U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

WASHINGTON

ADDRESS REPLY TO
NATIONAL BUREAU OF STANDARDS

IN YOUR REPLY
REFER TO FILE

September 8, 1948

5.9/433c

Dr. L.L. Newman
U.S. Bureau of Mines
Washington 25, D.C.

Subject: Data on Hydrocarbons

Dear Dr. Newman:—

You will be interested in the copy of the attached brief
review, prepared by our Dr. M.B. Epstein, of the data from
Spengler, Instut fur Kohlenforschung, which you were kind
enough to send to us.

With appreciation of your cooperation in our work, I am

Very truly yours,

Frederick D. Rossini
Chief, Section on Thermochemistry
and Hydrocarbons

Copy to Dr. A.J. Kraemer

Enclosure

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

TO : F.D. Rossini

DATE: September 3, 1948

FROM : M.B. Epstein

SUBJECT: Data of G. Spengler transmitted by Dr. L.L. Newman of the Bureau of Mines.

1. The material transmitted by Dr. L.L. Newman of the Bureau of Mines comprises a set of photostats of data obtained from Dr. Ing. habil. G. Spengler of the Institut fur Kohlenfoorschung, Laboratorium fur Mineralole and Teere an der Deutschen Hochschule at Prague. There are included brief summaries of the methods of preparation and purification, elementary analysis, specific gravity (d_4^{20}), boiling point at 760 mm Hg, freezing point, refractive index (n_D at 20°) and calculated molecular refractivities for the 23 individual compounds and pairs of cis-trans isomers listed in the attached table. There is, in addition, an appendix which tabulates and discusses Raman spectral data for a number of these compounds.

2. For 10 individual compounds or pairs of cis-trans isomers comparison can be made with accurate data in the files of the American Petroleum Institute Research Project 44. This comparison indicates that the data of G. Spengler does not equal in quality the best data that have been accumulated in this country during recent years. However, boiling points appear to be accurate to a few tenths of a degree, densities to 0.0010 g/ml, and refractive indices to 0.0004. Such data are superior to much that are published. I therefore have some confidence in the data for the compounds for which an accurate comparison could not be made, and regard the addition of G. Spengler's data to our files as well worthwhile.

Morton B. Epstein

PRODUCTION COSTS OF CO + H₂ MIXTURES FOR DIFFERENT METHODS OF GASIFICATION WITH OXYGEN AND VARIOUS FUELS.

by

Otto Hubmann

④

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PRODUCTION COSTS OF CO + H₂ MIXTURES FOR DIFFERENT METHODS OF GASIFICATION WITH OXYGEN AND VARIOUS FUELS

by

Otto Hubmann

INTRODUCTION

Gasification of coal has for many years been used for the production of heating gas in industrial plants mostly in connection with the production of metals and manufacturing plants of the metal industry. Gasification with air in a shaft-producer with a fixed fuel bed may be considered as the primary stage of gasification technology. A high content of nitrogen (45 to 55 percent) and a relatively low heating value are the main features of this so-called producer-gas.

Because of the need for a gas of a higher heating value and for hydrogen for chemical synthesis purposes, several methods of gasification were developed in which a nitrogen-free gas is produced by the reaction of carbon and steam. This endothermic reaction requires a large amount of heat. In the intermittent water-gas process, this heat is obtained by regenerative heating of the introduced steam as well as of the fuel bed by combustion of part of the carbon with air. In other methods, the reaction zone is operated continuously, and the heat required for the water-gas reaction is obtained either by the outside heating of a retort with combustion gas or by highly superheating the steam introduced into the fuel bed. Sometimes, part of the gas is recirculated through the heater and the fuel bed to increase the heat available for the water-gas reaction.

Recently a few of the recycling processes have used some oxygen to overcome the difficulty of heating large quantities of gas to high temperatures or circulating this gas with high velocity through a disintegrating fuel (as in the Schmalfeldt-Wintershall process).

Compared with the continuously-operated gas producer, all of these methods are complicated in operation and equipment. The only way of avoiding these complications is the separation of the nitrogen from the combustion air. For some time, therefore, the use of pure oxygen for gasification has been investigated by gasification engineers, but only recently could the oxygen be produced cheaply enough for use in gas production. As regards operating costs and utilization of inexpensive fuels, the superiority of gasification with oxygen proved to be so great that this method is considered the most important one for large-scale hydrogen-carbon monoxide production. Many processes have been developed, depending on the technical experience of the developing engineers, the special character of the fuel, and the required composition of the gases.

A rather complete description of the various methods of gasification which have been used in industry or tried in larger-scale experimental work is found in a report of L. L. Newman[*] to which reference may be made for detail. For the purpose of this paper, the figures of Newman's report are checked with the author's experience and with regard to further improvement and the gasification of fuels which are best suitable for this special method of gasification. Based on these figures, the economical value of the various methods is compared.

[*] L. L. Newman. Oxygen Production and Utilization in Gas Making Processes, 1946. Report of the Gas Production Committee of the American Gas Association.

As the chemical and physical properties of a fuel are most important for the gasification methods used for the production of liquid fuels as well as for the results of gasification in each of the various methods, these methods are also compared with regard to the coal resources which for economical reasons are most favorable for such an industry.

OPERATING PRINCIPLES OF THE VARIOUS METHODS

Gasification with pure oxygen can be operated in the same way as gasification with air. However, it allows a wider range of temperatures. Reactions can be intensified, but the danger of slagging and the necessity of an efficient control of operating conditions are increased. Operation of slagging producers with a fixed fuel bed is facilitated by oxygen.

The various methods may be classified according to the operating principles as follows:

Fixed fuel bed				Fluidized fuel bed	In suspension
Low temperature mechanical grate		High temperature slagging		High temperature	high and low temperature
Atmospheric pressure	High pressure	Leuna	Thyssen-Galoszy	Winkler process	pulverized coal
Viag-I.G.	Lurgi pressure gasification			Winkler generator	Koppers process
Leaside					
Lurgi carbonisation gasification					

There are several technical features connected with each of the above processes which are most decisive for the suitability of any one of them in a special project. These features concern the quality of coal which can be used and the composition of the primary gas which can be produced with the process in question.

Gasification in a Fixed Fuel Bed with a Mechanical Grate.

This gasification must be operated with a relatively low temperature depending on the fusion point of the ash. A high throughput without clinkering troubles can be expected only with a high fusion point of the ash, a uniformly medium-sized, non-caking coal or coke, and a high amount of steam, introduced with the oxygen. Consequently, a relatively high content of hydrogen and carbon dioxide in the gas is unavoidable. In case the producer is operated with carbon dioxide which must be recycled into the fuel bed, a high carbon monoxide content of the gas is reached also in this method.

Recovery of by-products can be combined with this method when non-caking coal is used, but a certain amount of hydrocarbons (CH_4) is unavoidable in this case, and a separate carbonizer plant is therefore advisable.

When operated under pressure, smaller sized coal can be used with an increased throughput and a high heating value of the gas, but for hydrogenation or synthesis purposes, the CH_4 of the primary gas must be converted into $CO + H_2$ by an additional thermic splitting.

The production of a hydrocarbon-free gas mixture directly from coal is possible in a 2-stage generator, in which a separate carbonization zone is combined with a gas producer zone operated with oxygen and steam. A relatively high carbon monoxide content of the gas can be reached in this case by a partially parallel operation of oxygen and fuel.

Gasification in a Fixed Fuel Bed with Slagging Ash.

