LOW BTU GASIFICATION OF NORTHERN PLAINS LIGNITE IN A COMMERCIAL SIZED UNIT

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AMERICAN NATURAL SERVICE COMPANY
DETROIT, MICHIGAN

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INTRODUCTION

Since 1974 the Riley Stoker Corporation has been conducting developmental and research work on a commercial sized, thin bed atmospheric coal gasifier. The primary goal has been the refinement of the successfully established first generation technology to the standards imposed by both environmental and economic constraints in the synfuels marketplace. A secondary, but no less important goal, has been the gaining of hands-on experience in an area long treated as more an art than a science, and in which hard data is generally lacking.

During this time, a total of twenty-two demonstration runs with various eastern coals was carried out on this unit, together with an equal amount on a smaller, one-fifth scale gasifier. Results of this program, together with a summary of practical operating experiences have been presented before other bodies.[1,2,3]

This paper is a report of the results of the first full scale modern demonstration test to be carried out in the U.S. on North Dakota lignite to produce low Btu gas.

Figure 1 depicts the full-sized 3.2 meter (10′-6″) I.D. unit as it stands today, and Figure 2 is a schematic of the test facility.

LIGNITE GASIFICATION

Other than a few isolated attempts at continuous water-gas production in the forties,[4] the gasification of lignitic fuels received little attention in this country during the heyday of the manufactured gas industry. The data base for producer gas operation was therefore limited to eastern coals. With the realization of the enormity of this western resource, attention has recently turned toward efforts to include it in the behavior matrix.

In 1977 and again in 1978 the Riley Stoker Corporation, under contract to American Natural Resources, carried out a series of test runs on North Dakota Lignite on its .61 meter (two-foot) I.D. gasification test facility. These tests were to establish feasibility guide lines for the gasification of this fuel, together with the establishment of operating parameters, as the basis of a decision to proceed to full-scale testing.[5,6]

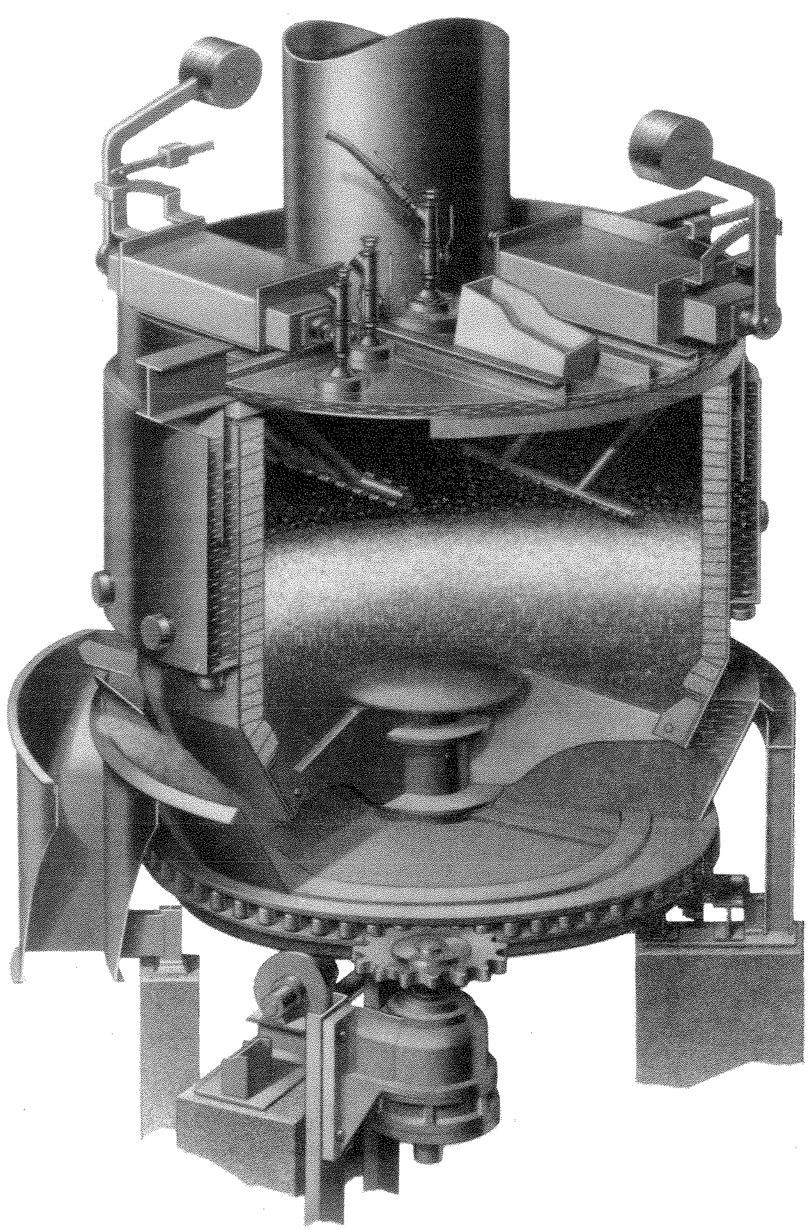

Figure 1 Cross-section of the Full Sized Riley Gasifier

Another desired goal from those tests was the establishment of lignite reactivity relative to other coals. One of the most interesting sources of coal reactivity data dates back to the turn of the 20th Century. The newly formed U.S. Bureau of Mines tested 173 coals in a 2.1 meter (7-foot) diameter gasifier.[7] Coal rank varied from peat to semi-anthracite. Figure 3 correlates coal rate, gas yield and fixed carbon gasification rate as a function of the coal rank, as characterized by percent fixed carbon in the coal. The higher reactivity of the lower rank coals is shown by the much greater coal feed rates observed in comparison to high rank bituminous coals. On this basis, lignites react about three times faster than eastern bituminous coal. However, gas yield per pound of coal increases with increasing coal rank, but yield per pound of fixed carbon remains constant. Likewise, the specific gasification rate of the fixed carbon is essentially constant for all coal ranks. It should be pointed out that the Bureau of Mines tests were not designed to test the limiting capacity of each coal in the gasifier, but rather to operate a downstream internal combustion engine at fixed load.

