SECTION 4. GENERAL DISCUSSION OF FACTORS AFFECTING ECONOMICS OF GASIFICATION PROCESSES

In any process such as the gasification of coal, many factors must be considered not only in the design of equipment for new proposed processes, but also in the design of new and improved equipment for currently available processes. In the present study, particular emphasis has been placed on (a) coal feed quality, (b) methods of coal feeding, (c) process variables, and (d) scale of operation.

A. Coal Feed Quality

A discussion of quality of coal for use in gasification should begin with the one property of coal that was stated to be most important by all operators of coal gasification plants interviewed during the field trips; namely, uniformity. Provided the coal is of uniform quality within the wide limits specified for the process, operation of a given gasification plant is efficient and continuous.

In summary, it can be stated that those gasification processes that use coal in suspension are least limited by coal quality. Therefore, such processes have been carefully studied to determine whether the oxygen consumption can be reduced and whether throughputs comparable to those of the fixed-bed or fluidized-bed processes can be achieved. Such developments could lead to a universally applicable process using coal regardless of origin, properties, rank, or ash content.

Other coal properties, as they pertain to individual coal gasification processes, are discussed in the sections that follow.

1. Size: Coal of proper size is of great importance for the operation of gasification processes. Not only the initial size but also the size retention is important. Obviously, the requirements of a fixed-bed process are quite different from those of a fluidized-bed or suspension process. The strictest requirements as to fuel quality are found in processes that use the fuel not only for gasification, but also for the storing of heat of combustion in cyclic operation to make the gasification reaction possible.

For the water-gas process, the best fuel is a large size, high-strength coke. The greater the strength and size of the coke, the higher the throughput and the higher the yield, and quality of gas. Similarly, in the slagging coke producer, because of the high blast velocities at atmospheric pressure, the best fuel is one that does not soften or break in the fuel bed. In fixed-bed processes, as the gasification pressure increases, the blast velocity required usually decreases, and the requirements as to size of coal are mitigated. Thus, in the Lurgi process, coal that is dust-free and above 1/8 to 1/4 inch in size is satisfactory.

In fluidized-bed processes, attrition of the feed coal to very fine dust results in increased fuel carry-over and loss. This can partly be compensated for, e.g., in the Winkler process, by starting with a larger size if the coal abrades readily. Dust carried over is usually collected and burned in power plants.

Suspension processes have the least requirements as to uniformity of size and size retention. Pulverized fuel of finer size is needed as the reactivity of the coal decreases or as the rank increases.

2. Ash: The coal ash influences coal gasification. Two main factors are involved: (a) the percentage of ash, and (b) the ash melting point.

The absolute level of ash content has a minor influence on the efficiency of most gasification processes. Fluidized-bed processes appear to be the most sensitive in this respect; the reactivity of the carbon in the bed in these processes seems to depend upon its carbon content. A high ash content will be of greater influence in non-slagging processes, and can be handled more readily in slagging processes without loss of carbon in the residue withdrawn from the gasifier.

The ash melting point is of importance and, depending on the process, two diametrically opposed requirements exist. In slagging processes, a low ash melting point is desirable. However, even coals with very high ash melting points can be successfully gasified in slagging oxygen-blown producers at very high temperatures. The ash melting point can be decreased by fluxing at an added cost to the process. In non-slagging processes, like the normal commercially used Lurgi process, a high ash melting point is an advantage. A high ash melting point permits higher operating temperatures and lower steam-oxygen ratios which lead to higher throughputs and higher thermal efficiencies.

There is little published quantitative information available about the influence of the content and the melting point of coal ash on the cost of the gas produced. The British have evaluated three coals of varying ash melting point and ash content.(3) The influence of the ash on gasification cost is masked by the swelling and caking properties of the coal and the mechanical properties of the resultant coke.

On several occasions during the survey, sodium chloride present in the coal ash was mentioned as the cause of caking in fixed beds; this was attributed to the low melting point. It was also mentioned as a cause of corrosion.

3. Rank: The rank of coal influences gasification in two ways: (a) as an index of the plastic properties of the coal, and (b) as an index of the coal reactivity and/or volatile matter content.