A safe and controllable operation with slagging ash requires a solid lumpy fuel with a low or medium fusion point of the ash. Sometimes even an addition of limestone or other fluxing material is needed to keep the ash sufficiently fluid. A high throughput and high velocity of the gases in the fuel bed are necessary for a sufficient control of the slugging. Gasification of bituminous and subbituminous coal is not feasible under such conditions because purification and handling of a gas with much dust and heavy tar is difficult and expensive. The advantage of a hydrocarbon-free gas would also be lost when operated with coal. The content of hydrogen in the primary gas is limited to approximately 30 percent with respect to the slagging operation.

A 95-percent carbon monoxide gas can be produced with the slagging method if carbon dioxide is available from some other resource.

Gasification with a Fluidized Fuel Bed (Winkler gas).

Small-sized, disintegrating coal or char can be gasified with a very high gasification rate. However, by-products cannot be recovered. The consumption of oxygen is high and the thermal efficiency relatively low, the moreso with less reactive bituminous coals and coke from such coals. Only a gas with a high hydrogen content can be produced, and the carbon dioxide content of the gas is so high that a water-wash is unavoidable for any utilisation. The amount of blown-over fuel is also high.

Gasification of Pulverized Coal (in suspension).

In this process, any coal which can be pulverized at reasonable cost, can be gasified. The recovery of by-products is not possible. The composition of the gas can be changed in a wide range between 2:1 and 1:1 CO to H_2 ratio. A relatively high content of carbon dioxide (above 10 percent) probably makes the elimination of carbon dioxide unavoidable, even with the 2:1 ratio. Until now, it is the only method available for a direct gasification of caking coals.

UTILIZATION OF THE GAS AND THE QUALITY REQUIRED.

It has been mentioned before that the method of gasification determines certain features of the primary gas. In order to estimate the advantages of the gasification methods, it is necessary to analyze the requirements of the gas-consuming industry.

Heating- Public Utility Supply.

At present, this field of consumption is supplied by natural gas of 900 to 1000 B.t.u. or by carburetted water gas of 500 to 550 B.t.u./cu.ft. Supposedly this consumption is increased or has to be replaced by gas from coal. Then a gas of 500 to 600 B.t.u. is needed with 30 percent hydrocarbons and 30 to 40 percent hydrogen. Probably the gas has to be under a pressure of 10 to 20 atmospheres because carbon dioxide must be eliminated and a larger plant would be erected at the mine where production costs are lowest.

Hydrogen Gas for the Hydrogenation and Ammonia Synthesis.

For hydrogenation, practically pure oxygen is needed. Compression of the raw gas and the elimination of carbon dioxide are unavoidable. A high hydrogen content of the primary gas is of great advantage. Hydrocarbons are a great disadvantage and should not exceed one and one-half percent. Organic sulfur is of no great importance.

For the synthesis of ammonia, a pure hydrogen can be mixed with nitrogen, or the synthesis gas can be directly produced by gasification with oxygen-enriched air or 40 to 50 percent oxygen content. Low content of methane and sulfur are essential.

Synthesis Gas for the Fischer-Tropsch Synthesis.

Gas of a $CO:H_2$ ratio of 1.5:1 to 1:2 is needed. Organic sulfur and gum-forming hydrocarbons are to be reduced to a minimum as poisons for the synthesis catalyst. Compression of the gas normally is required, for the synthesis and for the elimination of carbon dioxide.

Gas for the Synthesis of Organic Acids.

Gas of a very high carbon monoxide content is used for the synthesis or organic acids.

Gas for Power Production.

Gasification of cheap fuels with air may be developed as a future method of power production in connection with a gas turbine. In this case, hot dust-free gas is needed, under pressure of 5 to 20 atmospheres.

THE RECOVERY OF BY-PRODUCTS

For a comparison of the economical aspects of the various methods of gasification, the valuation of by-products is very important. Until now, such by-products may be of little value as no market can be found. This situation will change immediately when production of gasoline from coal has been started, because then the by-products of gasification after refining can be mixed with products

of hydrogenation and synthesis which thus may sometimes even be improved, or gasification by-products can be hydrogenated at much lower cost than coal. Therefore, a maximum of by-products should be provided in connection with coals of high tar content, as long as their recovery does not cost much more or even simplifies the production and purification of the synthesis gas. In Germany, the tar sold to hydrogenation plants was valued at 40 to 50 percent of the production costs of synthetic or hydrogenation gasoline from coal, and these plants were operated with the lowest production costs for gasoline. However, it should be remembered that for caking coals, no inexpensive method of carbonization or by-product gasification has been developed so far.

TECHNICAL PERFORMANCE AND POSSIBLE IMPROVEMENT OF THE DIFFERENT METHODS.

Fixed Bed, Mechanical Grate, Atmospheric Pressure.

This method of gasification is very suitable for the production of hydrogen-rich gases for hydrogenation and synthesis from coke, semi-coke, or anthracite. Such a gas is highly concentrated, and can be easily purified. For the gasification of raw bituminous coal, the content of CH_4 is a drawback, except in case the gas should be used as a heating gas, possibly after passing a synthesis plant.

Therefore, this gasification method should be considered primarily for the utilization of highly bituminous, non-caking coals, in connection with a carbonization plant. The auschwitz works, built in 1942, were based on this method.

Mechanical units with a capacity of 60 to 80 tons of coke or 120,000 to 150,000 normal cubic meters of carbon dioxide-free gas per day and a relatively low consumption of oxygen account for low investment and low operation costs of such a plant.

Carbonization and gasification can be combined in a modified Lurgi carbonizer. Such a combination obviously improves the heat and the material balance and saves investment and labor costs compared with separate carbonization and gasification plants. Units of a capacity of 300 tons of bituminous coal per day, corresponding to 300,000 to 350,000 normal cubic meters of carbon dioxide-free gas from gasification of coke are the usual dimensions of a Lurgi carbonizer. The gas production can be increased to 400,000 normal cubic meters per day and unit by a splitting of the distillation gas with oxygen.

Downwards operating with part of the used oxygen saves part of the steam, and allows production of a gas with a high carbon monoxide content. Even the ratio 2:1 for CO to H_2 can be produced if part of the carbon dioxide is recycled from the water wash.

Gasification with Fixed Fuel Bed Under 20 Atmospheres Pressure.

This method is suitable for the gasification of all non-caking fuels in sizes above 1/8 inch. A primary gas with 20 percent CH_4 is produced with only 50 percent of the oxygen consumption of other methods and even 35 percent based on thermal units. No compression of the gas is required, and the hydrogen sulfide can be removed with the water wash.

For the production of hydrogen or synthesis gas, the primary gas must be split with oxygen, and the total quantity of oxygen is equal to the amount needed in straight gasification under atmospheric pressure. Organic sulfur and gum-forming compounds are removed completely. The splitting stage allows a regulation of the $CO:H_2$ ratio in a wide range between 1.5:1 and 1:2,

By-products are recovered in very good quality. City gas with 500 to 800 B.t.u. can be easily and cheaply produced by converting part of the carbon monoxide and hydrogen in a 1-stage synthesis into gasoline.

The capacity of a 2.6 cubic meter unit, when operated with coal of medium or high fusion point of the ash, is 100 to 120 tons of water-free coal per day. Construction of a mechanized unit of 3.5 cubic meters and a capacity of 180 to 200 tons of coal or 220,000 to 250,000 normal cubic meters of carbon dioxide-free gas per day cannot offer serious difficulties according to the experience available.