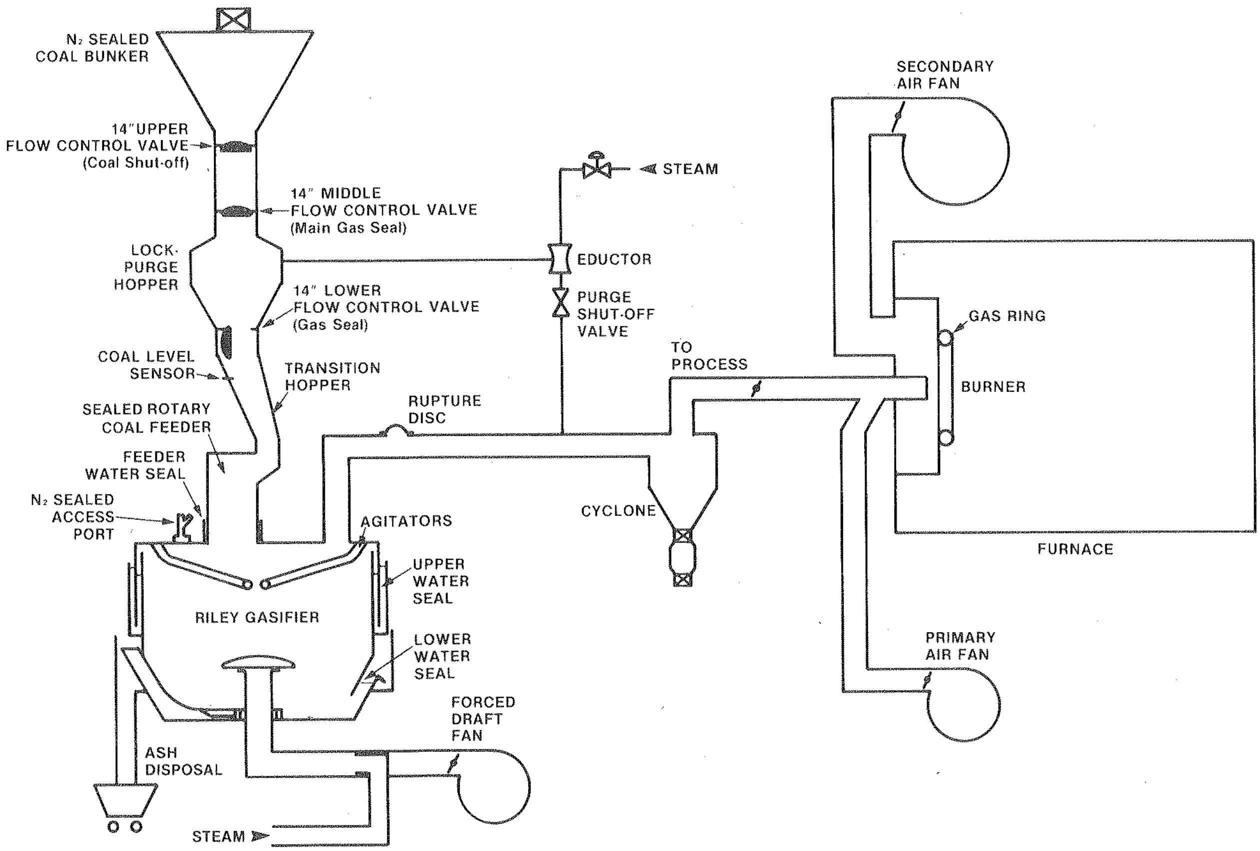

Figure 2 Schematic of the Test Facility

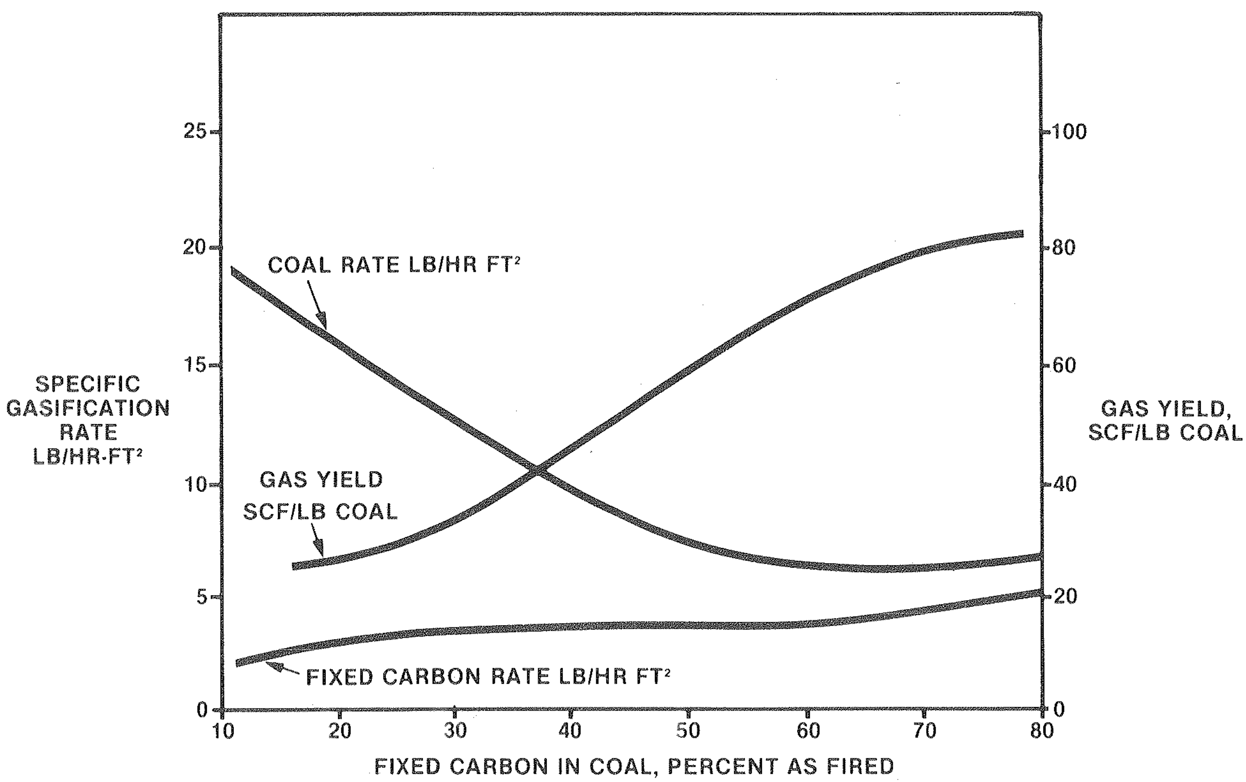

Figure 3 U.S. Bureau of Mines Coal Reactivity Data on 2.1 Meter (7 Foot) I.D. Gasifier

More recently, a similar program was carried out at Riley Research, gasifying four American coals in a .61 meter (two-foot) diameter gasifier.[5] Subsequent test work sponsored by American Natural Resources added data on North Dakota lignite in that same gasifier.[6] Again, limiting absolute gasification rates were not measured but relative gasification rates were determined by correcting to constant inlet air flow rate. The results are plotted in Figure 4. Again lignite appeared to be several times more reactive than anthracite. Gas yield per pound of coal increased with increasing coal rank, but gas yield per pound of fixed carbon was essentially constant. Fixed carbon gasification rate also appeared constant.

