STRONGLY CAKING COAL GASIFIED IN A STIRRED-BED PRODUCER

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INTRODUCTION

Partial combustion of coal with continuous addition of steam converts a large fraction of the energy in the solid fuel into combustible gases: carbon monoxide, hydrogen and hydrocarbons plus a small fraction of non-combustible carbon dioxide. This gasification process is well known, and it has been practiced on a large scale for many years. It is carried out in a retort-type vessel called a producer, and the product is known as producer gas.

Gasification with air dilutes the gas with inert nitrogen to the extent of about 50 percent. This dilution can be reduced or eliminated entirely by substituting oxygen for a part or all of the air. Process requirements and economics for each application determine whether air or oxygen will be used.(1)[1/]

Gas producers are usually classified in three categories according to the characteristics of the fuel bed, namely: fixed, fluidized, or entrained. Within this broad description, many innovations have been proposed. Sixty-five producers of all types are described in a recent report.(2) The fixed-bed producer is the only type accepted thus far for commercial use. Fixed-bed producers reached their maximum use in the United States about 1925 when approximately 11,000 were in service in the United States. They are still used to a minor extent in Europe, South Africa, Australia, and Japan for firing industrial furnaces and generating town and synthesis gas.

Interest in pressurized gas producers is increasing here and abroad for application to thermal power generation using combined gas and steam turbines with gas cleaning proceeding combustion. The first commercial plant of this type is scheduled for completion the summer of 1971. Its output is 170 Mw, and the location is Lünen, West Germany. The pressurized gas producer also has potential for the production of high-Btu pipeline gas from coal because of the substantial amount of methane formed during gasification.

1/ Numbers in parenthesis refer to references at end of paper.

The U.S. Bureau of Mines is undertaking the development of a fixed-bed producer at its Morgantown, W.Va. Energy Research Center.(3) This experimental producer provides more extensive stirring of the fuel bed than has been the practice heretofore. It conforms to the accepted concept of a fixed-bed producer in all other respects.(4) The designation stirred-bed producer is proposed in order to distinguish this type from the others.

The fixed-bed producer has demonstrated thermal efficiencies (percentage of heating value of the fuel appearing in the gas) of about 90 percent for hot raw gas and about 75 percent for cold clean gas. Generally the fuel has been limited to coke, anthracite, or noncaking bituminous coals. Mildly caking coals have been used in some commercial producers which were provided with a mechanical stirrer for agitating the top level of the bed. This stirring action broke the weak coke that formed and filled voids in the bed. The bulk of the bituminous coal located in the eastern half of the United States is too strongly caking to be gasified in a fixed bed. A strongly caking coal from West Virginia's Pittsburgh seam was gasified in tests performed at Dorsten, Germany, in a fixed-bed producer equipped with a top stirrer. The caking property had to be reduced by adding ash from local coal in order to prevent adherent coke from stopping the coal flow.(5) A coal's performance under conditions existing in a fixed bed varies with its plastic properties, mineral content, heating rate, particle size, and operating conditions. Development of equipment and techniques for gasifying caking coals in a fixed bed will provide a versatile, economical system for converting coal to gas.

EXPERIMENTAL

Equipment

The stirred-bed producer is shown in figures 1 and 2. It operates at pressures to a nominal 100 psia. Inside dimensions are 3.5 feet in diameter and 24 feet in length. The fuel-bed agitator or stirrer is the design feature that distinguished this experimental producer from other producers of fixed-bed design. The agitator consists of a vertically mounted rotating shaft to which is attached two horizontal arms, or rabbles, located 2-feet apart. Both rabble arms and the entire length of the shaft are cooled by circulating water. A third rabble, uncooled and positioned 2-feet above the middle arm, levels the top of the bed. The variable speed drive acts through two lever arms and ratchet mechanisms which rotate the shaft and move it vertically in reciprocal motion. The distance traveled vertically is controlled by the positioning of limit switches within a maximum span of 6-feet 4-inches. For the experiments reported here, the vertical travel was limited to 2-feet. Settings of 2 or 3 on the variable speed drive gave agitator rates of 15 or 22-1/2 revolutions per hour and 3-1/2 or 5-1/4 feet per hour travel, respectively. Limits in rotation were 8 to 40 revolutions per hour and in vertical travel 2 to 9-1/3 feet per hour. A setting of 3 was used most of the time during these tests.

Continuous infrared analyzers record the concentration of carbon monoxide and carbon dioxide in the product gas. Continuous monitoring of the fuel bed for bed depth, occurrence of voids, location of combustion zone, and presence of excess ash is obtained by nuclear instruments, figure 3. The percentage of gamma-ray radiation transmitted through the vessel from a cobalt-60 source varies with the thickness and bulk density of the material through which the gamma-rays pass. Coal, ash, and gas attenuate the radiation in varying degrees dependent upon their presence or absence and bulk density, but attenuation by the vessel wall is constant.(6) A 625-millicurie source with three detectors locates the top of the fuel bed. Coal is added when the middle detector indicates "empty". A 4-curie source and two detectors with outputs recorded on a strip chart shows the presence or absence of voids or high-ash level as indicated in figure 4. Adjustments to the stirring rate are based on this data.