This method has some important advantages for the gasification of all non-caking coals, for the production of city gas and the gasification of small-sized, non-caking coal with a tar content above 5 percent, for the production of gas for synthesis and hydrogenation. These are by-product recovery and low power consumption.

Gasification in a Fixed Bed in a Slagging Producer.

Only a solid coke above 1-inch size can be gasified with this method. The $CO:H_2$ ratio of the primary gas is above 2, the carbon dioxide content low enough for a direct use in a synthesis process. 300,000 to 350,000 Normal cubic meters of synthesis gas can be produced per unit per day. This method is favorable when high-grade coke and anthracite is available at a low price and a high $CO:H_2$ ratio is needed for the synthesis process that follows. An additional shift conversion of carbon monoxide is normally required, and an elimination of the carbon dioxide formed in the shift reaction.

Gasification of Pulverized Coal.

This method may be considered the most universal with regard to the fuels. Even caking coals, not suitable for any other method of direct gasification, can be gasified. Consumption of oxygen and steam are relatively low, the oxygen consumption slightly higher than in stationary fuel bed operation. The additional costs of pulverization may be important with hard fuels, such as anthracite, splint coal, woody lignite, and some carbonization residues. By-products can be recovered only by a separate carbonization.

The method has been developed technically only in an experimental unit, but no exceptional difficulties should be expected in developing an industrial unit of 300 to 500 tons capacity per day for atmospheric pressure operation. The gas production of such a unit may safely be estimated as 500 to 600,000 normal cubic meters per day.

For the eastern coal fields of the United States, where caking coals probably are primarily available for the production of liquid fuels, gasification of pulverized coal seems to be so important that the development of an industrial unit should be considered urgent, even if the method is less favorable for other coal fields.

The production costs of the gas could be reduced considerably in case gasification of pulverized coal would be operated under 10 atmospheres pressure.

Selection of the Gasification Method.

Except for the production of city gas in which gasification under pressure probably will be most economical for non-caking coals, gasification of pulverized coal is the only available method for caking coals for the large-scale production of $CO + H_2$ in connection with the production of gasoline by hydrogenation or synthesis.

In both cases, production can be relatively cheap in large plants only, and with a cheap coal. Run-of-mine coal generally will be the material to be used in the production of gasoline and all auxiliary plants included, such as power production, steam production, and fuel consumption for the mine. In case of hydrogenation, the production of hydrogen requires only a small percentage of the coal, especially if the residual gas of hydrogenation is cracked. In a hydrogenation plant, a suitable coal size may be easily found for any gasification method. Gas production in a synthesis plant requires a much higher amount of the total coal consumption; only 20 to 30 percent may be needed for other purposes. Methods needing a selected lump size coal or coke for gasification cannot be used in a synthesis plant because the quantity required cannot be procured without a surplus of lower-grade fuel. Moreover, the costs of such high-grade fuels, such as coke, as the main raw material of the production obviously increase the production costs of the gasoline to an uneconomical level. There may be exceptional cases of highly volatile bituminous coal in which the recovery of more than 10 percent tar suitable for hydrogenation cover the costs of carbonization and procure a lumpy coke at a low price (Utah).

The present slagging methods generally cannot be considered for these same reasons. Even for gasification in a fixed bed under atmospheric pressure, which needs a coke above 1/4-inch, difficulties may arise in order to procure enough of this coke in an independent synthesis plant, without wasting fuel. Conditions are slightly better if carbonization and gasification are combined and an additional disintegration of the coke by transport and screening is avoided.

With gasification under pressure which can be operated with 1/8-inch coal, usually no difficulties exist in utilizing the fuel below 1/8-inch for the mine and for the production of power and steam.

There are no size restrictions for the utilization of the Winkler and the Koppers method.

Composition and purity of the gas also are of great importance.

For hydrogenation, hydrogen only is of interest, and its preparation requires a shift reaction with any gasification method, the compression of the gas, and the removal of carbon dioxide by water wash. A low content of nitrogen and methane is essential; a high content of hydrogen of the primary gas is advantageous. Any method, avoiding CH_4 by using coke or by splitting the hydrocarbons, is suitable. Production of the gas under pressure would be a great advantage, not only for reduced power consumption but also for simplified sulfur removal, and for the reduction of investment and operating costs of compression. All the gasification methods may be used for the production of hydrogen. A high carbon monoxide content in the primary gas can be converted in the unavoidable shift conversion plant with relatively low additional cost.

For synthesis purposes, the situation is not so clear yet. Though the superiority of iron catalysts may be proved, it still is an open question which ratio of $CO:H_2$ is most favorable, and also, whether operation under pressure is essential or even profitable for a good efficiency and quality of products. In case the engineering problem of heat transfer and temperature control can be solved satis-

factorily, as in a fluidized or suspended catalyst system, operation under pressure no doubt will be more efficient. It has sometimes been claimed that a 2:1 ratio of $CO:H_2$ is desirable for iron-catalyst operation. However, experience shows that a 1.5:1 ratio is quite satisfactory, and even a 1:1 gas can be used very well for an iron catalyst. In a *fluidized* system, such as the *Hydrocol* process, even a 1:1.8 ratio can be used with very good results. For the production of Diesel oil, mainly with a cobalt catalyst, a 1:2 ratio of $CO:H_2$ is required.

