Bureau of Mines
Report of Investigations 5272

COST DATA FOR GASIFICATION OF LIGNITE IN AN EXTERNALLY HEATED RETORT

BY O. C. ONGSTAD, M. H. CHETRICK, AND W. H. OPPELT

United States Department of the Interior — November 1956

COST DATA FOR GASIFICATION OF LIGNITE IN AN EXTERNALLY HEATED RETORT

BY O. C. ONGSTAD, M. H. CHETRICK, AND W. H. OPPELT

* * * * * * * * * Report of Investigations 5272

UNITED STATES DEPARTMENT OF THE INTERIOR
Fred A. Seaton, Secretary
BUREAU OF MINES
Marling J. Ankeny, Director

November 1956

COST DATA FOR GASIFICATION OF LIGNITE IN AN EXTERNALLY HEATED RETORT

by

O. C. Ongstad,[1] M. H. Chetrick,[2] and W. H. Oppelt[3]

CONTENTS

1/ Chemical engineer, Utilization Section, Bureau of Mines, Region III, Grand Forks, N. Dak.
2/ Formerly chemical engineer, Utilization Section, Bureau of Mines, Region III, Grand Forks, N. Dak.
3/ Supervisor, Utilization Section, Bureau of Mines, Region III, Grand Forks, N. Dak.

TABLES

ILLUSTRATIONS

SUMMARY AND CONCLUSIONS

Experience from pilot-plant operation of a large, externally heated annular-retort gasifier indicates that the retort size used is near maximum size for commercial application. Cost data for the experimental unit and an estimate of synthesis-gas cost for a plant producing 50 million cu. ft. of (H_2+CO) per day are presented in this report. The cost data, although reported per 1,000 cu. ft. of (H_2+CO), are based on the production of cooled, tar- and dust-free, raw synthesis gas and do not include purification costs or return on capital investment.

The cost for major equipment and material comprising a single gasification unit is estimated at $29,466. The externally heated alloy tube for the retort and the alloy-tube nest for the heat exchanger constitute 50 percent of this cost.

Based upon cost information available and experimentally determined operational characteristics of the retort, it is concluded that retort capacity is of prime importance for economic plant operation and that dried lignite is a more economical fuel for retort operation than natural (as-received) lignite. The operating cost for gasifying natural lignite in a plant with a capacity of 50 million cu. ft. of (H_2+CO) per day is estimated to be 37.6 cents per 1,000 cu. ft. of (H_2+CO). Operating cost for gasifying steam-dried lignite in a plant of the same capacity is estimated to be 32.0 cents per 1,000 cu. ft. of (H_2+CO).

INTRODUCTION

The gasification of solid fuels has aroused increasing interest during the past two decades. Many processes have been developed for producing hydrogen-carbon monoxide mixtures from various rank coals as raw materials for chemical synthesis. Synthesis gas can be used, after conventional intermediate processing and purification, for manufacturing ammonia, alcohols, oxo-reaction products, commercial hydrogen, and synthetic liquid fuels, as well as directly as a reducing agent in various chemical and metallurgical applications.

In gasifying solid fuels, heat energy to carry out the endothermic reaction between steam and carbon of the fuel can be supplied either internally or externally. Since partial combustion of the fuel in the reactor with air produces a gas of high nitrogen content, commercially pure oxygen must be used to obtain synthesis gas of high carbon monoxide-hydrogen concentration. Gasification processes employing heating by oxygen are characterized by high specific gasmaking capacity; however, oxygen requirements add considerably to the cost of the gas. External heat supply has the advantage of using a relatively cheap source of process heat but results in reduced capacity per unit volume of reactor space owing to limitations on heat-transfer rates through the reactor wall at acceptable temperature levels.

Externally heated gasification processes have their maximum promise for use with the low-rank coals, which have relatively high rates of reaction at low temperature levels. From 1945 to 1951 gasification of lignite in an externally heated annular retort was investigated by the Bureau of Mines at its Grand Forks, N. Dak., station. Detailed descriptions of the externally heated gasification process, including the operating conditions, mechanical design of the large, commercial-scale pilot plant, and review and correlation of the experimental data, have previously been reported (2, 3, 4, 5, 7, 8, 9).[4/] Operability of the annular-retort process has been demonstrated, and a large amount of operating data has been accumulated during several years of operation of the Bureau of Mines commercial-scale pilot plant. This pilot plant has been operated for 8,749 hours, during which 1,882 tons of natural and steam-dried lignite was processed in producing over 84 million cu. ft. of gas.

As the Bureau's experimental work on the annular-retort gasification process has developed, considerable interest has been expressed in process costs and in the cost data that apply to this particular externally heated process for producing synthesis gas from lignite. Experimental results obtained indicate that the experimental retort unit was of near maximum size for this type of retort and that larger plants would be supplied by multiple groups or batteries of such units. Equipment cost data for the large-scale prototype gasification unit are available and represent an unusually reliable source of gasifier cost data. It is the objective of this report to present these cost data on the externally heated gasifier and to apply the data to an estimate of synthesis-gas cost. This cost includes only those costs associated with the production of cooled, tar- and dust-free raw synthesis gas and does not include purification costs or return on capital investment.

DESIGN OF EXTERNALLY HEATED GASIFIER

The basic design of the externally heated gasifier is shown schematically in figure 1. The unit is composed essentially of four functional sections - a retort-heating section, a lignite-charging section, a residue-discharging section, and the annular gasification section or retort.