The influence of coal rank on the gasification results for the fixed-bed Lurgi process is shown in Table 4-1. Medium volatile coals that are highly caking and expanding during carbonization are not included in the table; such coals have not been used on a large scale in the Lurgi process. In general as the coal rank decreases, the throughput increases, the oxygen consumption decreases, and the gas quality improves. The great difference between the low rank brown coal and the higher rank bituminous coal with regard to throughput and consumption is of interest. This difference is indicative of the influence that reactivity of the fuel has and of the ease with which volatile matter can

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(3) The Gas Council and the National Coal Board, "Lurgi Study Group Report," London: Kelly and Kelly Ltd., 1963. pp 18-9.

TABLE 4-1. RESULTS OF TESTS WITH VARIOUS FUELS IN LURGI GASIFIER AT HOLTEN PLANT*

	Rheinish Brown Coal	Bituminous Coal, High Volatile		Bituminous Coal, Low Volatile	Coke
Fuel Analysis					
Volatile Matter, Percent maf Basis	53	42	40.0	9.6	1.8
Ash, Percent Dry Basis	5.8	8.1	23.0	4.8	12.2
Gas Composition, Crude, Volume Percent					
Carbon Dioxide	32.2	28.9	28.8	26.5	37.0
Gas Composition, Purified, Volume Percent					
Carbon Monoxide	25.2	26.9	25.6	28.5	26.4
Hydrogen	54.0	56.2	57.0	58.0	65.8
Methane	17.6	13.9	13.9	10.7	5.0
Nitrogen	0.7	0.7	1.0	0.7	0.8
Gross Heating Value, Purified Gas, Btu/scf	435	410	410	385	345
Gasification Rate, Purified Gas, scf/sq ft-hr	5,060	4,000	4,860	4,620	2,010
Oxygen Consumption, scf/scf Purified Gas	0.13	0.18	0.20	0.19	0.33

* "Chemistry of Coal Utilization, Supplementary Volume," Lowry, H. H., ed., New York: John Wiley and Sons, Inc., 1963. p 961.

be gasified with low oxygen consumption.

A similar influence of rank can also be seen in the data and results for coal gasification in suspension as shown in Table 4-2. The data also indicate that reactive fuels with a high volatile matter content can be gasified more readily and with a lower oxygen consumption than anthracite, a fuel with a high fixed-carbon content.

4. Expansion: Many coals used in the Lurgi gasifier go through a plastic stage upon heating and, under the influence of the stirrer, form coke of a size consist that is independent of the size consist of the original coal. The behavior of coals that are highly expanding is a factor that has not yet been fully explored. In the Lurgi plant in Dorsten, a highly expanding coal was used for a short experiment; and it was reported that operation of the process with recycle of 20 percent ash was possible. The behavior of highly expanding coal without the addition or recycle of ash has not been tested fully. Plans for such tests have been reported.

5. Petrographic Composition: The petrographic composition of the coal, according to the present technology of coal gasification, is of importance insofar as it is an index of rank, and, thus indirectly an index of volatile matter content of the coal and of the reactivity of the fixed carbon. Generally, petrographic components of coal with a high volatile matter content are readily gasifiable in the present coal gasification processes. However, further study of the influence of petrographic composition on the gasification of coal is needed and is indicated. Data and information needed to establish criteria for coal quality are not available for coal gasification processes even though highly developed precise criteria are available for metallurgical coke processes. Selected literature references on recent developments in coal petrography are also included in Appendix 3.2.

B. Methods of Coal Feeding

The cost of feeding coal into gasifiers at high pressure is substantial. Coal feeding costs at 70 atm pressure have been estimated at about 1.7 cents and 2.3 cents per MM Btu in the gas for slurry and lock hopper systems, respectively. (See Appendix 4.1.)

In lock hopper feeding at 70 atm, the cost of power and gas compressors is estimated at 1.75 cents per MM Btu in the gas. The investment cost of the lock hoppers alone amounts to about 0.5 cent per MM Btu in the gas.

Elimination of the bulk of the cost of the lock hopper gas and its compression, as well as part of the lock hopper costs, appears possible by use of a piston (or plunger of diaphragm-type) pumping device in place of the lock hopper system. In such a device, the coal would be fed in a suspension of the product gas, so that the product gas is recycled to the gasifier without release.