Except for very high carbon monoxide contents which can only be produced in a slagging operation, a 1.5:1 ratio of $CO:H_2$ can be produced with all the other methods. Some of them require recycling of carbon dioxide from the water wash of the synthesis gas or the residual gas of the synthesis. A shift reaction can and should be avoided even for a 1:1.8 ratio. The elimination of carbon dioxide from the synthesis gas, however, is unavoidable because with none of the methods in question a primary gas with less than 10 percent carbon dioxide can be produced. Compression of the gas and water wash probably will be required, or will be of advantage in any synthesis plant, even if pressure is not important for the synthesis itself. The product of carbonization (Thiophene and gum formers) would require an additional active carbon equipment if they are not sufficiently cracked in the gasification process itself. Favorable conditions for the complete removal of organic sulfur and gum-forming individuals are a very important economical factor of a gasification method in connection with the synthesis of hydrocarbons.
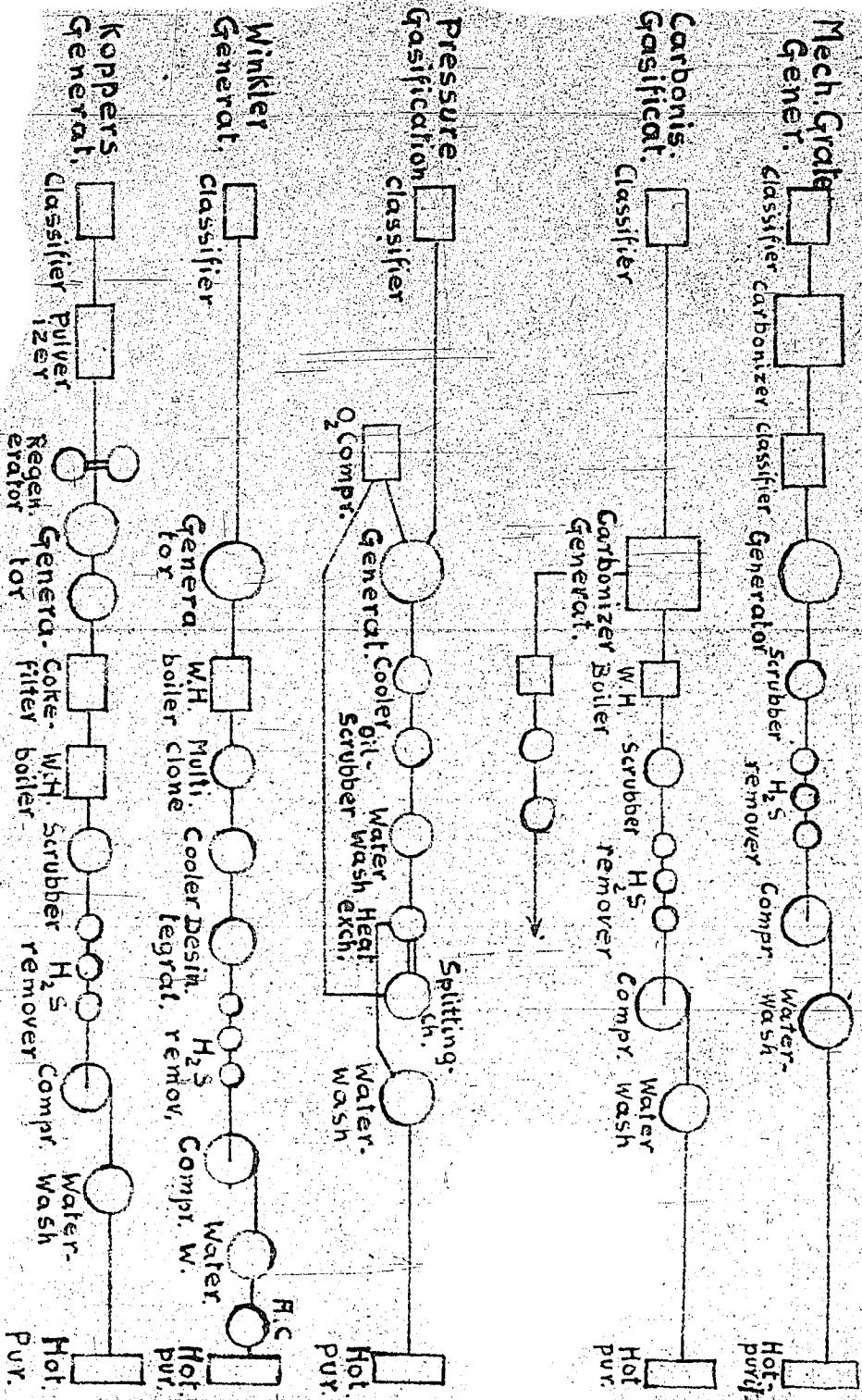
For a rough estimation, it may be mentioned that according to calculations on the German works, the costs of compressed hydrogen amounted to 5-7 Pfennig per normal cubic meter, based on production costs of 1.5 to 2 Pf. per normal cubic meter of raw gas. Compression, sulfur removal, shift conversion, and removal of carbon dioxide are the causes for very high additional costs.

Besides these facts, the actual production costs per unit of purified synthesis gas, based on the available fuel, are decisive for the selection of the most economical method of gas manufacture.

FLOWSHEETS OF GAS PRODUCTION OF THE VARIOUS METHODS (Table 1).

Considering the fact that the preparation of the coal and the composition of the primary gas are different with the various methods, and that the difference in pressure, sulfur content, and resins requires different means of purifying before the gas is suitable for the synthesis process, it is very instructive to compare the flowsheets of production of each method. They start from run-of-mine coal and oxygen under atmospheric pressure and end with the purified gas before entering the synthesis reactor. These flowsheets also refer to the production of hydrogen for hydrogenation in which the primary stage of gasification might be operated with more steam, except for an additional shift reaction and a second water wash which are equally required for each method. A comparison of these flowsheets shows that the gasification and purification of the gas are relatively simple when a carbonized fuel is gasified in a fixed fuel bed under atmospheric pressure. Removal of the hydrogen-sulfide at atmospheric pressure cannot be avoided though the water

Table I.

Methods of Gasification with Oxygen.

Mech. Grate
Gener.

Classifier Carbonizer Classifier Generator Scrubber H₂S remover Compr. Water-Wash Hot purif.

Carbonis.
Gasificat.

Classifier Carbonizer Boiler Generat. W.H. Scrubber H₂S remover Compr. Water Wash Hot pur.

Pressure
Gasification

Classifier O₂ Compr. Generat. Cooler Oil- Scrubber Water Wash Heat exch. Splitting ch. Water wash Hot pur.

Winkler
Generat.

Classifier Generator W.H. boiler Multi. Cooler Desin. Cyclone Integrat. remov. H₂S remov. Compr. W. Water Wash H₂C Hot pur.

Koppers
Generat.

Classifier Pulverizey Regenerator Genera- tor Coke- filter W.H. Scrubber boiler H₂S remover Compr. Wash Hot pur.

wash may be used for the last traces. Carbonization needs additional
equipment and must be paid by the recovery of the tar and benzine,
and the removal of most of the sulfur, especially the organic one and
the gum formers.

For non-caking coals, with high tar content and especially
if high in sulfur, carbonization and gasification must be considered
the most economical method. Combined carbonization and gasification
can be operated with lower investment and labor costs and with higher
efficiency.

Slightly caking coals can be used in the LURGI carbonizer.

Gasification under pressure, so far feasible only for ab-
solutely non-caking coals in the LURGI pressure generator, also al-
lows the recovery of by-products. The flowsheet, coal preparation
included, is most simple for the production of city gas. An addi-
tional splitting of the hydrocarbons is required for the production
of synthesis gas or hydrogen. There, a 2-stage gasification takes
place, with the same total amount of oxygen required as with other
methods in the 1-stage gasification. The second stage of gasifica-
tion (splitting of hydrocarbons) as an operation with clean gas
under pressure needs very little equipment and little operation
costs, which do not exceed the otherwise required costs for the re-
moval of H_2S, organic sulfur, and gum formers. At the same time,
the splitting operation allows the carbon monoxide content of the
synthesis gas to increase, according to the requirements of the syn-
thesis.

The Winkler generator and the Koppers generator do not allow the recovery of by-products, except in a separate, preceding carbonization plant (this was the case in all the Winkler generators operated in Europe). The flowsheets of these two methods are slightly more complicated than the preceding ones. However, operating with carbonized fuels for these two methods should be considered only with non-caking coal of a very high tar content because only in this case, the cost of carbonization and quality of by-products are favorable and because in the direct gasification of coal, the volatiles of a fuel are gasified and converted into $CO + H_2$ without an additional oxygen consumption. With carbonized or low-volatile fuels, a higher amount of oxygen per unit of gas is required.

A relatively low heat efficiency, a high temperature of the gas, and a relatively high content of ungasified carbon in the gas require a number of special apparatus for the recovery of waste-heat, the recovery of unburned carbon and the cleaning of the gas from a fine dust, and the removal of hydrogen sulfide for the protection of the compressor. An additional removal of organic sulfur and gum-formers may be necessary in case of the Winkler generator. With the Koppers method, pulverization of the coal and eventually additional drying require additional equipment.

With cheap fuels, such as strip-mined subbituminous coal, the costs of pulverization alone may be equal to some 20 to 30 percent higher heat loss of other methods, and the economic superiority of the method generally seems doubtful.

As the only method of gasifying caking coals directly, it should have a wide field of application of its own.

COMPARISON OF INVESTMENT AND PRODUCTION COSTS OF THE VARIOUS METHODS.