The retort is heated through gas combustion, and the required heat energy is transferred to the reaction zone through a metal wall. A combustion chamber of firebrick and insulating brick with supporting shell surrounds the annular retort. Heating gas is introduced into the combustion chamber through a total of 12 tangential burners arranged at 3 levels around the retort. Six burners operate at the lowest level and 3 at each of the 2 higher levels. Temperature control of the combustion space is regulated by adjusting the gas rate at each burner level. Maximum flame temperature is limited by admixing recycled products of combustion with the primary air. The resulting mixture is preheated in a heat exchanger by hot products of combustion to 1,300° F. before being admitted to the furnace burners. Owing to the high temperature of the entering products of combustion (1,600° F.), stainless steel type 309 is required for the tube nest and baffle system of the heat exchanger. The products of combustion leave the heat exchanger at 600° F. The sensible heat remaining is further utilized to superheat process steam in a small steam preheater between the exhaust fan and the stack.

The retort charging section consists of the charging dome, a rotating feed valve and reciprocating feeder, and a lignite hopper. The cylindrical charging dome, attached to the outer tube of the retort, serves as a lignite reservoir for the annulus. Lignite is fed into the charging dome through the synchronized action of the rotating plug valve and reciprocating feeder.

4/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this report.

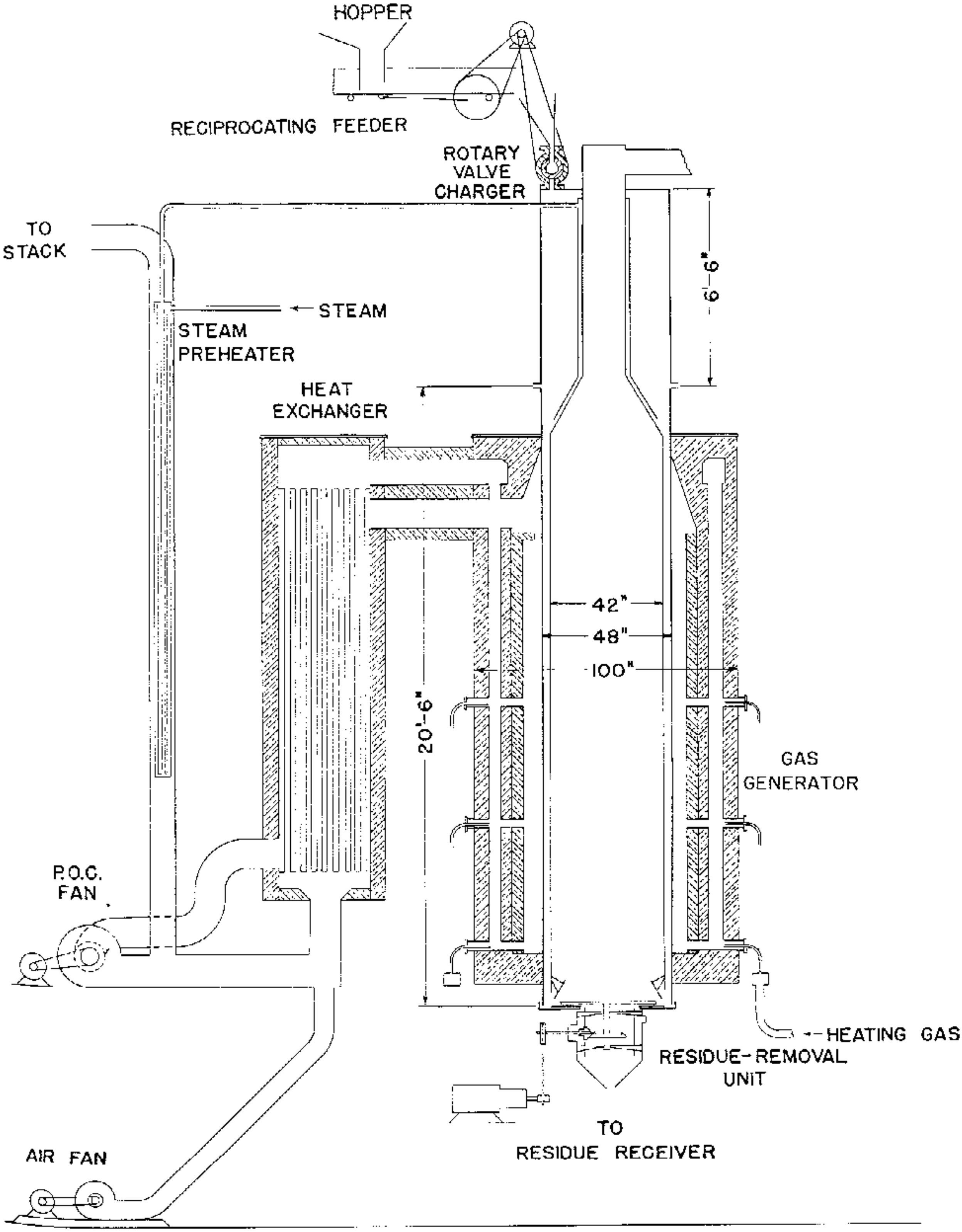

Figure 1. - Schematic view of externally heated gasifier, Bureau of Mines, Grand Forks, N. Dak.

The annular reaction chamber is formed by two concentric metal cylinders suspended in the combustion chamber. The inner tube of the annular retort also transports product gas to the outlet of the gasifier. Process steam is introduced to the lignite at the top of the annulus. Lignite and steam passing down through the annulus are heated to progressively higher temperatures to interact in the production of synthesis gas. The product gas is released from the bottom of the annulus through the gas offtake formed by a truncated cone arrangement attached to the inner tube and passes up through the inner tube to the gas outlet at the top of the retort.

