PRODUCTION AND GASIFICATION TESTS OF COAL FINES/COAL TAR EXTRUDATE

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ABSTRACT

Fixed bed gasifiers, such as those planned to be used to manufacture SNG commercially, require a sized feedstock, e.g., −2 in., +1/4 in. As an alternative to disposing the fines (−1/4 in.) which cannot be used in the boiler of such an SNG plant, they can be compacted and then fed to the gasifiers. General Electric R&D Center in Schenectady is developing an extrusion process which will enable the fines, mixed with an appropriate binder, to be fed directly into a fixed bed gasifier, bypassing the lockhoppers required for lump coal feed. Work is described on a recently completed extrudate manufacture and gasification program sponsored by GRI. GE's 6-inch diameter, single screw extruder was employed to produce the extrudate from Illinois No. 6 coal and coal tar, and the extrudate was subsequently gasified in GE's pressurized air-blown, stirred fixed-bed reactor. The test results indicate that the extrudate makes a satisfactory gasifier feedstock in terms of both thermal and mechanical performance.

INTRODUCTION

Gasification is a fuels conversion technology which permits the production of clean substitute gas from coal and other carbonaceous fuels. The first commercial application of this technology in the U.S. will be the Great Plains substitute natural gas (SNG) plant, which is due to begin production in late 1984. This plant will produce 125M SCF per day of pipeline quality gas using Lurgi, oxygen blown, fixed-bed gasifiers.

While the fixed bed gasifier offers proven performance in terms of both thermal efficiency and reliability, it requires a sized feedstock for optimum performance. Typically, coal below 1/4 inch is removed by screening prior to gasification in order to mimimize fines carryover from the bed and to minimize instabilities in gasifier performance caused by excessive fines content in the feed. Run-of-mine (ROM) coal, however, typically contains 25-35% of < 1/4-inch material, which means that up to 35% of the coal mined could not be utilized directly in the gasifier. Direct extrusion of the coal fines fraction with a tar binder offers a potentially attractive solution to this problem by consolidating the fines into a feedstock suitable for the fixed-bed gasifier and, at the same time, providing an advanced feed mechanism to the pressurized reactor.

The present paper describes the results of a recently completed extrudate evaluation program conducted at the General Electric Research and Development Center in Schenectady New York, under the joint sponsorship of the Gas Research Institute (GRI) and the New York State Energy Research and Development Authority (NYSERDA). A six-inch single screw extruder previously developed by General Electric was used to produce 88 tons of Illinois No. 6 coal extrudate using a 15% coal-tar pitch binder (Ref. 1). The extrudate was then successfully gasified in General Electric's 1 ton/hr, Process Evaluation Facility (PEF) scale, pressurized fixed-bed gasification system. Data is presented on gasifier performance, fines carryover rate, and tar yields from the extrudate. Performance data on the extrusion process is also included.

EXTRUSION TRIALS

General Process Description

General Electric began development of the coal extruder system in response to industry's need for an improved coal feed system and as a means of utilizing fines in a pressurized fixed-bed reactor. The work was initiated on a 1-inch extruder and progressed to the development of a 6-inch diameter single screw extruder capable of processing in excess of one ton per hour of coal against backpressures up to 350 psig. The later work was done under the sponsorship of EPRI (Project No. 357-1).

The extruder process is shown schematically in Figure 1. Coal under 1/4- inch is mixed with a binder, typically coal tar, in a heated mixer and then conveyed to a screw extruder where it is simultaneously compacted and forced into the pressurized reactor. Proper design and control of the die at the delivery end of the extruder maintains a gas seal and adjusts the frictional resistance of the compacted coal to forward motion. The extrudate exits the die as a solid log of coal which is subsequently broken up by a chopper inside the reactor.