From the preceding pages, it can be seen that each method has a special field of application, according to the properties of the coal, its price, and the utilization of the gas. Therefore, it is difficult to compare the methods economically in a general way.

Reliable figures for a comparison of the economy of two methods can only be based on a certain project, the same coal, and the possible combination of the gas production with the production of power and steam, and the requirements and surplus quantities of steam and energy used or available in the synthesis process.

In Table 2, the investment costs for the principal methods have been calculated for the production of 100,000 normal cubic meters per hour or 3,500,000 cubic feet per hour of $CO + H_2$ in a synthesis gas for a synthesis operated with an iron catalyst under 20 atmospheres pressure. The investment costs of the boiler and power house are decreased because in this case, steam and residual gas are available from the synthesis and in some methods energy is also available from waste heat of the gas production or from carbonizer gas. It also provides a direct drive of the big turbo-compressors required for the production of oxygen, and for the compression of the primary gas by means of steam-turbines. In this way, the investment costs of the power plant can be reduced considerably.

The investment costs do not include the equipment for the removal of the last traces of sulfur (hot removal) before entering the synthesis reactors. This equipment is the same for all the methods of gasification. The hot removal probably cannot be avoided even with pulverized coal gasification and after a splitting reaction.

Table 2.- Investment costs of gas production *(dollars)*
for 3,500,000 cubic feet per hour CO+H$_2$.

	Mechanical grate generator	Carbonizer generator	Pressure generator	Winkler generator	Koppers generator	Slagging generator
Coal handling	500,000	800,000	800,000	800,000	2,500,000	500,000
Carbonizer generator	1,600,000	2,400,000	4,100,000	4,200,000	6,000,000	1,200,000
Condensation cooling	1,200,000	1,500,000				1,200,000
Benzine recovery	---	900,000	800,000	---	---	---
Storage of by-products	---	200,000	200,000	---	---	---
Distribution of energy, steam, and water.	500,000	600,000	500,000	500,000	600,000	400,000
Recooling system	300,000	400,000	300,000	300,000	300,000	300,000
Water wash	2,800,000	2,500,000	3,800,000	3,000,000	2,500,000	---
Sulfur removal	600,000	600,000	---	800,000	800,000	1,000,000
Compresser plant	1,200,000	1,200,000	---	1,200,000	1,100,000	1,000,000
Oxygen plant	4,500,000	4,900,000	5,800,000	5,000,000	4,800,000	4,800,000
Roads, tracks	700,000	750,000	750,000	700,000	700,000	700,000
Office, laboratories, repair shops	700,000	750,000	750,000	700,000	700,000	700,000
Boiler, power house	7,000,000	5,500,000	6,000,000	6,500,000	6,000,000	7,000,000
Miscellaneous	1,100,000	1,100,000	1,200,000	1,200,000	1,200,000	1,000,000
Total	$22,700,000	$24,100,000	$25,000,000	$24,900,000	$27,200,000	$19,800,000

Figures are calculated with U.S. dollar = 2 RM, from the costs of German plants.

An approximate idea of the economical advantages and disadvantages of the different methods may be taken from a comparison of their main investment and operating figures (Table 3.).

Table 3.- Production figures: Production of 3,500,000 cu.ft. CO+H$_2$ per hour at 20 atmospheres pressure, purified. g/

Gasification method	Invest- ment costs b/ million dollars	Thermal efficiency of gas c/ percent	Fuel	By- pro- ducts	labor d/ m.d/men	O$_2$ con- sumption, cu.ft./ 310 B.t.u.	Outside steam from generator lb./h.	Com- pres- sion of gas	Power con- sump- tion KW/h.e/
Fixed bed Atmospheric pressure									
Mechanical grate producer	23,000	80	coke	no	320	0.25	110,000	yes	45,000
Carbonization gasification producer	21,000	80	non-caking coal	yes	280	0.24	100,000	yes	49,000
Slagging generator	20,000	75	lump coke	no	250	0.27	---	yes	42,000
20 Atmospheres pressure									
Lurgi city gas, 3,200,000 cu.ft./h.	15,000	83	non-caking coal	yes	250	0.11	225,000	no	21,000
Lurgi synthesis gas	22,000	70	non-caking coal	yes	320	0.30	110,000	no	35,000
Fluidized bed Winkler	25,000	65	non-caking coal	no	370	0.3		yes	44,000
Pulverized coal atmos. pressure (Koppers)	27,000	75	non-caking and caking coal	no	380	0.28		yes	44,000
20 atmospheres pressure	24,000	75	non-caking and caking coal	no	380	0.28	110,000	no	30,000 f/

a/ See also "Production of synthesis gas from Wyoming Coal". Investment costs of Koppers process are estimated according to Koppels. Lurgi figures are decreased for larger units and heat exchange in splitting stage.

b/ Includes boiler and power house, based on surplus of steam and residual gas from the synthesis.

c/ Thermal units of gas/thermal units of coal or coke (minus own consumption of gas).

d/ Labor for carbonization (100) is charged to by-products; laboratory, administrative, power house, and re- pair shops included.

e/ Includes oxygen production and compression of gas. Power from waste heat is deducted.

f/ For carbonization and tar recovery, $3,000,000 is deducted.

g/ This is to show the chance of further improvement of gasification of pulverized coal.

In order to bring these figures on the same basis with regard to by-product operation and direct complete gasification respectively, $3,000,000 of the investment costs and 100 laborers have been deducted from the total figures of by-product gasification. These figures show that there is no essential difference between the various methods with regard to production figures of gasification. The production of city gas by pressure gasification is the only outstanding process. Low oxygen consumption, low power consumption are reasons for low investment and production costs, without considering the high thermal efficiency and the higher heating value of the gas.

The table does not consider the value of by-products and the costs of the fuel. However, these two items are most important factors in the calculations of the production costs of the gas.

The value of by-products must be from the production costs of gasoline and Diesel oil when hydrogenation and synthesis methods are used. In this case, 0.20 to 0.25 RM/kg. of gasoline and Diesel oil have been the production costs of the more economical European plants and 15 cents per gallon of gasoline may be considered as a very optimistic figure to be expected in this country after further improvements of the methods and in very large plants. In Germany, 40 percent of the production costs of hydrogenation gasoline have been considered to be a very attractive price of tar as a raw material for hydrogenation plants. The plants treating tar by distillation and refining methods were operated on the same basis with regard to the price of tar. It seems reasonable to evaluate by-products of gasification and carbonization on the same ratio to the price of gasoline from coal, that is:

$$1 \text{ kg. of tar} = \frac{0.15}{3} \times 0.4 = \$0.02.$$

A complete calculation has been made for the production of synthesis gas from Wyoming coal. The principal figures of these calculations adjusted to Tables 2 and 3, and with the above evaluation of by-products, are shown in Table 4. The investment costs include carbonization and by-product recovery. These figures also show that the Winkler method and the Koppers method are not cheaper gasification methods as such. Their only advantage is the utilization of fuels which cannot be used in other methods. The gas production, however, is cheaper only in case these fuels are considerably cheaper than those required for the other methods. In Table 4, figures have been added for the slagging generator operated with oxygen and a lumpy coke. The last column gives the figures of a blue water-gas plant operated with the same coke at a price of $6.50 per metric ton. With a price of $4.00 per metric ton for semi-coke, the costs of the gas produced in a slagging generator equal the costs of the gas produced by the Winkler or the Koppers generator from subbituminous coal at $1.00 per metric ton.