Based on an inventive design, the costs of feeding pulverized coal as a dense fluidized suspension in a piston-type pumping device have been estimated at 0.68 cent per MM Btu in the gas. (See Appendix 4.2.) This is considerably less than the estimated cost for either the slurry or the lock hopper systems. Such a feeding device appears especially suitable for the new conceptual two-stage gasification process which has been proposed and evaluated in the present

TABLE 4-2. EFFECT OF COAL RANK ON PERFORMANCE OF ENTRAINED SLAGGING GASIFIER AT EQUIVALENT CARBON INPUT AND STEAM-CARBON RATIOS*

Coal Rank	Oxygen-Carbon Ratio scf/lb	Material Requirements per M cf $CO + H_2$ Oxygen, scf	Material Requirements per M cf $CO + H_2$ Coal, lb	Carbon Gasified, Percent	Calculated Exit-gas Temp, F	Heat Loss, Btu/lb Coal
Subbituminous C	10.5	310	53	79	1,800	475
	15.0	400	47	92	2,100	475
High Volatile Bituminous A	10.5	360	48	65	2,100	535
	15.0	410	38	90	2,300	950
Anthracite	10.5	465	53	61	2,000	925
	15.0	540	42	80	2,100	925

* "Chemistry of Coal Utilization, Supplementary Volume," Lowry, H. H., ed., New York: John Wiley and Sons, Inc., 1963. p 979.

study. It would also be suitable for the proposed studies on the pneumatic transport of ultrafine coal.

The present cost study indicates that the cost of feeding coal, especially at high pressure, will be a significant factor in the overall cost of coal gasification. A more accurate evaluation will be possible for specific processes after such factors as coal size, feed rate, and operating pressure are known.

Osthaus (4) has recently commented on coal feeding methods, as follows:

> The simple lock hopper has as a disadvantage the loss of gas compression energy which is a debit of pressure gasification. A decrease of this loss is possible by the use of two lock hoppers. At 30 atm maximum pressure, the gas loss is decreased from 31 to 17 times the lock hopper volume. By the use of additional lock hoppers, a further decrease in power consumption to about 10 percent of that of a single lock hopper is possible. Theoretically, the lock hopper gas loss can be completely avoided by the use of pistons or diaphragms between two lock hoppers. Practical implementation of this may be difficult.

C. Process Variables

Process variables, such as pressure, temperature, residence time, and steam-oxygen-coal ratio, have a different influence on each gasification process.

In regard to the general influence of pressure in coal gasification processes, an increase in gasification rate in a given reactor is observed as the pressure increases. For suspension gasification processes, the throughput seems to be directly proportional to the pressure. In fixed-bed and fluidized-bed processes, the throughput is roughly proportional to the square root of the pressure, since the limiting factor is the gas velocity causing an excessive pressure drop and carry-over of solids. Increased pressures, besides resulting in an increase in throughput per unit volume, also result in decreased heat losses of the system per unit of gas production; this leads to an increase in gasification efficiency.

In regard to the influence of temperature on coal gasification, two aspects have to be considered in addition to the requirements for slagging or non-slagging operation: (a) effect on the rate of reaction, and (b) effect on the equilibrium constants, and thus, the gas composition.

In general, the reaction rate will increase with increase in temperature, the amount depending on the rate controlling reaction mechanism. By contrast,

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(4) Osthaus, K. H., "The technological status and development possibilities of the Koppers-Totzek process for gasifying fuels," Mitteilungen (Koppers), 395-6 (Oct. 1964).

the equilibrium gas composition may become more unfavorable as the temperature increases. This is the case, for instance, in methane formation; the potential methane yield becomes more favorable as the temperature of reaction decreases. Since methane formation is favored by high pressure, operation at high pressure and low temperature, if feasible, would result in a low oxygen consumption.

The effects of residence time in coal gasification must be considered separately for two process groups: (a) suspension gasification in which coal and gas have the same residence time, and (b) fluidized-bed and fixed-bed processes in which the coal has a much longer residence time than the gases.