The outer tube of the retort is a cylinder 20 ft. 6 in. in length and 48 in. i. d. fabricated from 1/2-inch rolled plate and flanged at the top for suspension and attachment to the charging dome. The combined effect of high temperature and attack by products of combustion on the outside and by reducing gases, steam, carbon, and ash on the inside wall require the use of a heat- and corrosion-resistant steel. A type 310 stainless-steel alloy has given satisfactory service in pilot-plant investigation, and it is estimated that a tube life of 20,000 hours of continuous operation can be expected with this type of alloy at service temperatures of approximately 1,900° F.

The inner tube consists of 2 straight cylinders of 42 and 17 inches outside diameter joined through a conical section to form a continuous tube. Since service conditions for this tube are relatively moderate, replacement is not necessary when the tube is fabricated from 3/8-inch plate of type 309 stainless steel.

The residue removal unit is fitted over the bottom of the outer tube and seals the retort unit. Residue is removed from the bottom of the annulus by two rotating scraper arms driven by a simple shaft and gear arrangement attached to an external variable speed drive. The scraper arms move the residue to a central discharge opening, where it is discharged by gravity into a receiver.

COST OF GASIFIER

The costs of major equipment and materials for a single gasification unit are listed in table 1. These costs are based mainly on data from cost records at the Grand Forks station and manufacturers' quotations. A few minor items are based on literature cost data. The costs listed in table 1 do not include auxiliary gasifier equipment, such as piping, instrumentation, structural steel, or foundations, and do not include equipment installation or erection costs. Cost for the steam preheater is included in cost of pipework for the gas-generating system, appendix, table 10.

The total estimated major equipment and material cost for a gasifier unit, adjusted to September 1954 price levels, is $29,466. This cost includes $17,640 for the retort unit, $9,834 for the heat exchanger, $904 for the P.O.C. handling equipment, $643 for the residue-removal unit, and $445 for the combustion air-supply equipment.

From these cost data, it may be seen that the alloy retort tube and alloy tube nest represent approximately 50 percent of the total major equipment cost. The large percentage of total equipment cost represented by these two items is due to the high-quality alloy steel required for satisfactory functional life. Stainless steel type 310 is specified for the externally heated alloy retort tube, whereas stainless steel type 309 is specified for the heat-exchanger tube nest. Since the inner retort tube is exposed to less severe operating conditions, mild steel was satisfactory for experimental purposes. In a commercial unit, however, a 309 type stainless steel is recommended, and manufacturer's quotation on a type 309 tube is listed in table 1.

TABLE 1. - Estimate of major equipment and cost of materials for externally heated gasifier

Item	Base cost1/	Adjusted cost2/
Retort unit:		
Retort shell and support..........................	$1,150.00	$2,225.00
Brickwork for retort..............................	1,844.25	3,570.00
Mortar for laying brick...........................	222.00	430.00
Plastic insulation................................	15.00	30.00
Charging dome.....................................	280.00	540.00
Alloy retort tube.................................		3/7,500.00
Inner retort tube.................................	2,200.00	2,520.00
Feed bin..		4/200.00
Reciprocating feeder..............................		4/100.00
Rotating plug valve, motor, and speedranger.......		4/525.00
Total..		17,640.00
Residue removal unit:		
Concentric reducer................................		4/100.00
Motor and speedranger.............................	181.00	350.00
Speed reducer.....................................	75.00	145.00
Misc. gears and drive equipment...................	25.00	48.00
Total..		643.00
Heat exchanger:		
Shell...	1,250.00	2,420.00
Alloy tube nest...................................	3,600.00	6,970.00
Support for heat exchanger........................	40.00	77.00
Insulating blocks.................................	190.00	367.00
Total..		9,834.00
Flue-gas handling equipment:		
Flue-gas blower...................................	344.80	667.00
Outlet damper.....................................	27.00	52.00
Inlet valve.......................................	25.00	48.00
Stack...	30.00	58.00
Wafer-type butterfly valve........................	40.88	79.00
Total..		904.00
Combustion air supply:		
Air blower..	203.50	394.00
Wafer-type valve..................................	26.48	51.00
Total..		445.00
Total cost.....................................		29,466.00

1/ Original equipment costs, from cost records at Grand Forks station, unless otherwise indicated.
2/ Adjusted to September 1954 price levels.
3/ Based on quotation from manufacturer.
4/ Estimated from literature source.

MATERIAL AND HEAT BALANCES

Operation of the annular-retort gasifier can be controlled through three principal variables: Combustion-space temperature, lignite feed rate, and steam feed rate. Maximum allowable combustion space temperature is limited by the metal used in the outer tube. For a 310 alloy steel tube, this temperature is about 2,000° F. In addition to the above, the operability of the retort is affected by the condition of the lignite feed. Reducing the moisture content of the feed by steam drying increases the capacity of the retort and permits production of a lower H_2-CO ratio gas.

Maximum production of (H_2+CO) was obtained in the experimental unit when operated to produce low H_2-CO ratio gas. Operating on natural lignite, maximum (H_2+CO) production was obtained at a 2.5 H_2-CO ratio gas. Using a steam-dried lignite of 12 to 15 percent moisture, maximum (H_2+CO) production was obtained at a 2.0 H_2-CO ratio gas.