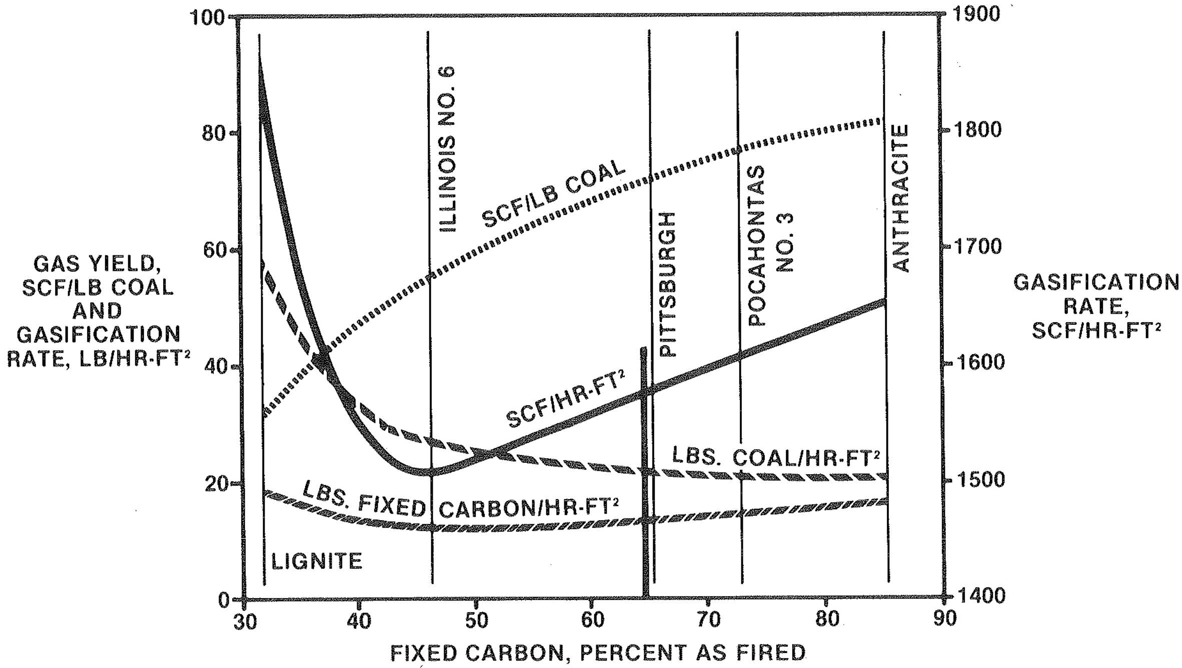

Figure 4 Riley Coal Reactivity Data on .61 Meter (2 Foot) I.D. Gasifier

With the completion of several highly successful small scale gasification tests on lignite, it was felt that a full-sized lignite gasification test would be essential to the definition of those parameters sensitive to scale-up. It was hoped that lignite gasification rates perhaps three times as great as those observed with anthracite might be achieved. Thus in early 1979, planning began for a full-scale demonstration run on the Riley Morgan gasifier at Riley Research in Worcester, Massachusetts. Preparations for the test continued throughout the summer, including the installation of a specifically designed low Btu gas kiln burner in the Riley combustion test facility. By October, test preparations were nearly complete, and 900 metric tons of North Dakota lignite were pre-screened to a nominal 51 × 13 mm. (2 × ½") size and shipped by rail to Massachusetts.

TEST OBJECTIVES

A number of parameters became objectives of the test, in order to establish criteria upon which the demonstration would be evaluated.

Capacity

The primary objective of the test was to establish a "reasonable maximum" gasification capacity for this unit on a heretofore untried western fuel. "Reasonable maximum" is defined as that level at which gasification is achieved yielding a high quality product for a sustained period of time without recourse to extraordinary measures. From a thermodynamic model, this level for this fuel was projected to be a specific gasification rate of 683 kg/m² (140 lb/ft²)/hr or 5443 kg. (12,000 lb)/hr.

Fuel Size

While it is generally accepted that the optimum size of the coal feed to any fixed bed gasifier lies in the range of commercially screened 51 × 25 mm (2″ × 1″) lumps, indications from prior testing[6] were that there was little sensitivity of capacity to size down to 51 × 13 mm (2″ × ½″). The thin bed feature of the Riley unit tended to reinforce this position. Hence, the latter fraction, screened at Indian Head mine in North Dakota, and receiving no further treatment, was selected, and the validity of this prior finding became an objective.

Gas Quality

Gas of consistently high quality resulted from prior testing. Modelling for the full scale at capacity was projected at 6183 kJ/m^3 (166 Btu/SCF). On line stream sampling was accomplished by parallel analytical trains of RSC and Radian Corporation.

By-products

Measurements and sampling of all gasifier input and discharge streams were made for two equally important reasons: (1) the data on major by-products such as tar, water, dust and ash to be used as design criteria for future plant installations, and (2) identification of possible "workplace" or "worker health" hazards.

Process Efficiencies

Long-term, steady state measurements of representative material and energy balances were to be made to establish process efficiencies.

System Hardware

A number of process modifications have evolved at RSC during the five year test period; most of them having to do with environmental integrity of the system. This test was seen as an opportunity to evaluate them as a whole under true operating conditions.

Other

A number of objectives having to do with combustion of the product gas, improvements to some of the fuel handling, gas transport, gas burner operations and the like were included, but are beyond the scope of this paper and will be presented elsewhere.

ABSTRACT OF RUN

The test facility was operated from December 4 to 15, 1979, and during this period a total of 374 metric tons of North Dakota lignite was gasified, processed and combusted. Because of some non-gasifier problems, two interruptions caused shutdowns early in the test. The major portion of the test fuel was processed in the last five days of operation, and the results presented herein represent data taken from this continuous period.