As a result of the long residence time of the fuel in fixed-bed and fluidized-bed processes, a much larger inventory of fuel is present for reaction with steam; this leads to a higher steam conversion in these processes and to a correspondingly lower gas exit temperature.

In general, the longer the residence time, the more complete the gasification reaction will be; however, in experimental small-scale equipment, this may be overshadowed by a higher heat loss by the coal in the gasifying zone, which, in turn, leads to lower gasification efficiency.

The steam-oxygen-coal ratio is dictated by the thermal balance of the gasifier system and varies for the different types of processes with their different carbon inventories, different gas exit temperatures, and different degrees of mixing within the reaction zone.

The simplest relationship exists for processes for gasification of coal in suspension. As the oxygen-to-coal ratio increases, carbon utilization as well as gas exit temperature and oxygen consumption based on the gas production will increase.[5] Thus, an optimum must be found for the combined use of oxygen and coal. The optimum steam ratio depends somewhat on the steam preheat temperature. In general, a low steam-coal ratio can only be used for slagging operation.

In non-slagging fixed- and fluidized-bed processes, a steam-oxygen ratio must be selected that gives a maximum temperature at which the coal ash does not melt. Because of the high thermal conductivity of fluidized beds in a vertical direction, processes using such beds are expected, within a given range of operating conditions and using the same coal, to permit the use of lower steam-oxygen ratios and, thus, in this respect be more favorable than fixed-bed processes.

In slagging operation, the temperature limitation by ash melting obviously disappears. However, the reduction of silica in the coal ash, at very high temperatures, leads to the volatilization of SiO_2; and deposits of SiO_2 in lower temperature zones of the gasifier then result in obstructions and disruption of operation. Thus, here too, a temperature limit exists which dictates the steam-oxygen-carbon ratio.

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(5) "Chemistry of Coal Utilization, Supplementary Volume," Lowry, H. H., ed., New York: John Wiley and Sons, Inc., 1963. pp 979-81.

It is fair to state that the range of suitable steam-oxygen-coal ratios can be determined with limited accuracy from experience with existing processes and heat balance calculations. However, experimentation will be needed to determine the optimum for new processes or for processes requiring novel operating conditions, such as operation at higher pressures than those used so far. The complexity of gasification reaction kinetics and the lack of information about fuel reactivity during gasification do not allow a precise theoretical treatment at this time.

D. Scale of Operation

The present study is concerned primarily with two different types of gases, namely, synthesis gas, suitable for conversion into pipeline gas; and, fuel gas, suitable for local use. For these, two different types and sizes of plants will be required.

For the production of synthesis gas for pipeline use, the plant size should be large enough to justify transportation of the gas by pipeline, which is the normal way of marketing the gas. In past investigations, plants producing about 90 MM scfd of gas of pipeline quality have been considered.

Operation of gasification units at higher pressures than used heretofore permits use of much higher capacity gasifier units than in the earlier studies. Therefore, a larger plant size than 90 MM scfd is economical.

Benson (6) indicates that a considerable decrease in investment and operating costs is possible by increasing the size of the plant from 90 to 400 MM scfd. (See Figure 4-1.) The present studies show that for operation at high pressure, a 250 MM scfd plant would be of appropriate size to realize the bulk of the cost advantage indicated for the plant size range used by Benson. Such a 250 MM scfd plant is expected to have five parallel gasifier trains, shift reactors, and methanators. It will require about 12,000 tons per day of coal, and have two separate in-plant maximum size coal preparation and transportation systems, together with two large size steam boilers. An increase in plant size at this level would not involve an increase in size of the gasifier units and the other process equipment, but it would still permit some economies connected with a greater number of units. On the other hand, a decrease in plant size would mean a considerable increase in cost per unit, since either the gasifier size would be decreased, or the proportion of spare units would become greater. For the chosen plant size, large centrifugal compressors, with their low first cost and low maintenance, can be used throughout.

For the production of local fuel gas, a plant size of about 100 MM Btu per hour is appropriate. This corresponds to the output of one large size fixed-bed producer, and will be of such size that industrial plants, such as glass melting furnaces, brick factories, etc., could be supplied and operated independently of any supply of pipeline.