Material and heat balances for a retort operated either on natural or steam-dried lignite are given in tables 2 and 3. The figures are based on a gas-production rate of 14,000 cu. ft./hr.,5/ 70-percent carbon conversion, and the production of a nominal 2.5 H_2-CO ratio gas using natural lignite. For gasification of steam-dried lignite, the figures are based on a production rate of 17,600 cu. ft./hr., 75-percent carbon conversion, and a nominal 2.0 H_2-CO ratio gas. Steam and thermal requirements as reported in the tables are based upon correlations of experimental data previously reported (4, 5).

ESTIMATE OF SYNTHESIS GAS COST FOR 50-MILLION-CU. FT./DAY PLANT

Commercial production of (H_2+CO) using the externally heated retort process will require numerous individual gasifiers. The individual gasifiers would have to be grouped into batteries for practical plant layout. Heating-gas requirements for a battery would be supplied by a low-cost gas, such as producer gas. The use of producers for generating heating gas for the gasifiers is of particular advantage when the residue from the gasifier is used as fuel.

Major equipment in a battery consists of 10 gasifier units, arranged in 2 parallel rows of 5 units each, 2 gas producers with scrubbing system, a synthesis-gas scrubbing system, and equipment for handling lignite, residue, and ash. Gas required for heating the retorts is produced by gas producers fired with lignite residue from the retorts, supplemented by natural lignite as required. Process steam for the producers is generated in the water jacket of the producer. A water-scrubbing system is used to cool and clean the gas before use. Raw synthesis gas from the individual retort units in a battery is washed in a central water scrubber to remove undecomposed steam, tar traces, and dust.

Material and utility requirements for a battery of 10 retort units operated on natural or steam-dried lignite are given in table 4. This table includes the material requirements for the gas producers and the proportionate material requirements for a central steam-generating plant. Power and water requirements for the gas producers were estimated from operating data on Koppers-Kerpely gas producers (6), whereas feed requirements and capacity were based on data for German producers of conventional design which used brown coal as feed (1). These data are listed in table 5. Cooling water rate for the water scrubbing system was estimated from unpublished experimental data. Power requirements were calculated from the total connected load of all electrical equipment in a battery plus that prorated to each battery for operating the plant conveyor.

The estimated capital cost for a 50-million-cu. ft. (H_2+CO)/day plant using natural lignite is \$24,257,200. The cost of a plant of the same capacity operated on steam-dried lignite of 12 to 15 percent moisture is estimated at \$19,396,400. Breakdown of these capital costs are given in tables 8 through 12 in the Appendix. Reduced cost for the plant operated on steam-dried lignite is due to the reduced number of gasifiers required.

5/ All gas volumes reported in this publication are based upon 60° F., 30 inches Hg, dry.

TABLE 2. - Material and heat balance for externally heated gasifier operating on natural lignite[1]

	Item	Weight, lb.	Volume, cu. ft.	Thermal data[2] Temperature, ° F.	Sensible heat, B.t.u./hr.	Potential heat, B.t.u./hr.	Total B.t.u./hr.	Total Percent
In	Natural lignite......	627		60	0	4,357,600	4,357,600	66.2
	Steam................	250		340	3/290,585	0	290,585	4.4
	Heating gas..........	923	13,839	60	0	1,937,600	1,937,600	29.4
	Air..................	1,318	17,300	60	0	0	0	.0
	Total..........	3,118			290,585	6,295,200	6,585,785	100.0
Out	Product gas..........	548	14,014	725	188,350	4,016,400	4,204,750	63.9
	Steam................	213		725	3/291,300	0	291,300	4.4
	Char.................	116		1,000	31,300	1,235,000	1,266,300	19.2
	P.O.C.	2,241	28,552	350	304,400	0	304,400	4.6
	Losses...............				519,035		519,035	7.9
	Total..........	3,118			1,334,385	5,251,400	6,585,785	100.0

1/ Based upon 1 hr. operation producing a 2.5 ratio gas using natural lignite with 37 percent moisture.
2/ Base temperature, 60° F.
3/ Includes latent heat of vaporization.

TABLE 3. - Material and heat balance for externally heated gasifier operating on dried lignite[1]

	Item	Weight, lb.	Volume, cu. ft.	Thermal data[2] Temperature, ° F.	Sensible heat, B.t.u./hr.	Potential heat, B.t.u./hr.	Total B.t.u./hr.	Total Percent
In	Dried lignite........	572		60		5,365,360	5,365,360	68.7
	Steam................	433		340	3/503,290		503,290	6.4
	Heating gas..........	925	13,869	60		1,941,660	1,941,660	24.9
	Air..................	1,321	17,336	60				
	Total..........	3,251			503,290	7,307,020	7,810,310	100.0
Out	Product gas..........	696	17,583	725	235,580	5,248,500	5,484,350	70.2
	Steam................	187		725	3/255,700		255,700	3.1
	Char.................	122		1,000	32,940	1,146,800	1,179,740	17.5
	P.O.C.	2,246	28,612	350	305,050		305,050	3.9
	Losses...............				585,470		585,470	5.3
	Total..........	3,251			1,415,010	6,395,300	7,810,310	100.0

1/ Based upon 1 hr. operation producing a 2.0 ratio gas using dried lignite with 12-15 percent moisture.
2/ Base temperature, 60° F.
3/ Includes latent heat of vaporization.

