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PRESSURIZED FEEDING ON THE GEGAS SYSTEM

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ABSTRACT

A continuous process to feed coal directly into a pressurized gasifier is described. Coal fines are heated and mixed with a recycled tar binder and extruded through a novel die system against gasifier pressure. Performance data on a 2" system is given and scale up to a larger 6" system is described.

INTRODUCTION

The fixed bed gasifier has historically been limited to coal of a restricted size and type. Coal fines below 1/8" were screened out and stockpiled because the fines, if gasified, tended to plug up the bed, and if the air flow was high, to be eluted from the bed before gasification could occur. However, run of mine coal can contain as much as 30% - 40% fines and with today's energy prices, one is forced by economics to utilize this fraction. In General Electric's gasification work, the approach taken to utilizing the fines has been to extrude the coal directly into the gasifier using tar as a binder. This technique has the advantage of utilizing the gasifier tar and coal fines, of eliminating the maintenance and gas handling losses associated with conventional lock hopper systems, and of enabling continuous feeding to pressurized reactors.

Success of the operation hinges on the ability of the extruder to meet the following goals: provide the necessary sealing capability to withstand gasifier pressure; have the ability to extrude the coal fines at a competitive cost and power requirement; and have the size, reliability and wear resistance to handle large tonnages of coal without excessive downtime and maintenance.

Work has been done in the past in the area of coal extrusion, such as the Coal Logs[1] work done in the late 1940's or the more recent work by the Bureau of Mines[4], but none of it has focused on the use of the extruder as a pressure feeder, and this is where its real advantage lies - in its ability to pump compacted coal directly into a pressurized system. The present alternative to direct extrusion is to use commercially available double roll presses to briquette the coal fines and to use an additional lock hoppering step with its inherent losses to inject the briquetted fines into the gasifier.

EXTRUSION PROCESS EQUIPMENT

A general schematic of the coal extrusion process is shown in Fig. 1. Screened coal fines are mixed with a tar binder and fed into the hopper of the extruder. The mix is conveyed down the barrel by the screw and compressed into a solid continuous rod of extrudate in the die area. A chopper downstream of the die is used to break the extrudate off into sized lengths one diameter long and may be used on larger machines to quarter the extrudate. Both the chopper and die are operated at gasifier pressure which in the GEGAS-D machine will be up to 23 atm. The feed hopper is at atmospheric pressure as is the extruder barrel, with the critical gas seal being maintained by the coal pack in the die. With this system, no lock hoppers are needed to feed coal into the gasifier. On the GEGAS machine, an isolation chamber with two valves will be provided between the extruder and the gasifier to permit off-line pressure testing, and to isolate the extruder from the gasifier in the event a leak develops or if system maintenance is required.

We have worked with five extruders in developing this process to the present pilot plant scale. The first machine was a modified one inch plastic extruder capable of 15 lb/hr of extrudate. Our present machine is a six inch capable of 4000 lb/hr. The following is a description of the equipment in more detail and a summary of the operating results.

