of this country on account of their distance from the few fields of such gas. There is no certainty as to when one or any number of such sources of gas will cease flowing, and it is believed that manufactured gas will for a long time to come, hold sway
in the majority of the communities of the country.

The manufacture of water gas is unlike the manufacture of many other things where the size of the manufacturing equipment has considerable influence upon the efficiency and economy of manufacture, for a small water-gas set can be made to operate as efficiently as a large one and in many instances more so. This is proven time and again by small companies that will show operating results, as far as the raw material required to make a certain quantity of gas are concerned, much below the results obtained by the larger companies. There are many reasons for this; the most obvious of these being the fact that in a small plant with proper supervision the variables are not so numerous as in a large one. Also, since there is only so much gas to be extracted from a given quantity of fuel and since regulation from a mechanical as well as thermal point of view is much simpler with the smaller units, it is possible to outdo the large ones. From these facts it will be realized that production costs cannot always be reduced by increasing the size of the equipment and since it is the constant aim of the operating man to cut costs in every way possible, the heavy oil type of operation offers one way that this may be accomplished by some plants.

The writer had the pleasure of studying Heavy Oil Operations as carried on in the Northeastern States for the Haverhill Gas Light Co., and subsequently designing and assisting the supervision of the construction of the equipment for changing this company's plant over to use these heavy petroleum products.

He has been in close contact with the operation of this equipment for one and one-half years and at this writing is working on the possibility of recovering a new residual from this type of operation that may make Heavy Oil Utilization even more desirable and economical.