With coal of 7.2 percent tar content, the value of by-products equals the costs of the coal required for by-products and gas production, and the total production of liquid fuels is increased by 30 to 40 percent. Even if the costs of coal above 1/4-inch size are increased by 20 percent to $1.20 per metric ton (column 5), the production costs of the gas would be increased only very slightly.

The figures of Table 4 show that with a higher tar content of the coal, the difference of production costs is increased in favor of by-product methods.

Hubmann, Otto: Production of Synthesis Gas From Wyoming Coal.

Table 4.- Production costs for 3,500,000 cu.ft./hr. synthesis gas (CO+H2), purified and compressed.

Process	Subbituminous coal, $1 per metric ton			Carbonization		Semi-coke, $4 per metric ton		Coke, $6.5 per metric ton
	Winkler generator	Koppers gasification of pulverized coal	Lurgi pressure gasification	gasification with oxygen	carbonization, gasification with air	Mechanical Erato generator	Slagging generator	Water gas generator
Investment costs, million dollars	25	27	25	23	23	23	20	18
Coal consumption, metric ton/year	800,000	740,000	945,000	925,000		600,000	600,000	650,000
Tar products, metric ton/year	—	—	44,200	60,500		280	250	280
Laborers	370	380	420	380	380	280	250	280
Coal, million dollars	0.8	0.74	0.945	0.925	1.11b/	2.40	2.40	4.22
Wages, million dollars	0.93	0.95	1.05	0.95	0.95	0.70	0.63	0.70
Material and overhead, million dollars interest on operating capital	0.35	0.40	0.40	0.40	0.40	0.35	0.35	0.35
Interest amortization, 12.5 percent replacement material.	3.13	3.38	3.13	3.00	3.00	2.88	2.50	2.25
Value of tar, million dollars	—	—	0.884	1.21	1.21	—	—	—
Production costs, million dollars/year	5.21	5.47	4.641	4.065	4.25	6.33	5.88	7.52
Production costs, dollars/1000 Nm3	6.20	6.50	5.52	4.83	5.06	7.53	7.00	8.9
Production costs, dollars/1000 cu.ft.	0.174	0.183	0.156	0.126	0.143	0.215	0.20	0.256

a/ Figures from German plant.
b/ Costs of subbituminous coal above 1/4-inch, $1.20 per metric ton.

The gasification of caking coals for which gasification of pulverized coal is the only feasible method in this country, obviously can produce gas at a similar price as the gasification of strip-mined subbituminous coal only if the caking coal is very cheap.

With a price of $2.00 per ton of caking coal, the costs of the gas production are increased by "2 x 600,000 - 740,000) = $460,000 approximately. The costs of the gas are increased by $\frac{460,000}{840,000}$ or $0.54 per 1000 Normal cubic meters $CO + H_2$.

to $7.05 per 1000 normal cubic meters $CO+H_2$

or $0.20 per 1000 cubic feet $CO+H_2$.

Based on a recovery of 150 gallons of finished gasoline per normal cubic meter ($CO+H_2$), the costs of gas per kg. (gallon) of gasoline, depending on the method of gas production and on the coal, have been calculated (see Table 5).

Columns 1 to 4 are figures for a cheap subbituminous coal with a medium tar content; the by-product methods are more favorable. If the tar content of the coal is lower, the difference between the by-product methods 3 and 4 and the methods 1 and 2 decreases. If the coal is mined mostly as a powder, method 1 or even method 2 may be the only method to handle this fuel without briquetting.

Column 5 relates to a synthesis plant based on cheap caking coal.

Column 6 is based on a small-sized coke or semi-coke, produced from a non-caking, bituminous or subbituminous coal in a Lurgi carbonizer plant. Naturally the production costs for the gas are slightly higher than in a combined carbonization-gasification as in Column 4. A 1/6- to 1-1/2 inch coke probably is also available at a similar price from large coke oven plants.

Table 5.— Costs of synthesis gas (CO+H₂) per gallon gasoline.

150 gallons gasoline per Nm³ CO+H₂

1 gallon of gasoline = 3.78 x 0.72 = 2.72 kg.

Fuel	Subbituminous coal, $1 per metric ton				Caking coal Semi-coke, $2 per metric ton	Coke $6.50 per metric ton	
Process	Winkler generator	Koppers generator	Lurgi pressure generator	Carbon-ization generator	Koppers generator	Mechanical grate generator	Water gas generator
	1	2	3	4	5	6	7
Cost of gas, cents/kg.	4.14	4.34	3.69	3.23	4.70	5.02	5.98
Cost of gas, cents/gallon	11.20	11.75	10.01	8.76	12.75	13.60	16.2
Primary gas, $CO:H_2$	1:1	2:1	1.2:1-0.8:1	1.5:1-1:1	2:1-1.2:1	1.5:1-1:1	1.2:1

Column 7 is based on the water-gas generator with a price of $6.50 per metric ton for a 2-inch coke. Such a coke could also be produced from a cheap high-volatile bituminous coal in a carbonizer plant at a price of approximately $4 to $5 per metric ton.

The differences in the production costs of the gas in the various coal fields, and in using a method adapted to the character of the fuel, seems to be within limits, sometimes compensated by lower freight rates for the gasoline and by a certain reduction of investment and operating costs by lower freight and labor costs in building and operating the plant.

The influence of by-products on the price of the gas and on the price of synthesis gasoline is also seen in Table 5, showing the low costs of gas in columns 3 and 4.

In order to compare the production cost of the various methods independent of the utilization of the gas or for those cases where steam and residual gas are not available from the synthesis plant, the production costs have been calculated under the conditions that steam, energy, and oxygen are purchased from other works as far as they cannot be obtained from waste heat or carbonization gas of the gas production.

Investment and consumption figures are shown in Table 7. The production cost can be seen from Table 8. In this case, the production cost depends on the cost of energy and oxygen, and must naturally be higher than in a combined system with reduced cost of overhead, administration, laboratories, etc., and with better thermal efficiency of a combined production of energy and utilization of exhaust steam for the gasification. The production of a high B.t.u. gas (420 B.t.u. per cubic foot) has also been considered in

(in thousands of dollars); number of men per shift (underlined figures)

Table 7.— Investment costs and energy consumption of gas production only.

Process	Mechanical grate generator		Carbonizer generator		Pressure generator		Winkler generator		Koppers generator		Slagging generator		Water gas generator	
Coal handling	500	3	800	5	800	5	800	5	2500	7	500	3	500	3
Carbonizer generator	1600	8	2400	10							1200	5		
Condensation cooling	1200	2	1500	3	4100	18	4200	12	6000	12	1200	2	5500	16
Benzine recovery	—		900	2	800	2	—		—		—		—	
Storage of by-products	—		200	1	200	1	—		—		—		—	
Distribution of steam, energy, and water	400	2	500	2	400	2	500	2	400	2	300	2	300	2
Recooling system	250	1	350	1	250	1	250	1	250	1	250	1	250	1
Water wash	2800	6	2500	6	3800	8	3000	6	2800	6	—		—	
Sulfur removal	600	1	600	1	—		800	2	800	2	1000	2	1000	2
Compressor plant	1200	2	1200	2	—		1200	2	1100	2	1000	2	1000	2
Roads, trucks	600	1	650	1	650	1	600	1	600	1	600	1	600	1
Office, sanitation equipment, repair shops	600	10	650	12	650	12	600	10	600	12	600	12	600	12
Miscellaneous	600	3	650	3	700	3	650	3	650	3	500	3	500	3
O2 compressor, boiler	—		700	2	800	2	—		—		—		—	
Total investment	10350		13600		13150		12600		15700		7150		10250	
Total labor, man/day	156		208		220		176		192		120		160	
Oxygen consumption, Nm3/hour	26500		28000		30000		30000		28300		27000		—	
Purchase steam at 80 atmospheres, metric ton/hour	50		—		75.4		—		—		—		—	
Purchase energy, KWH/hour	22100		17100		10500		25300		25200		24000		20000	

Table 8.— Production costs of synthesis gas per unit (CO+H₂) compressed and purified.
Cost of energy 0.5 cents/KWH; steam $1/metric tons oxygen 0.5 cents/Nm3.
Labor cost, $2500 per man per year.