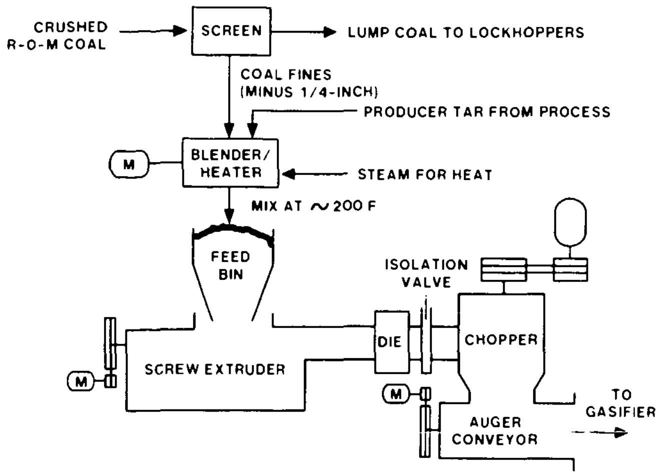

Figure 1. Coal Extrusion Process

The General Electric extruder is driven by a 60 hp variable speed drive which permits screw speed to be varied from 0-45 rpm. Screw construction is segmented with individual auger sections stacked along a central drive shaft to give a continous worm. The auger sections are cast from high chrome steel having a Rc 60-67 hardness to minimize wear. The length-to-diameter ratio of the machine is 4:1. The barrel is made up of two steam-jacketed sections, each equipped with a hardened and ribbed steel liner. Two counter-rotating packer wheels are used in the feed hopper to help promote flow of the preheated extrudate mix into the screw cavity. Extrudate formation is controlled by a patented variable area, variable length die which permits on-line control of extrudate density. This feature has been found essential for permitting stable operation of the extruder over a range of operating conditions and on a variety of feedstocks. Power consumption and machine wear are also minimized.

Steam-jacketed, 15 ft^3 scale-mounted paddle mixers were used to prepare the hot (150-175F) coal-tar extrudate blends. Milled coal was supplied to the mixer via a fines elevator. The coal was prepared for testing by hammermilling stoker grade Illinois No. 6 coal through a nominal 4-mesh screen. A screen analysis of the coal taken after crushing indicated a size distribution nearly identical to that of coal fines obtained from underscreened ROM coal. The coal was not dried prior to size reduction. Typical mix times for a 400 lb test batch were 12-15 minutes.

Mix Evaluation

Several different tar binder-coal combinations were evaluated prior to the start of production to arrive at a mix which extruded well and which possessed sufficient mechanical strength to withstand the handling and bed forces encountered during a gasification test. A total of 17,000 pounds of material was processed using seven different tars at varying weight percentages with Illinois No. 6 coal.

A list of the binders tested is shown in Table 1. All are coke oven derivatives with the exception of the asphalt pitch, and represent a commercially available range of softening points from slightly above room temperature to almost 200°F. Producer tars from actual gasification plants were not included in the study due to the lack of availability of these tars in sufficient quantities.

Table 1

TAR BINDERS TESTED

Tar Supplier	Designation	Softening Point[a]
General Electric	V-1 PEF gasifier tar	<40°C[b]
Koppers	Medium-soft coke oven	50-55°C
Koppers	Medium coke oven pitch	56-64°C
Reilly	No. 12 coke oven tar[c]	<50°C)
Reilly	Medium coke oven pitch	54-62°C
Reilly	Hard coke oven pitch	82-95°C
—	Canadian Asphalt pitch	

[a]ring and ball
[b]estimated
[c]selected for production run

Reilly No. 12 coal tar pitch was chosen as the test binder, based on its satisfactory performance in the extruder, its commercial availability, and the satisfactory mechanical properties of the extrudate obtained. The relatively low softening point of this tar also more closely approximated that of the raw tar which would be obtained from an actual gasification plant. A blend of 15% tar, 85% coal by weight was selected for the final production run. The use of this low softening point binder required modifications to be made to the mix preparation system to allow consistent production of extrudate with adequate green strength. This entailed lowering the mixer jacket temperature from 350°F to 190°F, and installation of a tempering water spray just upstream of the extruder inlet to further cool the extrudate mix. With this configuration, mixes of <120°F could be consistently produced, which was sufficiently low to allow production of good quality extrudate.

Extrudate Production

Approximately 88 tons of extrudate were produced offline in the 6-inch extruder over a 9-day operational period. The continious 6 1/2-inch diameter logs were cut manually into 2-ft lengths, allowed to cool for approximately 2 to 4 hours, then crushed to <1 1/2-inches in a rotary crusher. The resultant extrudate was screened to remove any fines generated during size reduction and stored for testing.