SYSTEM BEHAVIOR

Coal Feed And Locking System

Early tests on lignite in the .61 meter (2 foot) Riley gasifier produced tar deposits at the coal feed inlet in such quantity that the inlet valve required removal and cleaning for continued operation. Despite this discouraging development, the full scale coal feed and locking system, already developed and tested during bituminous gasification, was retained for full scale tests on lignite. However, steam purging, prior to evacuation of the lock hopper system, was added to ensure the continued operation of the coal feed and coal sensing system in the presence of tar.

Operation Sequence — The coal feeding-gas containment cycle is an automatically controlled, seven-step operation:

1. At startup, the upper and middle control valves are closed and no coal flows. When closed, the top valve must support a head up to 6.4 meters (21 feet) high with a pressure of approximately .5 atmospheres (1,000 pounds per square foot). The intermediate valve is closed to contain gases within the hopper. The lower valve is open to admit lock hopper coal to the gasifier feeder.
2. When the feeder coal supply sinks below the bottom valve, its level is automatically detected, and the bottom valve closes. After cleaning the surge line, a steam ejector exhausts product and other gases from between the lock hopper valves. The exhausted gas is fed back into the output or producer gas stream going to the burner. The bunker is continuously sealed with nitrogen at a pressure higher than that of the gasifier gas, so that any leakage will be into the gasifier and not out of the system.
3. The middle valve opens. Nitrogen enters the lock hopper.
4. The upper valve opens, admitting a charge of coal (about ¾ ton) and more nitrogen to the lock hopper.
5. The upper valve then shuts, stopping the coal. It closes against and is again supporting a 6.4 meters (21-foot) head of coal.
6. The middle valve, above the coal in the lock hopper, shuts to seal the hopper and gasifier.
7. The bottom valve opens to admit coal to the gasifier feeder and the cycle is completed in about one minute.

Access Ports — Specially designed nitrogen sealed "poke holes" are accessories to the coal feed system. They provide access to the coal bed for information and management.

Tar Assessment — Post test inspection of the interior of the coal feed and locking system showed no buildup of tars sufficient to interfere with operation of any part of the system including the access ports.

Environmental Assessment — Analysis of gas discharge was performed during the lignite gasification by the Radian Corporation under EPA contract. As listed in Tables I and II, concentrations of organic vapors and raw gas components in the environment were at barely detectable levels. This constitutes a major advance in low-Btu gasification technology.

Piping System

Deposition of tar/soot upon the walls of piping systems, which is a major consideration when gasifying bituminous coals and transporting the product in a hot, raw state, was not expected to be a factor with lignite; this conclusion was drawn from the results of the prior, small-scale testing, and is due solely to the water content of the fuel (30%). Exit gas temperatures for the same bed height run considerably cooler with such a fuel than with the drier, geologically older coals having comparable volatile matter contents. The tars produced from fuels having high moisture contents are thus not subjected to the high temperatures experienced with normal bituminous operation, thereby avoiding severe cracking conditions which lead to carbon production and large molecular repolymerization. In addition, the lignite tars tend to be more highly oxygenated due to the high oxygen content of the feed, and consequently "lighter" in character, or non-pitchlike.

What was expected, therefore, was the possible condensation of liquids (tar/oil/water), should insulation of the piping system not be adequate, or if gas exit temperatures were so low as to approach the dewpoints of the liquids. Experience at the U.S. Bureau of Mines pilot facility at the Twin Cities Research Center in Minneapolis in October of 1979 had suggested this possibility. For this potential problem a new 30-inch I.D. steel line, heavily insulated externally, was run between the cyclone and the combustion test furnace. The existing 36″ I.D. refractory lined exit pipe between the gasifier and the cyclone was left intact. In addition, three 4″ tar/liquid collecting drains were installed at low points in the system and directed to seal pots. Behavior of these collectors was carefully monitored during the run.

DATE	TIME	LOCATION	CONCENTRATION (ppm as CH_4)
12/13	1100 hrs	Gasifier Building — all walkways	1.5 ppm
12/13	2200 hrs	Gasifier Building — all walkways	1 ppm
12/13	2200 hrs	Gasifier Building — top of gasifier during poking operation	1 ppm
12/13	2223	Coal Bin — 2-inch gate on top	5-6 ppm

Table I Organic Vapors Analysis

DATE:	12/14	
TIME:	0645 hours	
FLOWRATE:	0.022 m³/sec (actual)	
GAS ANALYSIS:		
	N_2	95.4%
	H_2	1.1%
	O_2	0.2%
	CO	Below detection limit
	CH_4	Below detection limit
	CO_2	Below detection limit

Table II Poke Hole Discharge During Simulated Poking Operation

Neither expectation was realized for the entire duration of the run; not a single gallon of tar was obtained in the three collectors. Some water did condense, but not in measurable quantities, and merely colored the seal water brown. The only evidence of tar condensation within the piping was a light commingling with soot and dust found chiefly near the test furnace.

That condensate presented no problems in the downstream piping system is due to (1) the fact that tars production as a percentage of volatile matter is a much lower value than for bituminous coals (see material balance) and (2) the thin bed character of the process, which allows gas exit temperatures on the order of 260°C (500°F) and more, well above condensate dewpoints, a factor to be considered in variable bed height operation. Adequate piping insulation is, on a hot gas system, considered a must.

The implications of (1) are significant when considering a cold gas system with cleanup, for this low yield impacts the design of downstream cleanup units, and if the trade-off is tar to gas, outputs per gasifier are increased by as much as 10-15 percent. For a hot gas system the difference is not significant.

Bed Pressure Drop

In general, fuel bed pressure drops for lignite during the run exceeded those for other fuel at comparable air/stream flows and bed heights. Contributing factors are, of course, bed fuel size and ash size. While no hard evidence of lignite degradation occurring during gasification was apparent, this possibility exists, especially in light of recent findings at the Bureau of Mines test facility in Minneapolis; these findings are discussed in a paper by one of the co-authors being presented at another forum this month.[8]

Figures 5 and 6 map some selected variables during a twenty-five hour portion of the test which shows that the character of the fuel bed was changing with time, and that some steady-state condition was being approached only at the end of this period.