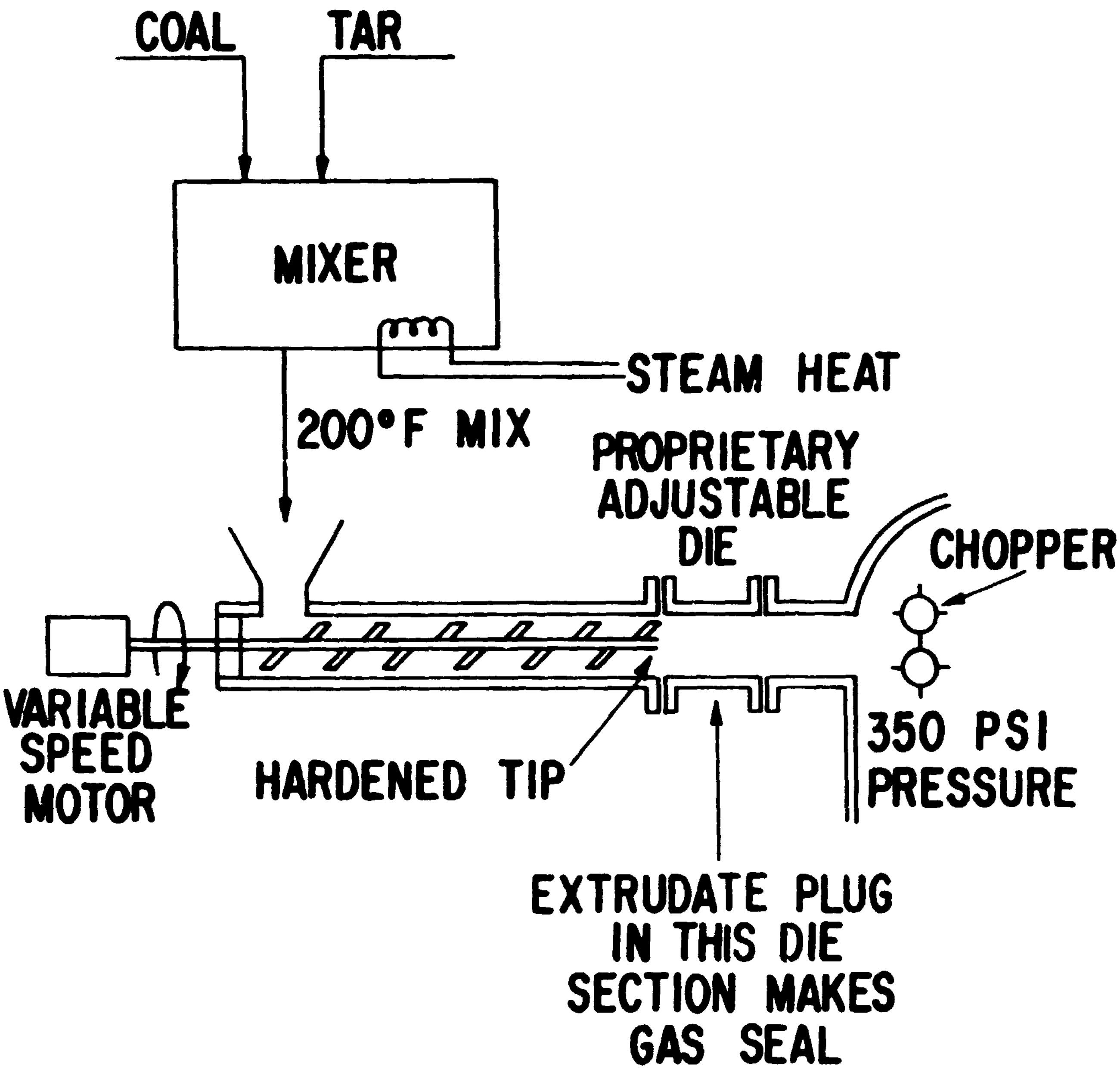

Figure 1. Pressurized Coal Extrusion Feeding Process

ONE INCH EXTRUDER

Our original idea for coal extrusion was to use the plastic properties of the coal itself by heating it to approximately 750°F, at which point it softens to a semi-liquid which can be extruded. We used a one inch plastic extruder with a 24:1 electrically heated Xaloy® barrel and a two stage vented screw made out of chrome plated 4140. This approach was dropped at an early stage, however, due to difficulties in controlling the process. Coal is an extremely variable substance and when heated its properties change rapidly with time. Large amounts of gas are evolved during the softening process and this plus the fact that the coal can change from a powder to a tarry consistency to a rigid solid as a function of time and temperature led us to abandon this in favor of a low temperature extrusion process using supplied tar as a binder.

Modifications were made to the one inch screw and hopper to permit feeding the dry coal tar mixture, and a fixed length die of one inch ID was added to form the extrudate. Using ash as a diluent and with the extruder directly connected to our one ft. laboratory gasifier as shown in Fig. 2, we made our first successful run on highly swelling Pittsburgh #8. Maximum output of the machine was 15 lb/hr at a specific power consumption of 17 lb/kw-hr. Density of the extrudate was on the order of 75 lb/ft^3.

Figure 2. One-Inch Coal Extruder During On-Line Testing

The variability of coal became evident very early in our work as it was discovered that different coals required different back-pressures in the die to form a coherent rod of coal. Too low a backpressure and the density and strength falls off to the point where the extrudate is not strong enough to withstand the ΔP from gasifier to atmospheric pressure. Too high a back-pressure and the die will jam up. We also found that with binder percentages less than ∿14% the coal mix would not flow through a die whose cross section was less than that of the barrel.

Screw wear also proved to be a problem with the one inch machine and as the screw wore the pumping efficiency fell off rapidly. The smooth Xaloy barrel liner while it stood up to the abrasion of the coal very well, also did nothing to help the pumping efficiency due to the low co-efficient of friction between it and the coal.

TWO INCH EXTRUDER

Using the operating experience gained on the one inch, we scaled the process up to a two inch extruder, the basic components for which were supplied by the Bonnot Company, located in Kent, Ohio. The machine has a large feed hopper, a short 6:1 barrel with a heat treated ribbed liner for high pumping efficiencies, and 17-4 ph heat treated stainless steel screw for erosion and corrosion resistance. The barrel is jacketed for 150# steam; the feed hopper is cooled to prevent hang up of material due to softening of the tar binder. On both this and the one inch machine, the coal and pulverized tar are premixed and fed cold to the extruder. Heat from the steam jacket and from frictional work being done on the coal during compaction is sufficient to melt and spread the tar binder. Screw speed can be varied from 10 to 90 rpm; power is supplied via a 3 hp electric drive.

TWO INCH DIE

To control extrudate formation on line using different coal inputs, an adjustable back-pressure die was developed. As in any extrusion process, the die is perhaps one of the most critical components in the system, ours being no exception, and much development work has gone into the design and construction of a die which could compensate for the different operating conditions required of different mixes. The die has two modes of adjustment - the surface area in contact with the coal can be varied, and the cross-sectional discharge area can be adjusted to give the proper backpressure to the forming coal rods. The die is circular in cross-section and can be varied from one diameter to 2.5 diameters in length. Adjustment can be made manually via hydraulic actuators or can be accomplished automatically using a feed back control system. Die material is stainless steel.