Process	Winkler generator	Koppers generator	Lurgi pressure generator	Carbonized generator	Mechanical grate generator	Slagging generator	Water gas generator	Pressure gasification 420 B.t.u
Fuel	Subbituminous coal, $1 per metric ton	Subbituminous coal, $1 per metric ton	Subbituminous coal, $1 per metric ton	Semi-coke, $4 per metric ton	Semi-coke, $4 per metric ton	Semi-coke, $4 per metric ton	Coke $6.50 per metric ton	Anthracite slack $2 per metric ton
Fuel consumption, metric tons per year	740,000	700,000	820,000	925,000	420,000	450,000	650,000	580,000
Investment costs, million dollars	12.6	15.7	13.15	13.6	10.35	7.15	10.25	12.0
Tar consumption, metric tons per year	--	--	44,200	60,500	--	--	--	--
Costs, million dollars								
Coal	0.74	0.70	0.80	0.925	1.68	1.80	4.225	1.16
Oxygen	1.26	1.185	1.26	1.175	1.115	1.135	--	0.84
Steam	--	--	0.64	--	0.42	--	--	1.05
Energy	1.06	1.055	0.582	0.714	0.925	1.005	0.84	0.46
Wages	0.44	0.48	0.55	0.52	0.39	0.30	0.40	0.45
Material overhead	0.3	0.35	0.35	0.35	0.30	0.30	0.30	0.30
Interest amortization, repair material	1.762	2.18	1.84	1.905	1.425	1.002	1.43	1.68
Total cost, million dollars/yr.	5.562	5.95	6.042	5.589	6.255	5.542	7.195	5.94
Value of tar, million dollars	--	--	0.884	1.21	--	--	--	--
Production cost of gas, million dollars	5.552	5.95	5.158	4.379	6.255	5.542	7.195	5.94
Production cost, dollars/1000 Nm3	6.6	7.08	6.12	5.20	7.42	6.59	8.55	7.01
Production cost, dollars/1000 cu.ft.	0.185	0.202	0.175	0.149	0.213	0.188	0.243	0.201
CO:H₂ ratio	1:1	1.5:1	1:1	1.2:1	1.2:1	2:1	1.2:1	1:1.8

this table. The same amount of gas of nearly 50 percent more B.t.u.'s can be produced in this case at the same cost per unit, because the equipment for splitting of methane and the additional oxygen consumption are avoided. It indicates the favorable conditions of this method for a combination of a synthesis of hydrocarbons with the production of city gas.

In this case, the synthesis gas contains only 75 percent $CO + H_2$, but the synthesis reactors can be operated with a high space-time yield because the otherwise unwanted C_1-C_3 hydrocarbons can be sold with the residual gas at a good price.

If the residual gas of a synthesis plant can be sold, the synthesis plant has an additional consumption of low-grade coal for the production of energy and the necessity of utilizing small-sized coal in the gas generators may be considerably reduced. The Winkler and the pressure gasification method may even be operated with slack coal screened above 1/8-inch.

CONCLUSIONS

The comparison of investment and production figures of the various methods shows that investment and operating costs, oxygen and power production included, are lower with methods using a fixed fuel bed.

The methods using a fluidized fuel bed or a powdered fuel require additional costs for a lower efficiency (conversion of carbon, consumption of oxygen), and higher investment costs for the necessity of handling very large volumes of gas with a high dust content.

The pulverization of the coal requires further costs which may run up to 50 percent of the coal costs in case of cheap coal. These costs cannot be compensated by higher efficiency, and they show clearly why the method of gasifying pulverized coal must be more expensive than other methods.

The costs of pulverization can be compensated only if cheaper coal can be used than with other methods. This may very often be the case where slack coal is available at a lower price than run-of-mine coal.

Gasification of pulverized coal is the only method of utilizing caking coals for the production of synthesis gas. Therefore, it should be developed as the most important base of a large-scale synthesis industry in the eastern coal fields.

The Winkler process (fluidized fuel bed), though slightly cheaper in operating costs, may lose its interest as soon as the pulverized coal gasification has been developed further, especially if this later method could be operated under several atmospheres pressure.

For the gasification of non-caking coal or coke, gasification methods operated with a fixed fuel bed are more economical. The recovery of by-products from highly volatile coals can decrease considerably the production costs of gas, and may increase the production of liquid fuels by 30 to 50 percent per ton of coal.

A separate carbonization and gasification of the coke in a mechanical grate generator or slagging generator as practiced in Germany may not be equally interesting in this country. The slagging method, using the same high-grade coke as the water-gas process, cannot be considered superior to this process except in case

a very high carbon monoxide content is needed or cheap oxygen is used with an expensive coke. The relative advantages of slagging generators and mechanical grate generators depend on the physical quality of the coke and the fusion point of its ash.

A combined carbonization and gasification of coke in one unit has great advantages; the investment costs would be lower and the loss of fines and heat in the handling of the coke would be avoided. A separate treatment of the carbonization gas and the gasification gas facilitates the purification of the gas considerably. Lower production costs for the synthesis gas can be expected from this method of gasification.

In case a higher heating value of the gas is wanted as for heating purposes (city gas, long distance supply), or in case the synthesis of hydrocarbons can be combined with the production of a high-quality gas, the gasification of non-caking coal under 20 to 25 atmospheres pressure (Lurgi pressure gasification) is more economical than other methods.

The production costs of synthesis gas per gallon of motor fuel can be expected to be lowest with the present methods of gasification about 9 cents per gallon from subbituminous Wyoming coal and about 13 cents per gallon from caking coal in the eastern coal fields.

Roughly, the total production costs of the gas can be subdivided into the following items:

	Percent
Coal	15 – 25
Labor	15 – 20
Capital costs	60 – 50
Miscellaneous (water, material, administration)	10 – 5.

It seems possible to reduce the labor costs in large plants by increasing the units and by mechanizing their operation. With reduced labor costs, a reduction of the gas production costs by 10 percent may be expected after many years of experience.

The capital costs with at least 50 percent are the largest item among the production costs of the gas. They may be subdivided further, after a deduction of 3 million dollars for by-products, as follows:

	Percent of capital costs	Percent of production costs
Coal handling, gasification, cooling	20-30	10-15
Water wash, CO_2 removal	20-15	10-75
Oxygen production (includes power production)	35-30	17.5-15
Energy production (excludes oxygen)	10	5
Miscellaneous, buildings, pipes, compressors	15	7.5
	100.0	50.0

In the capital costs and in the total production costs, the percentages of water wash (CO_2 removal) and oxygen together are 50 percent and 25 percent, respectively. These costs exceed the costs of coal, without considering that part of the costs of coal, 10-15 percent, which is caused by power consumption for water wash and oxygen production. A reduction of the oxygen consumption and elimination or reduction of the water wash would be important for decreasing investment and production costs. Oxygen production and water wash also require one-third of the total labor costs, so the proportionate costs of oxygen production and water wash amount to 30 to 35 percent of the total production costs of the synthesis gas.