TABLE 4. - Utility and material requirements per battery of 10 gasification units

Type lignite		Natural lignite	Dried lignite
H_2-CO ratio		2.5	2.0
(H_2+CO) produced	1,000 cu. ft./day	2,710	3,560
Gasifier thermal requirements	million B.t.u./day	465	466
Lignite to gasifiers	tons/day	1/75.4	2/68.6
Char recovered	do.	13.9	14.6
Natural lignite to gas producers	do.	41.5	40.7
Natural lignite to steam generators	do.	6.3	10.8
Steam	1,000 lb./day	60.0	104.0
Cooling water	1,000 gal./day	242.8	271.0
Electricity	kw.	109.9	111.0

1/ Natural lignite with 37 percent moisture.
2/ Dried lignite with 12-15 percent moisture.

TABLE 5. - Design data for gas producers

Gas production - 900 cu. ft./(hr.) (sq. ft. grate area)
Heating value of gas - 140 B.t.u./cu. ft.
Power requirements - 20 kw./hr./ton throughput
Water to producer jackets for steam generation - 0.4 lb./lb. lignite
Water for washing and cooling gas - 41.4 gal./1,000 cu. ft. gas produced

Estimate of the capital cost is based upon major equipment costs with appropriate factors used to estimate associated equipment costs, direct and indirect construction labor, construction overhead, and fees. Capital cost does not include the cost for the main gasline connecting to the individual batteries and transporting the cooled and scrubbed gas to the point of use where gas-storage facilities are available. Based on pilot-plant operation, to provide for down time due to maintenance and repairs, an actual operating time of 330 days per year was chosen for the gas-generating equipment and auxiliaries. The number of batteries required was determined by dividing the total desired plant capacity by the gas capacity per battery. This quotient was raised to the next highest whole number to provide for additional spare units. A contingency factor of 10 percent is used. All costs were adjusted to September 1954 price level by applying the appropriate factors based upon material and labor index as reported by Zimmerman and Lavine (10, 11).

The estimated cost of producing synthesis gas in a 50-million-cu. ft./day plant is listed in tables 6 and 7. The cost is estimated at 37.6 cents per 1,000 cu. ft. of (H_2+CO) when natural lignite is used as feed and at 32.0 cents when steam-dried lignite is used. This cost includes only those costs associated with the production of raw synthesis gas and does not include purification costs. Required maintenance personnel was determined from experience gathered during operation of the commercial-scale gasifier at the Bureau of Mines station in Grand Forks, N. Dak. Percentage additions covering payroll extras and administration and overhead are based on available literature information on comparable types of plants at the time the report was prepared (1954). A depreciation rate of 5 percent was taken from literature references on rates generally applied to comparable simple equipment like boiler plants. Expenditures incurred for more frequent replacement of alloy-steel tubes are included in cost of process materials.

The cost of steam-dried lignite was obtained from unpublished information on the cost of preparing steam-dried lignite by the Fleissner process. The cost of \$3.60 per ton of steam-dried lignite is based on \$2.00 per ton of natural lignite, 75 percent yield of dried lignite, and a drying cost of \$0.70 per ton of natural lignite. Despite a higher cost of process materials, the total operating cost per 1,000 cu. ft. of (H_2+CO) is reduced by using steam-dried lignite as feed material. Decrease of gas cost is due mainly to increased capacity of a battery operated on steam-dried lignite. Reduction of the required number of batteries from 19 to 15 to produce 50 million cu. ft./day of (H_2+CO) results in substantial savings in direct production cost and fixed costs, due chiefly to reduced personnel requirements and capital cost of the plant.

TABLE 6. - Operating cost of plant producing 50 million cu. ft./day of (H_2+CO) from natural lignite

H_2-CO ratio = 2.5

	Dollars per year	Percent
Process materials:		
Natural lignite, 1,391 tons/day x 330 x \$2/ton	\$918,060	14.9
Alloy-tube replacement, 330 x 24 x 185 x 7,500/20,000	549,450	8.9
Total process materials	1,467,510	23.8
Direct production cost:		
Operating labor:		
Operators, 74 men/shift x 24 x \$2 x 365	1,296,500	21.0
Supervision at 15 percent	194,500	3.2
Maintenance:		
Labor, 20 men/shift x \$4,000	80,000	1.3
Supervision at 20 percent	16,000	.3
Materials at 50 percent of labor	40,000	.6
Payroll extras:		
16 percent of payroll	253,900	4.1
Operating supplies:		
20 percent of maintenance labor and material	27,200	.4
Total direct production cost	1,908,100	30.9
Utilities and auxiliary materials:		
Natural lignite, 882 tons/day x 330 x \$2/ton	582,120	9.5
Cooling water, 3,100 g.p.m. x 60 x 24 x 330 x \$0.05/1,000 gal.	73,660	1.2
Boiler feed water, 93 g.p.m. x 60 x 24 x 330 x \$0.25/1,000 gal.	11,050	.2
Electricity, 2,017 kw. x 24 x 330 x \$0.0055/kw.-hr.	87,900	1.4
Total utilities and auxiliary materials	754,730	12.3
Administration and overhead:		
25 percent of operating labor, maintenance, and operating supplies	413,600	6.7
Fixed costs:		
Local, county, and State taxes and insurance, 1.5 percent of investment	363,850	5.9
Depreciation at 5 percent	1,261,400	20.4
Total fixed costs	1,625,250	26.3
Total operating costs	6,169,190	100.0

(H_2+CO) produced, 50 million cu. ft./day x 330 = 16,500 million cu. ft./yr.
Total operating cost per 1,000 cu. ft. of (H_2+CO) = 37.6 cents.