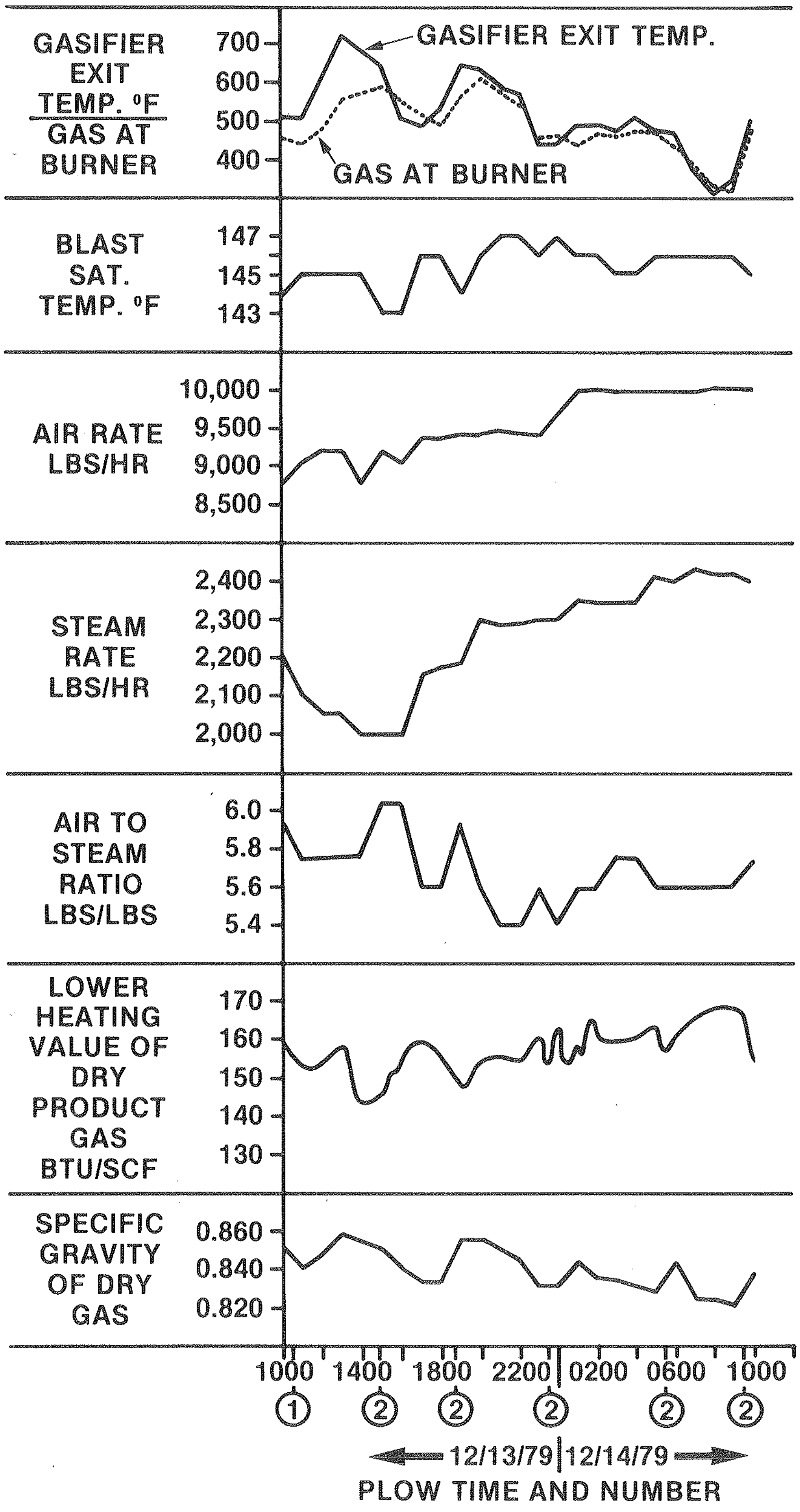

Figure 5 Process Variable for 24 Hour Period

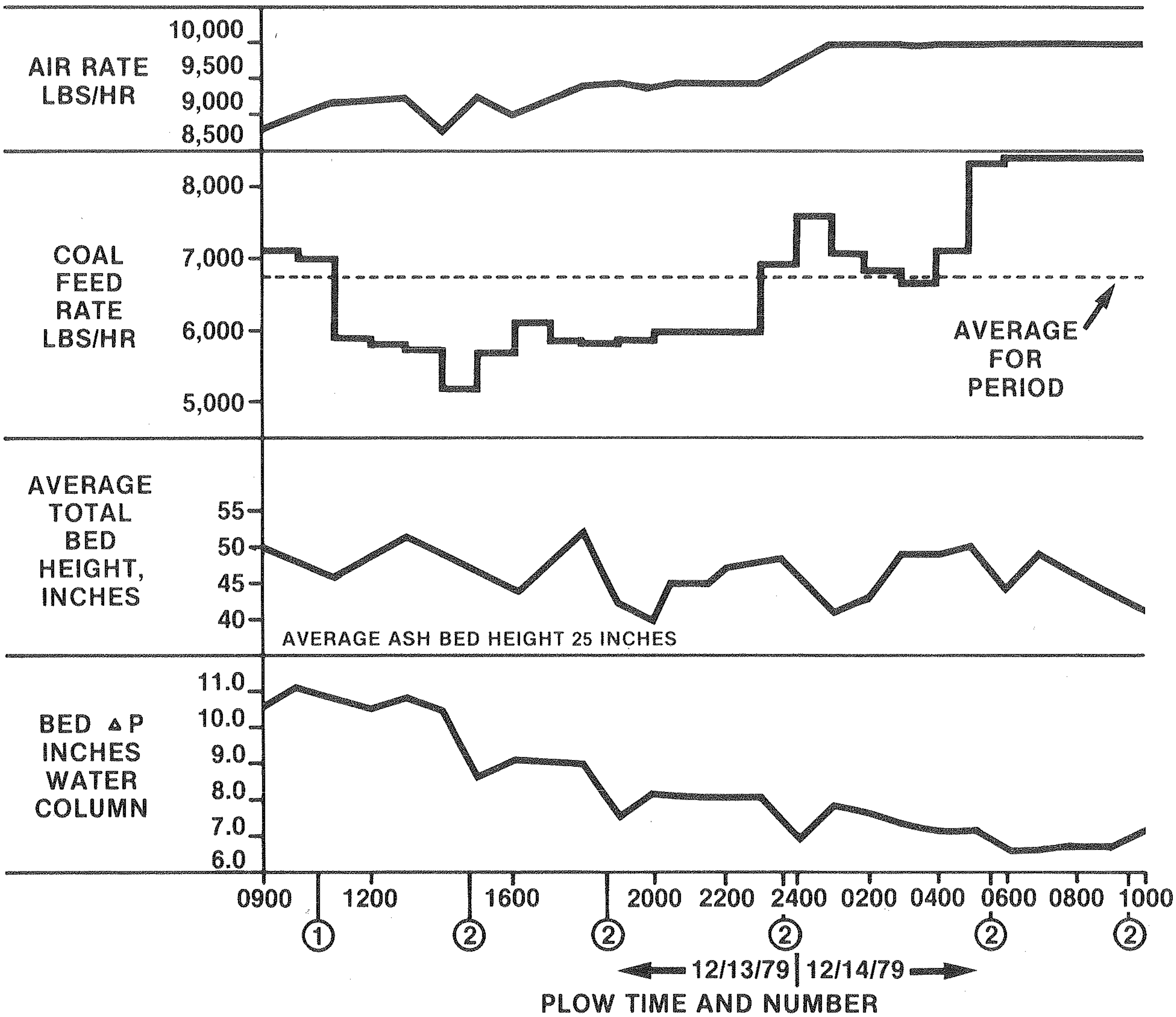

Figure 6 Bed Related Process Variable Plots for 25 Hour Lignite Run

FUEL BEHAVIOR

Performance of the fuel, when subjected to conditions duplicating a full-sized commercial operation, has yielded information of significant value, heretofore unavailable from laboratory or pilot-scale testing.

Stability

From experience during the two-foot tests and laboratory tests, problems with size degradation in handling were not expected to be a factor in this test. While not of the same *hardness* as bituminous and anthracites, Northern Plains lignite had exhibited a fiber *toughness* which was expected to make it of equal durability.

Prior to testing, one of the standard experiments adopted by RSC has been to run the candidate fuel through the system, making size determination at key points to observe any effect that fuel handling equipment may have on the fuel.

Table III illustrates the effect on this coal. The sharp increase to 37.2% beyond minimum size specification led to further determination as shown in Table IV. The values of nearly 50 percent below the 13 mm. (½″) cut were a cause for concern but not nearly as much as the quantity of fines below 6.3 mm. (¼″).

These values were far in excess of the recommendation of the 1978 test which stated "fines below 6.3 mm. (¼") exceeding ten percent not be considered for a commercial fixed bed gasifier application without further testing on a larger scale."

Much discussion concerning the exact point of maximum degradation followed. The screw feeder was selected for particular scrutiny, assuming the results of the single run were in error, the thought being that a screen should be installed just after it. Some small degradation in size had been detected in a prior run of bituminous, but the main area appeared to be the drop into the bunker. A carefully controlled experiment by ANR personnel confirmed the findings of Table IV.

It was decided for the purposes of this run to minimize the impact potential of a 4.9 m. (16 Ft.) drop into the steel bunker by simply running with as full a bunker as possible at all times, thereby cushioning this drop.

SIZE ANALYSIS	AT COAL PILE 11/3/79	OFF TRUCK	INTO GASIFIER
+1¼"	6.9%	1.9%	1.5%
−1¼ + 1	17.4	14.2	8.8
−1 + ¾	39.4	41.9	26.3
−¾ + ½	29.6	23.9	27.2
−½ + ⅜	6.7	9.3	17.2
−⅜ + #3		3.7	7.5
−3 + 4		1.2	2.6
−4 + 6		0.8	1.8
−6 + 8		3.1	1.7
−8			5.4
½" Total	6.7	17.1	37.2

Table III System Effect on Size —N.D. Lignite 11/13/79

SIZE ANALYSIS	FROM TRUCK	END SCREW FEEDER	BEFORE COAL FEEDER	INTO GASIFIER
+1¼"	3.6%	6.7%	7.8%	
−1¼ + 1	9.4	13.9	1.1	8.9%
−1 + ¾	31.9	32.1	22.1	23.3
−¾ + ½	24.8	26.2	19.7	22.5
−½ + ⅜	17.2	12.6	16.3	13.7
−3 + 4	7.6	4.0	9.9	7.6
−4 + 6	2.3	1.0	4.3	3.7
−6 + 8	1.0	0.5	3.2	3.2
−8 + 16	2.2	3.0	2.8	3.3
−16 + 30			4.3	4.7
−30 + 50			2.8	3.2
−50			2.1	2.4
			3.7	3.5
½" Total	30.3	21.1	49.4	45.3
¼" Total	5.5	4.5	23.2	24.0

Table IV System Effect on Size —N.D. Lignite 11/20/79