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(6) Benson, H. E., "Process and cost considerations in making substitute natural gas from coal," Presented at Am. Gas Assoc. Operating Section, Transmission Conference, 1963. CEP-63-10.

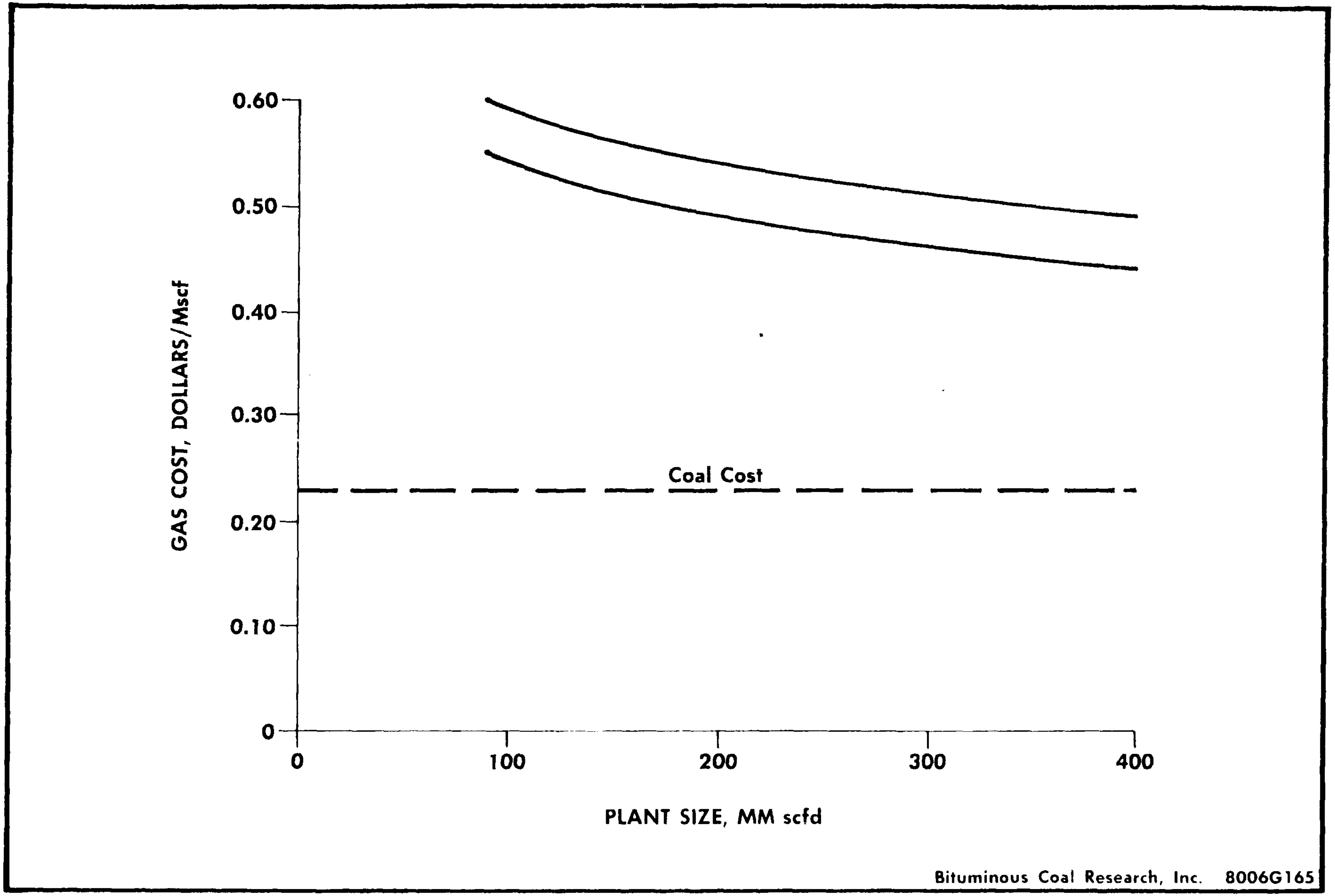

Figure 4-1 Effect of Plant Size on Cost of High Btu Gas from Coal by Hydrogasification According to Benson (6)