TABLE 7. - Operating cost of plant producing 50 million cu. ft./day of (H_2+CO) from steam-dried lignite

	Dollars per year	Percent
Process materials:		
Dried lignite, 964 tons/day x 330 x $3.60/ton	$1,145,200	21.7
Alloy-tube replacement, 330 x 24 x 140 x $7,500/20,000	415,800	7.8
Total process materials	1,561,000	29.5
Direct production cost:		
Operating labor:		
Operators, 57 men/shift x 24 x $2 x 365	998,600	18.9
Supervision at 15 percent	149,800	2.8
Maintenance:		
Labor, 16 men/shift x $4,000	64,000	1.2
Supervision at 20 percent	12,800	.2
Materials at 50 percent of labor	32,000	.6
Payroll extras:		
16 percent of payroll	196,000	3.8
Operating supplies:		
20 percent of maintenance labor and material	21,800	.4
Total direct production cost	1,475,000	27.9
Utilities and auxiliary materials:		
Natural lignite, 726 tons/day x 330 x $2/ton	479,160	9.1
Cooling water, 2,665 g.p.m. x 60 x 24 x 330 x $0.05/1,000 gal	63,000	1.2
Boiler feed water, 122 g.p.m. x 60 x 24 x 330 x $0.25/1,000 gal	14,500	.3
Electricity, 1,565 kw. x 24 x 330 x $0.0055/kw.-hr.	68,200	1.3
Total utilities and auxiliary materials	624,860	11.9
Administration and overhead:		
25 percent of operating labor, maintenance, and operating supplies	319,800	6.1
Fixed costs:		
Local, county, and State taxes and insurance, 1.5 percent of investment	290,950	5.5
Depreciation at 5 percent	1,008,600	19.1
Total fixed costs	1,299,550	24.6
Total operating costs	5,280,210	100.0

(H_2+CO) produced, 50 million cu. ft./day x 330 = 16,500 million cu. ft./yr.
Total operating cost per 1,000 cu. ft. of (H_2+CO) = 32.0 cents.

The effect of lignite cost upon estimated synthesis gas cost is illustrated in figure 2. From the plots it is evident that synthesis gas cost is relatively insensitive to change in cost of lignite because of the high proportion of gas cost represented by fixed charges, operating labor, etc.

The influence of the useful operating life of the alloy retort tube upon the economics of the process has been of interest since the conception of experimental work. The effect of tube life upon gas cost is shown in figure 3. Using 20,000 hours as a base, a decrease in tube life to 10,000 hours will increase the cost of the gas by 9 percent.

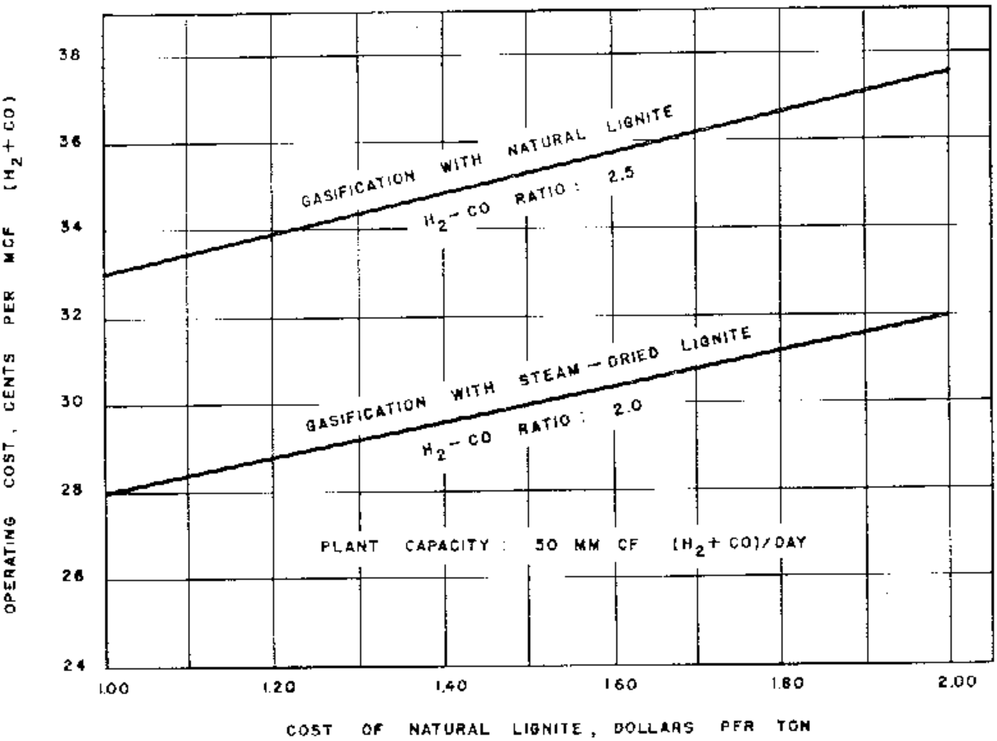

Figure 2. - Relationship between operating cost of synthesis-gas generation and cost of natural lignite.