Activity in this area led to a closer look at what was happening to the fuel in storage and transportation to the site, since some degradation appeared to be taking place during this phase of handling.

Surface degradation of the coal was undoubtedly occurring as the high moisture content was leaving the coal along bedding planes, but it was felt that this layer could be prudently avoided and did not amount to a large percentage of the total amount.

As the test progressed, it became apparent that far more than the surface was affected, as a number of trucks were received having an excessive amount of fines. Some of these were sent back, but some found their way into the gasifier. As an example, one of the latter was found to contain 24.7% fines less than 6.3 mm (¼″).

At the coal storage site it was found that in addition to the surface slack, random streaks of fines could be seen within the piles. Strict policing of the coal to be delivered for testing was decided upon, and it was left to the fuel handler to discard and disregard any loads of fuel with inordinate fines content.

Whatever the cause of this degradation, be it weathering in transit or transit itself, the need for an on-site final screening unit at a commercial plant is clear.

Fuel Reactivity

The significance of this characteristic of lignite in this demonstration is threefold.

Primarily, assuming the measurements associated with the material and energy balances are correct, a cold gas efficiency of 83.9% results. This compares to 71.4% on the most recent and successful run with Kentucky HVAB. The two-foot gasification tests indicated a value of as high as 90% possible.

Second, a negative result of this characteristic is that certain operations, such as fire zone measurement and extensive poking, which require that the bed rotation and coal feed be stopped, must be accomplished with much more alacrity than with other fuels. Remaining in this mode for an overlong time results in a rapid decrease in gas quality, and a weakened area of the bed.

Finally, this sensitivity is somewhat counterbalanced by the ability to bring the process back to normal conditions almost as quickly.

In the opinion of several observers experienced in the operation of the Riley gasifier, it is the quick recovery with this fuel which allowed a consistent production of high quality gas under the extremely adverse bed conditions existing during the first half of the test. It is doubtful that a burnable gas could have been made under equal conditions with other fuels. This fuel is therefore very suitable for the low Btu gasification process.

Ash

The ash content of this fuel varies to a considerable extent, as was seen from many analyses performed. The maximum variation appears to be from 5.4-9.5% on an as received basis. Whether this almost twofold variation is inherent in the fuel itself, or is a function of the mining technique is important. That it may be the latter is possible, since considerable amounts of clay underburden were commonly seen entering the process. If so, then steps to assure the uniformity of quality of feedstock in this area should be taken, within reasonble limits.