The necessity of compressing the gas absorbs 10 to 15 percent of the investment costs. However, it should be remembered that the oxygen has te be compressed in case of pressure operation, and the expansion energy of the steam used for gasification would not be available in case of pressure operation.

So far, the water-gas process is the only method without oxygen production and water wash. This advantage, however, is equalized by the much higher costs of the high-grade fuel and by the low efficiency of its conversion into synthesis gas. As there is very little chance to produce a coke suitable for the water-gas process at less than $6.00 per ton in a coke-oven plant, the production costs of the water-gas process will always be higher than in directly gasifying the coal with oxygen.

The costs of oxygen are reduced considerably by the exothermic methane reaction of gasification under pressure. If the synthesis can be combined with the delivery of city gas, such a combination would allow the production of CO and H_2 at lowest costs because oxygen consumption is lowest and the flowsheet of the process, the least complicated. The costs of oxygen and water wash may also be reduced by a further progress in power production. The residual gas of the synthesis under a pressure of 20 atmospheres is ideal for utilization in a gas turbine. Investment and production costs of power plants can be expected to be reduced in this case to some 50 percent, compared with the usual steam-based power production, burning coal.

It seems quite natural that the building of plants for the synthesis of liquid fuels will be combined with the delivery of heating gas. The fact that 25 percent of the heating value of the gas

entering the synthesis are available as a high-grade and clean gas under pressure, and the experience that natural gas used in the gas fields is the most economical resource for the production of synthetic fuels, and probably will become more expensive for long distance supply, will create a good market for the residual gas of a synthesis plant provided such a plant is not too far away from industrial and domestic consumers. It even seems worth while to consider the production of city gas as the main product and of synthetic gasoline as a by-product with a synthesis method of less efficiency but very low operating costs.

The flexibility of such production according to fluctuating consumption of heating gas is another advantage of such a combination.

Table 6 shows the suitability of the various methods for the gasification and utilization of the different kinds of coal, for the production of only liquid fuels, or for a combination of city gas and gasoline, respectively.
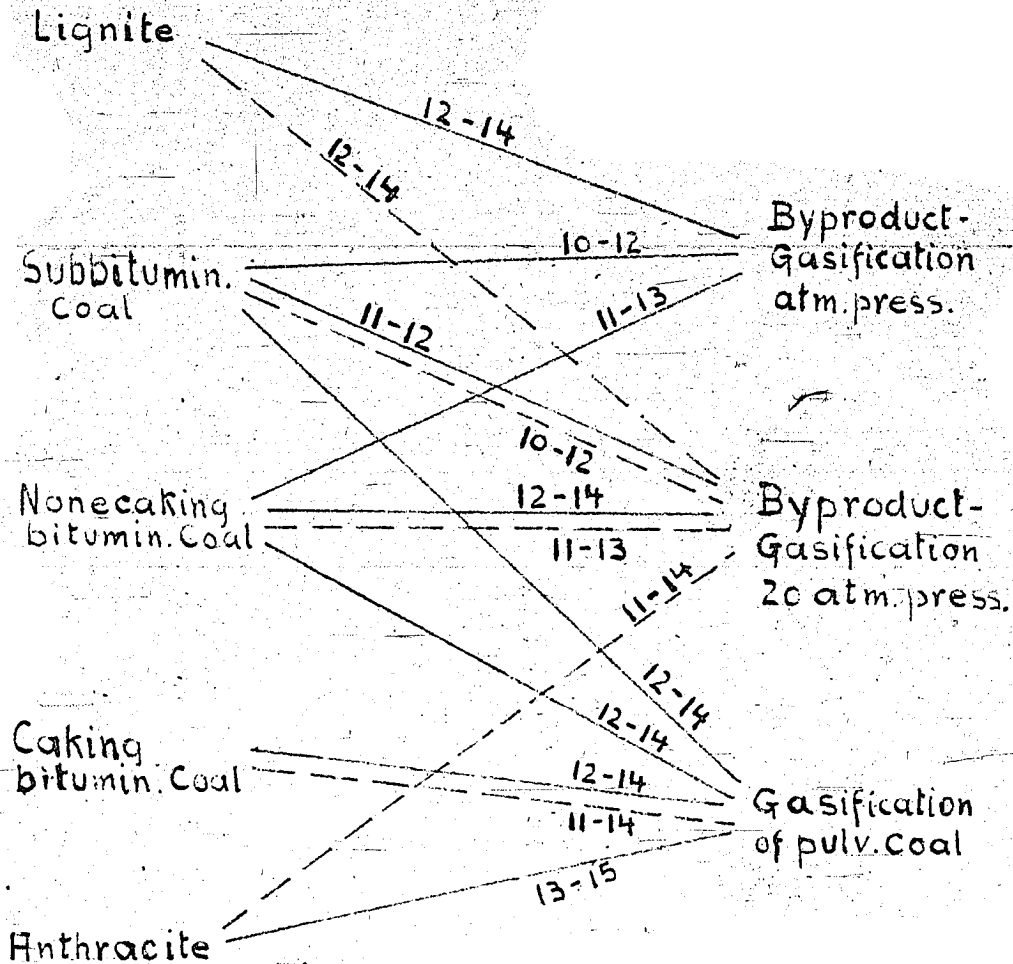
The value of the gasification methods with regard to production costs of the synthesis gas is indicated by Figures 10 to 15, which roughly might correspond to the relative costs of $CO + H_2$ per gallon of gasoline under medium conditions. (Table 6, cents/gallon)

The value of by-products from gasification makes by-product gasification more economical in proportion to the tar content of the coal and to the quality of the tar. The possibility of selling the residual gas of the synthesis also favors by-product gasification because the presence of methane even in the primary gas is an advantage, and in this case makes gasification under pressure superior to other methods for its low oxygen consumption and high heating value of the residual gas.

Table VI

Suitability of the Gasification-Methods
for Various Fuels
and Various Products.
—————— Synthesis of gasoline
– – – – – Combined Production of Gasoline & City-Gas
Figures indicate relative Cost of Synth.-Gas

Lignite

Subbitumin. Coal

Nonecaking bitumin. Coal

Caking bitumin. Coal

Anthracite

Byproduct- Gasification atm. press.

Byproduct- Gasification 20 atm. press.

Gasification of pulv. Coal

12-14   12-14   10-12   11-13   11-12   10-12   12-14   11-13   11-14   12-14   12-14   12-14   11-14   13-15

The following fields of application of the three principal methods of gasification can be clearly recognized:

By-product gasification under atmospheric pressure.	Lignite, subbituminous coal, non-caking bituminous coal, mainly for synthesis.
By-product gasification under high pressure.	Lignite, subbituminous coal, non-caking bituminous coal for city gas and combined synthesis and city gas production.
Gasification of pulverized coal.	All caking coals for synthesis and combined synthesis and city gas production.

All three methods seem to be important for future production of synthetic fuels, the by-product methods for the cheap coals of the Central region, and the gasification of pulverized coal for the bituminous coal fields of the East, where higher production costs are partly compensated by lower transport costs for the products (gasoline and gas).

Research and Development Division
Office of Synthetic Liquid Fuels
U.S. Department of the Interior
Bureau of Mines
Central Experiment Station
Pittsburgh, Pa.
igb