Operation

The fuel bed moves downward countercurrent to the ascending hot gases resulting from partial combustion of the coal. Air and steam are admitted below the grate. Fuel consumption is controlled by adjustment of the air rate, and temperature is controlled by adjustment of the steam rate. The temperature is held below the ash fusion temperature to avoid forming clinkers which clog the grate.

Coal is fed intermittently to the top of the bed by adding batches weighing 200 - 250 pounds about every 10 minutes through lock hoppers pressurized with inert gas. Ash is discharged by means of a rotating grate and removed through a lock hopper. The removal rate is adjusted by varying the grate rotation between 4 and 10 rph. The combustion zone is held about one foot above the grate. The normal bed depth above the grate is about eight feet. The interface between the ash and combustion zones is generally below the zone detected by the nuclear density gage; detection is by means of thermocouples having vertical spacing of 12 inches. Temperature differentials give a good indication of the interface location, although thermocouple temperatures are much lower than those in the interior of the bed because of the close proximity of the thermocouples to the water-cooled wall. A 5-foot length of the wall above the top of the grate is water jacketed with the remaining wall area faced with insulating brick.

Gases leave through a side outlet in the top cover, and are reduced in pressure by a control valve. The gas is cleaned of the large part of its dust load by flowing through a one-stage cyclone separator before it is burned in the atmosphere. The gas is continuously analyzed for carbon monoxide and carbon dioxide but is not sampled for steam, tar, or dust. Periodic samples are taken for laboratory analyses of the gas, ash, and cyclone dust.

Start-ups are made with anthracite in order to avoid depositing large amounts of tar in the cold producer. Bituminous coal feed starts when the exit gas temperature reaches 1,000° F. At steady conditions, the gas temperature reaches a maximum of about 1,200° F. About 1.5 tons of coal fill the producer, and one type of coal completely displaces the other in about four hours.

Operations are scheduled on a 3-shift, 5-day week basis. Light off and burnout each require one shift. Holding in banked condition over a weekend is possible, but burnout is the usual practice. These procedures give a 4-day operating period.

Data are presented for strongly caking high-volatile A bituminous, Pittsburgh bed, Monongalia County, West Virginia, and for moderately strong caking high-volatile B bituminous, No. 6 seam, Jefferson County, Illinois. Proximate and ultimate analyses are given in table 1. The Pittsburgh bed coal was cleaned and of 2 x 1-1/4 inch screen size. The Illinois No. 6 coal was cleaned and of 1-1/2 x 3/4 inch size.

Table 1. - Analyses of high-volatile coal (as received)

	W. Va. Pittsburgh seam2/	Illinois No. 63/
Ultimate		
Carbon	76.9	70.9
Hydrogen	5.5	6.4
Nitrogen	1.3	1.7
Sulfur	2.4	1.2
Oxygen1/	6.2	14.4
Ash	7.7	5.4
Proximate		
Moisture	1.3	6.9
Volatile matter	36.8	36.1
Fixed carbon	54.2	51.5
Ash	7.7	5.5

1/ By difference
2/ FSI 8, HV 13,850 Btu/lb.
3/ FSI 4-1/2, HV 12,050 Btu/lb.

RESULTS

Process conditions and performance data are given in table 2. These data are the average results from 2 to 4 nonconsecutive operating periods of 7 to 10 hours duration. The results do not represent steady state data, and are shown because they approximate what would be possible. Steam, tar, and dust contents of the gas are not known but can be estimated.

Temperature of the air-steam mixture at the inlet range from 230° to 260°F and producer gas at the outlet ranges from 900° to 1,200°F. The weight of air is approximately 6 times the steam weight. Air is supplied at about 200°F while steam is reheated to about 400°F, (75° superheat), thus the heat input is approximately 5 percent greater than it would be if combustion of coal were the only source.

A cooling water temperature increases about 25°F for the stirrer and 28°F for the shell jacket. Water flows for the stirrer and jacket are approximately 310 and 45,600 pounds per hour, respectively. The heat loss to cooling water for the stirrer is virtually nil and for the jacket ranged from 6 to 10 percent of the heat input.