The implications of an almost twofold variation are important to design considerations for ash removal systems. The ash produced was perceptibly different from ash produced from other coal ranks. Clinker of any appreciable size was absent in both cases. The chief difference lay in the proportion of fine ash particles in the lignite ash. A size analysis comparison does not delineate the chief difference. A visual inspection of the ash shows a distinct difference in the makeup of the particles. Ash from eastern coals tends to exist as clumps of yellowish-white structures of high porosity almost woody-looking in appearance. The western ash (where it was not fused into small clinkers) was largely composed of individual small granules of high density. The different packing characteristics of the two ashes will certainly result in different bed coefficients, and is an area which must receive further attention.

Another noticeable difference with this ash is that upon air drying, the entire surface of the ash became covered with a white powdery substance. Those having experience with lignite ash offer the opinion that it is a sodium salt, although analysis of the ash does not show an extremely high sodium content. That it exists as a soluble salt, however, must be considered in all areas where leachate migration might be a factor. This data will be forthcoming in the final Source Test and Evaluation Report for EPA by Radian Corporation.

PERFORMANCE

Capacity

While output performance was lower than projected, a consistent, reliable operation was demonstrated. The major constraint to achieving the projected capacity calculated to be possible for this unit with this fuel (6 TPH), was in feed fuel size. Uncontrolled and variable quantities of sizes less than 12 mm. (½″) made the gasification process at levels above four tons per hour uncomfortably close to system limits, especially in the area of fuel bed pressure drop. All data for yields and balances, then, are taken from the period when steady state conditions existed and the process was stable; i.e., in the area of 3629 kg. (8,000 lb)/hr.

Fuel Analysis

Variations in fuel analysis were considerable, especially in the areas of ash and sulfur. Table V is the fuel analysis upon which heat and energy balances are based.

PROXIMATE (as received) %		ULTIMATE (as received) %	
Moisture	34.10	Moisture	34.10
Ash	7.54	Ash	7.54
V.M.	30.68	Carbon	41.82
F.C.	27.68	Hydrogen	2.83
		Oxygen	12.70
		Nitrogen	0.70
		Sulfur	0.31
HHV, Btu/lb	6,967		
HHV, kJ/kg	16,205		
LHV, kJ/kg	14,669		

Table V North Dakota Lignite Analysis

Gas Analysis

Gas of consistently high quality was made during the test period. Table VI is a history of major gas components. Trace components and their concentrations are available in the forthcoming report to EPA.

Tars and Oils

The yield of these components was far less than that experienced in smaller scale testing, and much more than earlier studies of lignite distillation under coking conditions.[9] The yield of 7.5% of the volatile matter as tar compares to previous findings of 16% on a small scale, and of 24% for bituminous coals with comparable V.M. contents under similar gasification conditions. The accountable mechanism is undoubtedly the conversion of much of the oxygen-containing material in the form of pyrolytic water and oxides of carbon. Table VII contains initial results of tar/oil fraction characterization. An as yet unexplained anomaly exists in the high oxygen content and low heating value of the tar. Prior results[5,6] yielded tars from lignite with heating values on the order of 37216 kJ/kg (16,000 Btu/lb).

Date	Time Hrs	Volume Percent on Dry Basis					
		CO	CO_2	H_2	O_2	N_2	CH_4
Dec. 13	1000	NA	NA	NA	NA	NA	NA
	1100	NA	NA	NA	NA	NA	NA
	1200	NA	NA	NA	NA	NA	NA
	1300	NA	NA	NA	NA	NA	NA
	1400	26.9	7.0	16.6	1.1	46.8	NA
	1500	24.1	8.6	16.6	1.1	48.2	0.6
	1600	26.1	7.2	16.5	1.0	47.3	1.0
	1700	28.0	6.8	16.7	1.2	45.8	0.7
	1800	27.1	6.6	16.7	1.1	46.5	1.2
	1900	27.4	6.7	26.9	1.2	46.4	0.7
	2000	24.6	8.3	16.5	1.1	47.6	1.0
	2100	25.3	8.0	16.5	1.1	47.5	0.7
	2200	27.3	7.1	16.8	1.0	45.7	1.2
	2300	27.4	7.2	16.9	1.0	45.6	1.1
Dec. 14	2400	27.6	7.1	16.6	1.1	45.3	1.4
	0100	26.6	7.7	16.0	0.9	46.6	1.4
	0200	27.0	7.1	17.1	1.0	45.6	1.3
	0300	27.7	6.4	18.0	1.1	44.5	1.5
	0400	28.2	6.2	17.4	1.2	44.8	1.5
	0500	28.9	6.3	17.3	1.2	44.7	0.9
	0600	25.7	7.7	18.3	1.3	45.4	0.9
	0700	28.8	6.3	18.7	1.3	43.3	0.9
	0800	29.2	5.9	19.0	1.1	43.2	NA
	0900	28.9	5.3	17.3	1.0	45.9	NA
	1000	26.4	8.9	17.2	1.2	44.8	NA

Notes: 1. Compositions are Radian process gas chromatograph readings normalized to 100 percent.
2. Argon was not measured and is assumed to be 0.54 volume percent for all periods.

Table VI Major Gas Components
Riley Gasifier December 1979 Lignite Test

Composite sample from entire run.		Dry Basis Wt. %
	C	59.57
	H	8.40
	N	0.69
	Cl	0.06
	S	0.33
	Ash	0.20
	O	30.75
		100.00
HHV, BTU/lb		11,261
HHV, kJ/kg		26,193

Table VII Tars and Oils Analysis
Riley Gasifier December 1979 Lignite Test

Cyclone Dust

Collection of this by product yielded a value of 0.4% by weight of the feed coal. This is less than values of 1-1.5% for eastern bituminous coals, but is chiefly accounted for by the fact that this run was conducted entirely without mechanical agitation of the fuel bed. Rigorous adherence to a selected fuel size by

Composite sample from entire run	Lab Analysis Wt. %	Dry Basis Wt. %
Moisture	0.59	0
C	54.48	54.80
H	1.48	1.49
N	0.83	0.83
S	1.59	1.60
Ash	38.21	38.44
O	2.82	2.84
	100.00	100.00
HHV, BTU/lb	8,607	8,658
HHV, kJ/kg	20,020	20,139