Excellent performance was obtained from the extrusion system throughout the test period. On-line availability of both the mix preparation and extruder exceeded 98% and wear on machine parts including the auger was negligible. Specific power consumption of the extruder was exceptionally low and control over extrudate formation was good once stable operation had been achieved. A summary of the extruder operating conditions is shown in Table 2.

Table 2

PRODUCTION RUN SUMMARY — EXTRUDER OPERATING CONDITIONS

Machine	6 in. single screw
Die	6.5 in. i.d., adjustable
Auger	3 in. pitch, segmented
Mixture	85% Ill. No. 6, 15% Reilly tar
Total production	175, 500 lbs.
Throughput	1305 lb/hr.
Specific power	1.5 hp-hr/ton
Shaft speed	12 RPM
Die length	4 in.
Flap pressure	150-200 psig
Auger wear	Negligible
Barrel temp	Cooling water on
Control	Excellent

Extrudate Properties

Laboratory evaluations were performed to determine the mechanical properties of the extrudate. Tests run included a crush test to measure the mechanical strength of the extrudate before and after carbonization, a 1000°F oven test to determine the high temperature behavior of the samples, a softening point test to determine at what temperature the extrudate begins to soften, and a standard test to determine extrudate density. The results of the mechanical tests, which are summarized in Table 3, indicated that the extrudate should possess sufficient mechanical strength to withstand the gasification environment. These observations were later verified during the fired gasification trials.

Table 3

EXTRUDATE PROPERTIES

Mixture, wt%	85% Illinois No. 6, 15% Reilly No. 12 tar
Compressive strength, psi	810
Carbonized strength, psi	834
Density, lb/ft^3	72
Softening point,[a] T°F	130
Oven test results	Some swelling and distortion

[a]Point at which extrudate can be deformed by hand

GASIFICATION TRIALS

Gasification Facility

The General Electric Process Evaluation Facility (PEF), located in Schenectady, New York, consists of an advanced fixed-bed reactor, full-flow, low-temperature gas cleanup system, coal extrusion feed system, and an advanced computerized data acquisition, analysis and control system. The facility operates at a nominal pressure of 20 atm. and can gasify approximately 1 ton of feedstock per hour using air and steam as reactants. Deep bed stirring provides the capability for the gasifier to operate on caking coals and at thermodynamically attractive low steam-air ratios. The raw fuel gas is conditioned in a two stage cleanup system which removes solid particulates, hydrocarbon mist, and sulfur compounds from the gas stream. A schematic of the PEF is shown in Figure 2, and the gasifier is shown in cutaway side-section in Figure 3.

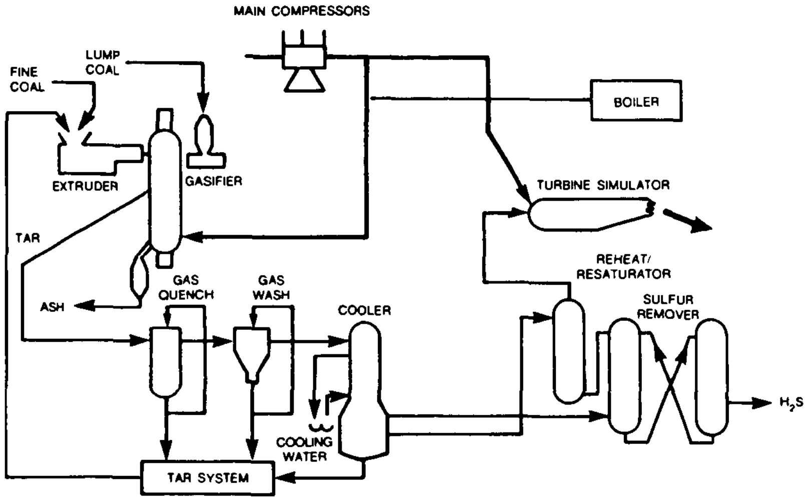

Figure 2. Process Evaluation Facility

Gasifier Performance

Approximately 50 tons of Illinois No. 6-Reilly No. 12 extrudate were successfully gasified in the PEF during a 50 hour operational test period in July, 1983. The gasifier was operated at steady-state, full pressure, full flow design conditions for the duration of the test run. The average gasifier operating conditions for a representative 20-hour time period are presented in Table 4. Ultimate and proximate analyses of the extrudate feedstock appear in Table 5.