Table 2. - Process conditions and performance averages

	W. Va. Pittsburgh seam		Illinois No. 6 seam
	Test 1	Test 2	Test 3
Data period, hrs. (cumulative)	16	31	36
Pressure, psig	80	80	80
Feeds,			
coal, as rec.1/, lb/hr	1,150	1,390	1,630
coal, lbs/Mscf gas	15.7	15.4	18.1
steam, lb/hr	560	720	630
air, lb/hr	3,830	4,600	4,600
Feed ratios, lb/lb			
steam:coal1/	0.49	0.52	0.38
air:coal1/	3.32	3.31	2.82
Gas yield			
M scf/hr	73	90	90
M scf/hr-sq ft2/	7.6	9.4	9.4
scf/lb coal	63.5	64.8	55.2
Gas composition, mol pct3/			
CO	20.0	20.5	21.7
H_2	15.5	15.6	15.8
CO_2	7.2	8.7	6.8
CH_4+	2.8	2.4	3.0
N_2	54.5	53.2	52.7
Heating value, Btu/scf (gross)	142	145	164
Heat Losses (estimated), pct of input	13	10	11
Cold gas efficiency, pct	62	65	72

1/ as received
2/ Grate area, 9.6 sq ft.
3/ Dry basis.

DISCUSSION

Performance

Experience with Pittsburgh seam coal indicates that gasification of strongly caking coals can be accomplished by stirring the bed to break coherent coke formations. The compound rotation and axial movement of the agitator provides slow continuous stirring that fills voids and keeps the bed permeable. The condition of the bed is determined by observing the gas quality and bed density as recorded by control instruments. Gross changes in bed density are immediately apparent and gas quality deteriorates or improves with a respective decrease or increase in density. The bed density gage has great value because it provides a definite and immediate indication of conditions in the bed. The gas analyzers have a time lag, and coal additions produce minor variations in gas composition. This density gage is mounted in a fixed position; it would have greater usefullness if it were mounted on a movable platform traversing the entire bed and the movement controlled from a remote station. A correlation between the stirring rate and gas quality was not obtained, but one probably exists as a slow stirring rate allows voids to be retained for a longer time before they collapse.

A predicted life for the agitator and grate cannot be made at this time. Based on last year's experience, long life can be anticipated. Chances of overheating either agitator or grate are virtually eliminated by controlling operations through the use of instruments. It does not appear to be necessary to extend the stirring into the oxidation zone, and the lower rabble arm is not subjected to high temperature in an oxidizing atmosphere.

Gas Quality

Gas quality is fairly typical for an air-blown producer except that carbon dioxide is 2 to 3 percent higher and carbon monoxide plus hydrogen is lower by the same amount than is normal for a commercial producer. This is attributed to gas temperatures being somewhat lower because the smaller experimental producer has more water-cooled surface per volume of reaction space. Lower gas temperatures in the reduction zone slows the rate of the reaction $C + CO_2 = 2\ CO$ and some CO_2 passes through the zone unreduced, expecially if the bed depth is shallow. Design geometry has another effect. The greater wall surface to reaction volume provides better opportunity for unreduced carbon dioxide and steam to leak around the fuel bed.

Heating Value

Gross heating value of the dry gas is slightly higher for Illinois No. 6 seam than for W.Va. Pittsburgh seam. The gas from Illinois coal contained 0.5 percent $C_3H_8 + C_3H_6$ to 0.1 percent for the latter. Heating values are in the range 140 to 165 Btu per scf, which is normal for air-blown producer gas.

Efficiency

The cold gas efficiency is the potential heat in the gas expressed as a percent of the heat input. Two tests with Pittsburgh seam coal gave efficiencies of 62 and 65 percent, while the test of Illinois No. 6 gave 72 percent. The lower values are considered more representative of the small experimental producer because heat losses to the cooling water are greater than would be experienced with a large producer operated continuously at steady conditions. Heat loss to the water-cooled stirrer is negligible because its surface area is relatively small, but the 6 to 10 percent loss to the water-cooled wall is 2 to 3 times greater than normal for a large producer.

Steam: Coal Ratio

The addition of steam has two very important functions: To improve the cold efficiency and to control clinkering of the ash. The decomposition of steam by reaction with carbon is strongly endothermic; hence, some of the sensible heat, which is lost when the gas is used cold, is converted into potential heat in the gas in the form of hydrogen and carbon monoxide. Enough steam must be added to prevent extensive clinker formation, which clogs the grate and stops the fuel flow, but excess steam causes excessive cooling and, passing through undecomposed, is wasted. Pittsburgh bed coal has a strong tendency to form hard clinkers, and--by trial-- a steam-to-coal weight ratio of 0.5 gave satisfactory results. Illinois No. 6 coal showed no tendency to form clinkers with a steam-coal ratio of 0.4.

Gas Yields

Gas yields are dependent upon the air rate which limits the combustion rate up to the point where fuel loss by entrainment in the gas stream becomes excessive. The maximum air rate in these tests was the full output of a compressor, 60,000 scfh. The gas yields at 80 psig are 63-65 scf per lb of Pittsburgh seam coal and 55 for Illinois No. 6. The smaller yield for the latter coal results in part from its lower carbon content.