Table VIII Cyclone Dust Analysis
Riley Gasifier December 1979 Lignite Test

	Mass Flow Rate		Temperature		Type of Heat*	Enthalpy*		Heat Flow Rate		
	kg/s	(lb/hr)	°C	(°F)		kJ/kg	(Btu/lb)	KW	(1000 Btu/hr)	Percent
Inputs										
Coal	1.045	(8,292)			Potential	16,205	(6,967)	16,932	(57,770)	96.0
			−2	(29)	Sensible	−33	(−14)	−34	(−116)	−0.2
Net Stream	0.274	(2,174)	164	(328)	Sensible	2,847	(1,224)	780	(2,661)	4.4
Air	1.554	(12,334)	−2	(29)	Sensible	−28	(−12)	−43	(−148)	−0.2
Total	2.837	(22,800)						17,635	(60,167)	100.0
Outputs										
Dry Gas	2.299	(18,245)			Potential	6,020	(2,588)	13,840	(47,218)	78.5
			270	(518)	Sensible	265	(114)	609	(2,080)	3.5
Moisture	0.440	(3,492)	270	(518)	Sensible	2,910	(1,251)	1,280	(4,368)	7.3
Tars and					Potential	26,193	(11,261)	566	(1,926)	3.2
Oils	0.0215	(171)	270	(518)	Sensible	205	(88)	4	(15)	—
					Potential	20,139	(8,658)	86	(294)	0.5
Cyclone Dust	0.0043	(34)	270	(518)	Sensible	205	(88)	1	(3)	—
					Potential	8,806	(3,786)	952	(3,248)	5.4
Ash	0.108	(858)	93	(200)	Sensible	58	(25)	6	(21)	—
Heat to Cooling Water								128	(437)	0.7
Unaccounted for Losses								163	(557)	0.9
TOTAL	2.873	(22,800)						17,635	(60,167)	100.0

* Enthalpy is 25°C (77°F) and H_2O liquid. Potential heats are based on the higher heating value (HHV).

Table IX Overall Heat & Material Balance
Riley Gasifier December 1979 Lignite Test

screening would no doubt have reduced this value further. Table VIII characterizes this char fraction. Rather than a highly devolatized coke, the material is closer in analysis to the raw coal. This is consistent with the relatively low gas exit temperatures to which the fuel is initially subjected, together with its fines content.

Material and Heat Balances

Both balances for the selected test period were within ±5% of closure and were adjusted to 100% as is shown in the combined Table IX.

Efficiencies

While the higher heating values of components are required in the overall heat balance to be consistent with the enthalpy basis in order to present process efficiencies, lower heating values (LHV) are more representative of the available heat energies. For this reason, LHVs for the fuels are used to calculate such efficiencies. The dry product gas LHV was calculated from the measured gas composition using published net heat of combustion for CO, H_2, CH_4, etc. The calculated dry gas LHV of 5850 kJ/m³ (157 Btu/SCF) corresponds well to the on-line calorimeter value of 5999 kJ/m³ (161 Btu/SCF) recorded during the test for the time period under study.

	Mass Flow Rate kg/s	LHV kJ/kg	LHV Heat Flow Rate kJ/s
Lignite Feed	1.045	14,783	15,448
Dry Gas	2.299	5,636	12,957
Tars and Oils	0.0215	24,398	525
Cyclone Dust	0.0043	19,821	85
Ash	0.108	8,706	940

Table X Potential Energy Flows by Lower Heating Value
Riley Gasifier December 1979 Lignite Test

E_{Base} = Dry Product gas potential heat/lignite potential heat
= 12957 ÷ 15448 = 83.9%

$E_{Hot\ gas}$ = Useful energy in products/useful energy in feeds, for a hot gas system
= potential plus sensible heat of dry product gas and tars and oils plus the sensible heat of the product gas moisture (excluding the latent heat of water vapor)/potential plus sensible heat of lignite and air, plus the heat required to produce the gross steam to the gasifier
= [12957 + 609 + 525 + 4 + 1280 − (2396 kJ/g) (440 g/s)] ÷ [15448 + (−34) + (144) + 921]
= 14321 ÷ 16291
= 87.9%

$E_{Cold\ gas}$ = Useful energy in products/useful energy in feeds, for a cold gas system
= Potential heat of dry product gas/potential plus sensible heat of lignite, air and gross steam
= 12957 ÷ [15448 + (−34) + (−44) + 921]
= 12957 ÷ 16291
= 79.5%

Note: Potential heat flows are based on lower heating values. Sensible heat flows are relative to 25°C, liquid water. The heat required to produce the gross steam to the gasifier is based on the total steam flow (rather than the calculated net steam flow) and an assumed boiler efficiency of 85% in producing that flow. (783 kJ/s − 0.85 = 921 kJ/s)

Table XI Gasifier Efficiencies
Riley Gasifier December 1979 Lignite Test

Table X gives the potential heat flows based on the lower heating values. Using these potential heat flows plus sensible heat flows from Table IX, gasifier efficiencies were calculated and are presented in Table XI. The base efficiency of the gasifier, which compares the potential heat of the product gas to the potential heat of the lignite, is 83.9%. For a typical hot gas installation, in which the product gas is combusted without cooling, the gasifier converts 87.9% of the useful input energy into product gas. For a system where the gas is cooled, the sensible heat of the gas is removed as are the tars and oils. The cold gas efficiency is 79.5%. If the tars and oils can be recovered and used as fuel, the cold gas efficiency improves to 82.8%. The actual efficiency of a cold gas installation would be slightly lower than these values depending on the energy consumption of the gas purification equipment required.

CONCLUSIONS

North Dakota lignite is a highly reactive coal and is an excellent candidate fuel for fixed bed gasification processes. This reactivity is evidenced by gas of consistently high quality 6334 kJ/m^3 (170 Btu/SCF) being produced in an air blown process. Liquids production (tar/oil) on the order of 4 grains per dry standard cubic foot of gas, and solids (dust/char) on the order of 0.4 weight percent of the feed, are low. Coupled, these characteristics result in high process efficiencies.

The normal care associated with correct feed sizing for a fixed bed process should not be stinted with this fuel. Installation of an on-site screen of 19 mm. (¾″) minimum size should be incorporated in commercial plants to eliminate the effects of particle size degradation caused by long-distance shipping, weathering, or lack of care in the coal preparation plant. Equal care must be taken in the design of in-plant handling facilities, eliminating operations which might cause equal degradation.

Environmental integrity for first generation producer gas plants is attainable through proper design of feed systems and access ports.

Gasification rates on the order of 732 kg/m^2 (150 lbs/ft^2) for Northern Plains lignite should be attainable for the fixed bed air-blown atmospheric processes.

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