Performance parameters characterizing the operation and efficiency of the gasifier were determined for the representative test period. These parameters are presented in Table 6 along with average results from previous baseline testing on Illinois No. 6 lump coal (Ref. 2).

The efficiency of gasification is quantified by the carbon, cold gas, and steam utilization efficiencies. The carbon efficiency provides an indication of the amount of input carbon which is converted to gaseous form in the tar and oil-free product gas. The cold gas efficiency

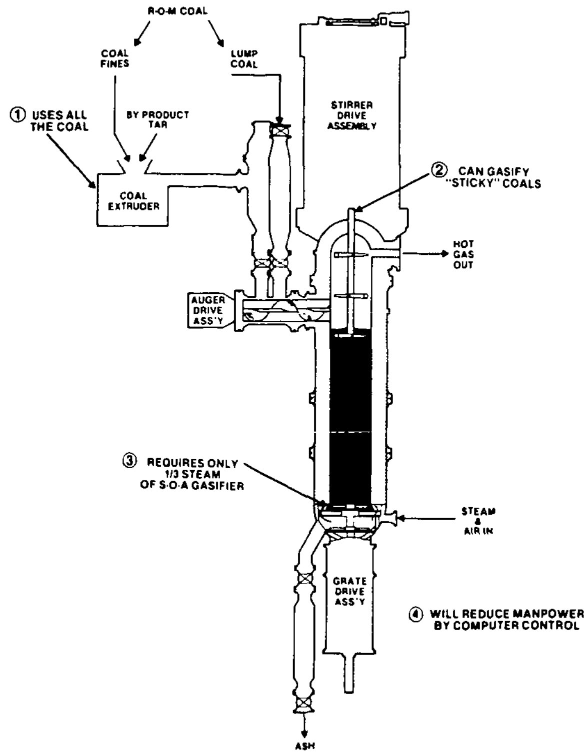

Figure 3. Advanced Fixed Bed Gasifier

Table 4

AVERAGE GASIFIER OPERATING CONDITIONS

Extrudate flow, lb/hr	1925
Air flow rate, lb/s	1.20
Steam flow rate, lb/s	0.48
Steam-to-air, lb/lb	0.40
Blast temperature, °F	363
Hot gas temperature, °F	1040
Vessel pressure, psig	300
Bed level, ft	10.7
Stirrer cycle	
raise, ft/min	1.0
lower, ft/min	0.5
Dry ash removal, lb/hr	176
Sludge removal, lb/hr	90

Table 5

EXTRUDATE ANALYSIS

	As Received	Dry Basis
Proximate Analysis (wt%)		
Moisture	7.60	–
Ash	9.12	9.90
Volatile	34.92	37.80
Fixed Carbon	48.37	52.30
Sulfur	1.34	1.45
Ultimate Analysis (wt%)		
Moisture	7.60	–
Carbon	69.11	74.78
Hydrogen	4.68	5.06
Nitrogen	1.55	1.68
Chlorine	0.11	0.12
Sulfur	1.34	1.46
Ash	9.12	9.90
Oxygen (difference)	6.48	7.01
Metals (wt% in dry ash)		
Sodium		0.35
Potassium		1.71
Iron		10.50
Calcium		2.75
Heating Value (Btu/lbm)	12342	13354
Moisture and Ash Free	—	14822
Free Swelling Index	3.9	

is defined as the higher heating value of the tar and oil-free raw gas at 60°F divided by the extrudate heating value. The steam utilization represents the percentage of the blast steam that takes part in the gasification reactions.

The carbon utilization of 83.5% for the extrudate run indicates good conversion of carbon to fuel gas heating value. The value is slightly lower than that obtained on Illinois No. 6 lump coal, primarily due to the higher condensible hydrocarbon content in the extrudate-produced gas. The higher tars and oils content also resulted in a slightly lower cold gas efficiency than determined for the lump coal. If the heating value of these tars is included, the calculated cold gas and carbon efficiencies would result in slightly higher values for the extrudate feedstock. The steam utilization value is excellent and nearly identical for both feedstocks, indicating good fuel reactivity and good gas-solids contact in the fuel bed.