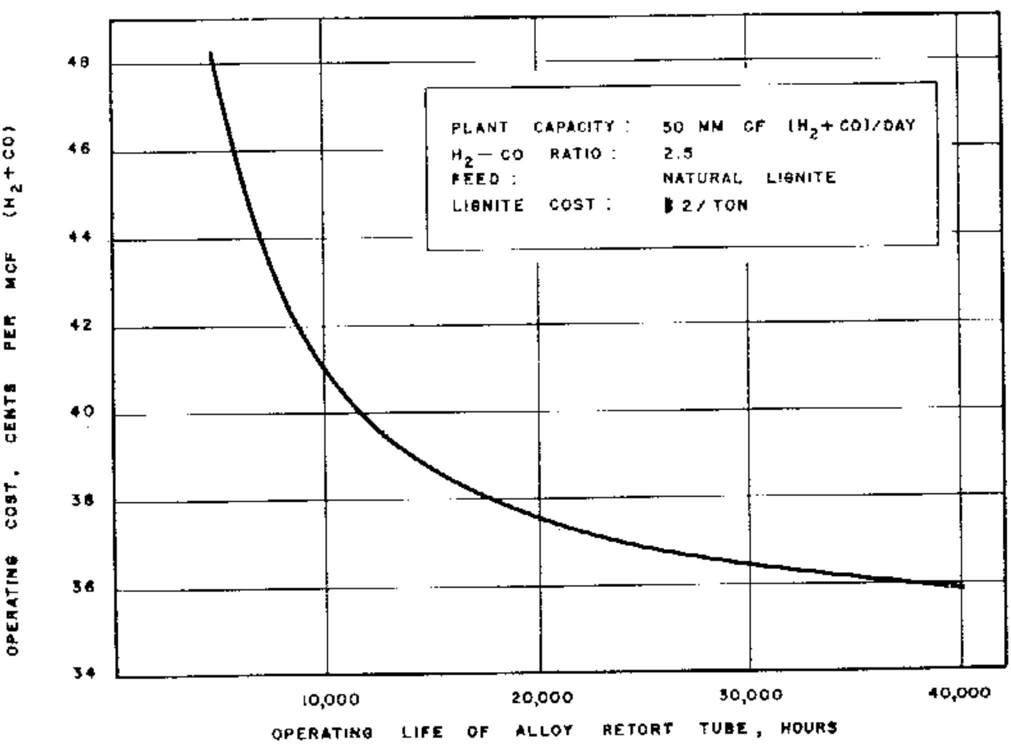

Figure 3. - Relationship between operating cost of synthesis-gas generation and operating life of alloy retort tube.

BIBLIOGRAPHY

1. BRAUNKOHLEN-ANHALTSZAHLEN, 3. Neudruck mit Ergänzungen. Ausgabe (1929) February 1931, p. 83.

2. BURR, A. C., ELLMAN, R. C., HOEPPNER, J. J., HOLTZ, J. C., KAMPS, T. W., KUBE, W. R., ONGSTAD, O. C., and OPPELT, W. H. Gasification of Lignite in a Commercial-Scale Pilot Plant, Progress Report January 1, 1949, to June 30, 1950. Bureau of Mines Rept. of Investigations 4997, 1953, 48 pp.

3. BURR, A. C., HOLTZ, J. C., KOTH, A. W., and OPPELT, W. H. Gasification of Lignite in a Commercial-Scale Pilot Plant, Progress Report of 1947-48. Bureau of Mines Rept. of Investigations 4940, 1953, 28 pp.

4. CHETRICK, M. H. Undecomposed Steam in Lignite Gasification. Bureau of Mines Rept. of Investigations 4738, 1950, 11 pp.

5. _____. Thermal Requirements for Gasification of Lignite in an Externally Heated Retort. Bureau of Mines Rept. of Investigations 4957, 1953, 7 pp.

6. KOPPERS-KERPELY GAS PRODUCER. Manufacturers' Data Sheet.

7. OPPELT, W. H., KUBE, W. R., CHETRICK, M. H., KAMPS, T. W., and GOLOB, E. F. Gasification of Lignite in a Commercial-Scale Pilot Plant, Progress Report from July 1, 1950, to December 31, 1951, and Summary of Work Previous to July 1, 1950. Bureau of Mines Rept. of Investigations 5164, 1955, 80 pp.

8. PARRY, V. F., GERNES, D. C., GOODMAN, J. B., WAGNER, E. O., KOTH, A. W., PATTY, W. L., and YEAGER, E. C. Gasification of Lignite and Subbituminous Coal, Progress Report for 1944. Bureau of Mines Rept. of Investigations 3901, 1946, 59 pp.

9. PARRY, V. F., GERNES, D. C., WAGNER, E. O., GOODMAN, J. B., and KOTH, A. W. Gasification of Lignite and Subbituminous Coal, Progress Report for 1945-46. Bureau of Mines Rept. of Investigations 4128, 1947, 69 pp.

10. ZIMMERMAN, O. T., and LAVINE, IRVIN. Chemical Engineering Costs. Ind. Res. Service, Dover, N. H., 1950, 419 pp.

11. _________. Chemical Engineering Costs Supplement. Ind. Res. Service, vol. 1, No. 1 through vol. 4, No. 4., Dover, N. H., 1951-1954.

APPENDIX

TABLE 8. - Capital cost of plant producing 50 million cu. ft./day of (H_2+CO) from natural lignite

H_2-CO ratio = 2.5

Gas-generating battery, 19 at $846,800	$16,089,200
Producer-gas system, 19 at $175,000	3,325,000
Cooling and scrubbing system, 19 at $181,800	3,454,200
Steam-generating plant and plant line	336,000
Coal handling, complete	692,000
General plant facilities	196,000
General plant utilities	165,000
Total plant cost (tax and insurance base)	24,257,200
Interest during construction	970,300
Subtotal (for depreciation)	25,227,500
Working capital	2,523,000
Total investment	27,750,500

TABLE 9. - Capital cost of plant producing 50 million cu. ft./day of (H_2+CO) from steam-dried lignite