Some additional improvement in gas yield appears possible if air flow is increased by adding more compressor capacity. Another approach would be to add oxygen to the air blast. This method could be used with a rotating grate discharging the ash as solids. The addition of oxygen increases the temperature in the combustion zone, and excess steam must be added to avoid clinker formation by ash fusion. When 100 percent oxygen is used the preferred ash removal method is fluid slag. This would require a hearth-type retort with oxygen admitted above the hearth through tyeres. In either case, the higher gasification rate is not expected to alter fuel bed characteristics, and stirring is expected to maintain nonagglomerated bed conditions.

CONCLUSIONS

Short-time tests in gasifying strongly caking coal in a stirred-bed indicate that continuous stirring of the fuel bed is necessary and succeeds in maintaining the fuel flow. Nuclear density and level gages supply the data needed to control operation of the producer and hold the gas quality uniform. Further increase in gas production rate appears possible by increasing the air blast rate. Some improvement in gas quality may be obtained by closer control and optimization of operating conditions. Additional tests are needed to obtain data showing gas yields and quality at maximum coal feed rates and to determine operability using smaller sizes of coal.

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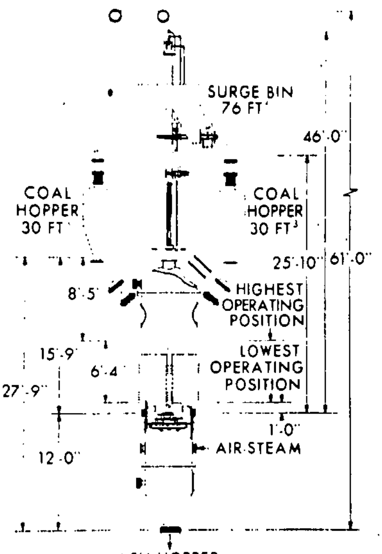

Figure 1. - Schematic drawing of gas producer

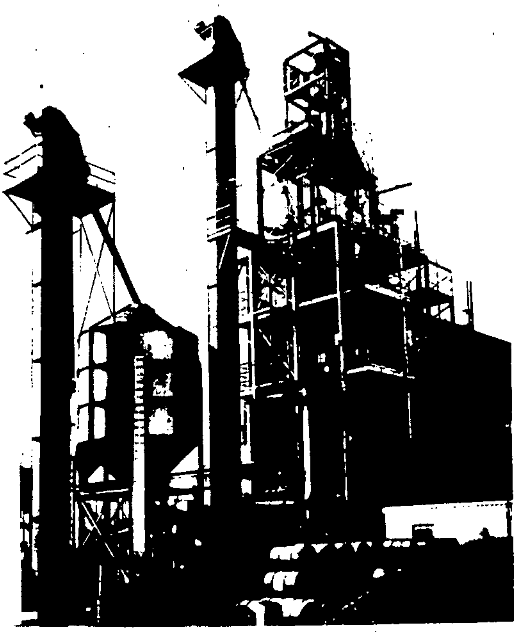

Figure 2. - View of gas producer

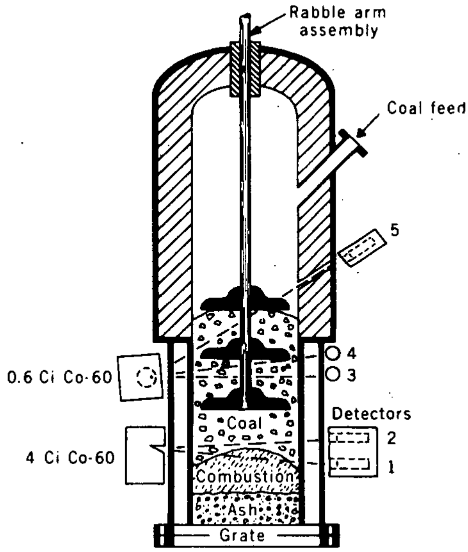

Figure 3. - Nuclear density gages applied to gas producer

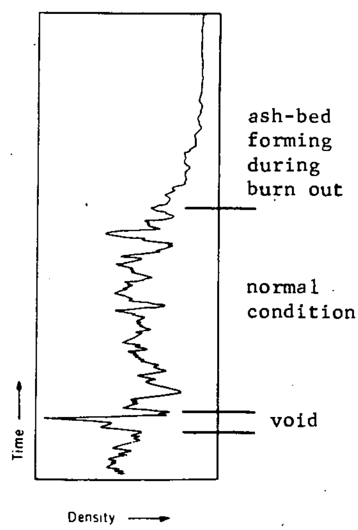

Figure 4. - Typical display and interpretation of density measurements for the combustion zone