The gas composition was similar for both fuels, the only detectable difference being a slightly lower methane content and slightly higher CO_2 level for the extrudate case. The overall dry gas heating value of 162 Btu/scf for the extrudate-produced fuel is satisfactory and compares favorably with results obtained from stoker grade lump coal.

Table 6

PERFORMANCE PARAMETERS COMPARISON

Performance Parameter	Extrudate Feedstock	Illinois No. 6 Lump Coal
Carbon utilization, %	83.5	86.0
Steam utilization,	55.7	56.0
Cold gas efficiency, %	71.2	74.7
Gas composition, vol%	64.7	68.0
H_2	21.0	21.0
CO	17.1	17.1
CO_2	13.2	12.8
N_2	43.8	43.9
CH_4	4.0	4.4
H_2S	0.3	0.3
Dry gas heating value, Btu/scf	162	166
Tar yield, wt% dry coal	7.8	4.0
Dry fines carryover, wt% dry coal	2.1	3.6

The dry fines carryover represents the percentage of feedstock carried over from the fuel bed to the quench vessel. The relatively low dry fines carryover value for the extrudate testing indicates that the extrudate maintained its integrity in the fuel bed during gasification. This result is particularly significant considering that the extrudate is produced from essentially 100% fines.

The gasifier exhibited excellent mechanical performance throught the extrudate run. No major problems with extrudate feeding, bed conditioning, or ash discharging were experienced during the test. The peak rotational torque loadings on the stirrer and grate paddle were 3,400 and 14,000 ft-lbs, respectively, and were safely below the design limit values. In general, the mechanical performance of the gasifier on the extrudate feedstock was very similar to that experienced during operation on lump coals.

Gas Cleanup System Performance

The gas cleanup system was operated at steady design conditions for the duration of the extrudate test run. All of the cleanup components functioned smoothly, indicating no specific problems associated with the extrudate-produced fuel gas. Results from the particulate sampling indicate that the overall cleanup system particulate removal efficiency was nearly 99%, typical of that seen on lump coal.

Comparative tar collection data is presented in Table 7 for both the extrudate and lump coal runs. The total tar collection rate obtained from the cleanup system components on extrudate was approximately double that obtained during Illinois No. 6 lump coal runs. This higher tar yield can be attributed primarily to carryover of vaporized extrudate binder, which, when added to the normal tar carryover from the volatile matter in the base coal, yields the rates shown. However, although the total rate is nearly double, it is only approximately 25% of that which would be obtained if all the binder appeared in the raw gas. This translates to an apparent cracking rate of 75% of the extrudate binder during a single pass through the gasifier.

Table 7

TAR CARRYOVER COMPARISON

	Extrudate Feedstock	Illinois No. 6 Lump Coal
Tar Collection Rate, lb/hr	117.7	57.0
Tar Yield, Wt. % Dry Coal	7.8	4.0

SUMMARY

The results of the test program indicate that Illinois No. 6-Reilly No. 12 extrudate makes an attractive feedstock for fixed-bed gasifiers in terms of both fines and tar utilization, as well as overall gasifier performance. Fines carryover was reduced from a typical value of 3 – 4% on lump coal to 2% on extrudate, a result which is particularly significant considering the extrudate is produced from essentially 100% fines. Approximately 75% of the tar binder cracked during the first pass through the gasification process. The cold gas efficiency of 71% and fuel heating value of 162 Btu/scf were comparable to results obtained on Illinois No. 6 lump coal. The mechanical performance of the reactor was also satisfactory.

The 6-inch coal extruder performed well throughout the program. Power consumption was low (1.6 kwh/ton), machine wear was negligible, and reliability excellent. Power consumption and wear would be expected to be somewhat higher under on-line extrusion conditions due to the need to maintain a gas seal in the die area. Accurate temperature control of the mix was found to be a critical variable in producing extrudate with adequate green strength when using a low softening point binder such as Reilly No. 12 tar.

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