H_2-CO ratio = 2.0

Gas-generating battery, 15 at $846,800	$12,702,000
Producer-gas system, 15 at $175,000	2,625,000
Cooling and scrubbing system, 15 at $181,800	2,727,000
Steam-generating plant and plant steam line	417,000
Coal handling, complete	600,000
General plant facilities	181,600
General plant utilities	143,800
Total plant cost (tax and insurance base)	19,396,400
Interest during construction	775,900
Subtotal (for depreciation)	20,172,300
Working capital	2,017,000
Total investment	22,189,300

TABLE 10. - Estimated capital cost for battery of 10 gasification units

Item	Quantity	Material	Labor	Total cost
Gas-Generating System				
Retort unit	10	$176,400	$	$
Residue-removal unit	10	6,430		
Heat exchanger	10	98,340		
Flue-gas-handling equipment	10	9,040		
Air supply	10	4,450		
Purge-gas unit	1	2,960		
Subtotal		297,620	58,320	
Instruments		31,000	12,400	
Electrical		20,000	12,000	
Structural steel		44,000	17,600	
Insulation		10,000	7,500	
Foundation		8,000	10,000	
Painting		2,000	6,000	
Pipework		60,100	30,000	
Subtotal		175,100	96,200	
Total direct cost		472,720	154,520	627,240
Field indirects				77,760
				705,000
Engineering				14,100
Administrative, overhead, purchasing				14,100
				733,200
Contingencies				73,300
				806,500
Fee				40,300
Total estimated cost, gas-generating system				846,800
Producer Gas System				
Gas producer, complete	2	50,000	10,000	
Instruments		2,000	800	
Electrical		5,000	3,000	
Structural steel		8,000	3,200	
Insulation		2,000	1,500	
Foundations		1,500	2,000	
Painting		500	1,500	
Pipework		25,000	12,500	
Subtotal		44,000	24,500	
Total direct cost		94,000	34,500	128,500
Field indirects				17,300
				145,800
Engineering				2,900
Administrative, overhead, purchasing				2,900
				151,600
Contingencies				15,200
				166,800
Fees				8,200
Total estimated cost, producer-gas system				175,000

TABLE 10. - Estimated capital cost for battery of 10 gasification units (Con.)

Item	Quantity	Material	Labor	Total cost
Cooling and Scrubbing System				
Synthesis gas water scrubbing unit:				
Stoneware water scrubber shell	1	$ 2,140	$	$
Cover, distributor, support plate, bottom section	1	550		
2-inch Raschig ring packing	318CF	2,110		
Water pump	1	1,050		
Total		5,850		
Producer-gas water-scrubbing unit:				
Steel water-scrubber shell	2	12,150		
Cover, distributor, support plate, bottom section	2	1,580		
2-inch Raschig-ring packing	1154CF	7,650		
Water pump	2	2,200		
Tar separator	1	3,690		
Total		27,270		
Water seals and relief unit:				
Safety seal tank	3	5,780		
Relief valve	3	3,480		
Total		8,790		
Positive-pressure blower:				
Exhauster pump	2	12,000		
Summary Cooling and Scrubbing System				
Synthesis-gas scrubbing unit	1	5,850		
Producer-gas scrubbing unit	2	27,270		
Water seals and relief unit	3	8,790		
Positive-pressure blower	2	12,000		
Subtotal		53,910	10,780	
Instruments		1,500	600	
Electrical		5,000	3,000	
Structural steel		8,000	3,200	
Insulation		2,000	1,500	
Foundations		1,500	2,000	
Painting		500	1,500	
Piping		25,800	12,900	
Subtotal		44,300	24,700	
Total direct cost		98,210	35,480	133,690
Field indirects				17,740
				151,430
Engineering				3,000
Administrative, overhead, purchasing				3,000
				157,430
Contingency				15,700
				173,130
Fee				8,670
Total estimated cost, cooling and scrubbing system				181,800

TABLE 11. - Estimated capital cost for coal-handling equipment

	Material	Labor	Total
Battery cost:	$	$	$
Lignite conveyor	6,800		
Char conveyor	5,800		
Ash conveyor	1,600		
Hopper in lignite bin	750		
Hopper in char bin	550		
Vibrating screen	2,100		
Extra screens	200		
Miscellaneous chutes, foundations, supports, etc.	1,250		
Cost per battery	19,050	3,800	
Plant cost for 19 batteries:			
19 batteries	361,950	72,150	434,100
Plant conveyor	77,700	15,500	93,200
Bulldozer for main storage pile	5,000		5,000
Total direct cost	444,650	87,650	532,300
Field indirects			43,800
			576,100
Engineering			11,500
Administrative, overhead, purchasing			11,500
			599,100
Contingencies			59,900
			659,000
Fee			33,000
Total estimated cost of coal-handling equipment			692,000

TABLE 12. - General plant facilities and utilities

General plant facilities of plant producing 50 million cu. ft./day of (H_2+CO) from natural lignite

H_2-CO ratio = 2.5

Office and laboratory	$ 75,000
Shop equipped	35,000
Change house	10,000
Warehouse	15,000
Rolling stock roads	25,000
Railroad trackage	10,000
Yard grading and fill	20,000
Plant fencing	6,000
Total	196,000

General plant utilities of plant producing 50 million cu. ft./day of (H_2+CO) from natural lignite

H_2-CO ratio = 2.5

Sewers and waterlines	50,000
Electrical distribution	40,000
Steam distribution	20,000
Air supply	10,000
Fire lines and hydrants	25,000
Yard lighting	10,000
Telephones	10,000
Total	165,000