An off line pressure vessel is used to simulate gasifier pressure. The vessel is rated at 1200 psi and is bolted up to the extruder and pressurized to the desired operating conditions. Water is presently being used in the system for convenience and for safety reasons in the event a leak develops back through the extruder. A simple breaker plate is used inside the vessel to break the extrudate off in lengths about one to two diameters in length. The extruder, its control system and feed hopper can be seen connected to the pressure vessel in Fig. 3.

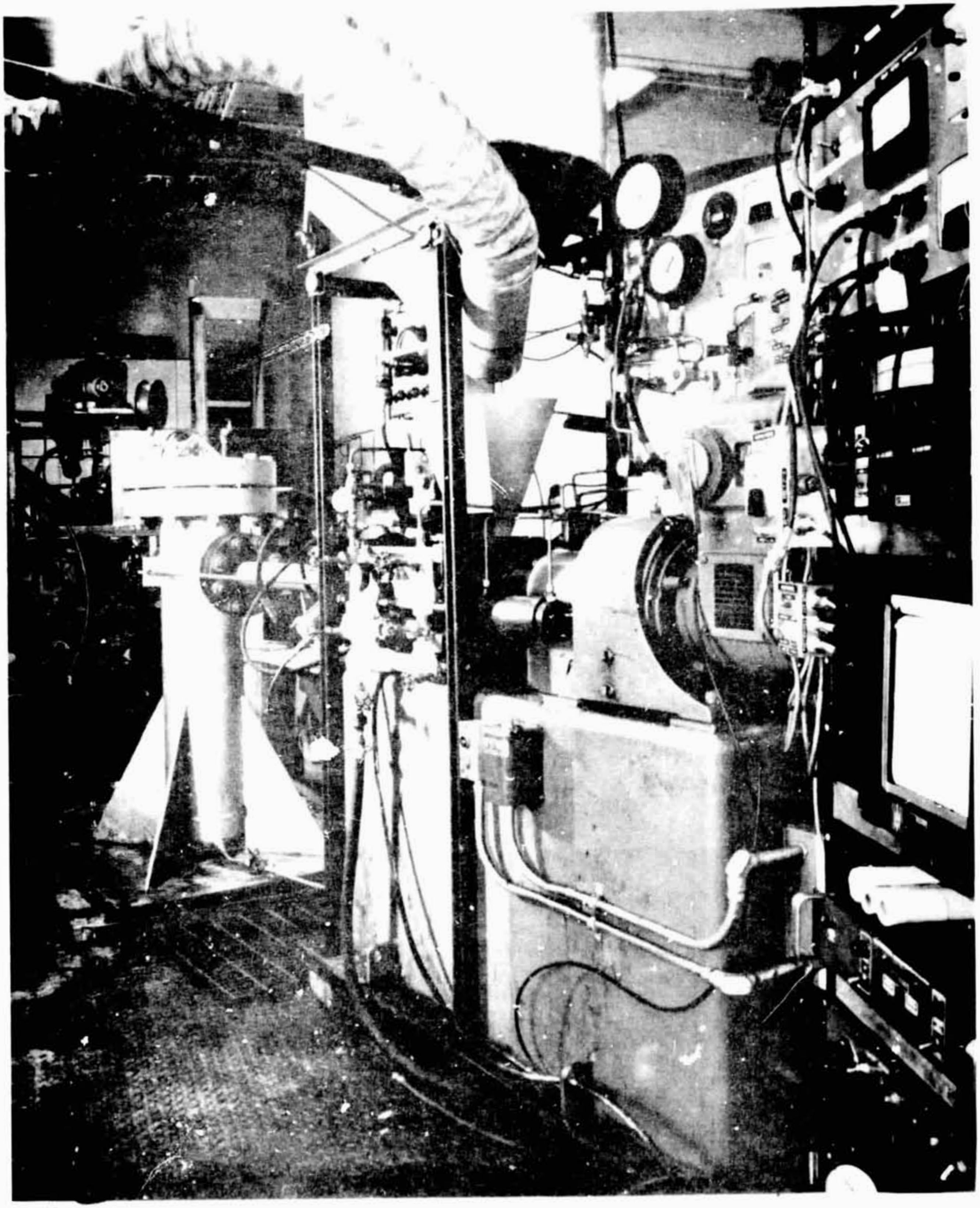

Figure 3. Two-Inch Coal Extruder Feeding Into 1000 PSI Pressure Vessel,

TWO INCH SCREW PERFORMANCE

Table 1 shows our operating results to date. Although we have done test work on a variety of coals ranging from lignites to anthracite, most of our work has concentrated on Pittsburgh #8, which has become our reference feedstock. All of the mixes which these results were obtained on were 90% coal, 10% asphalt pitch and all percentages are on a weight basis.

Whether one chooses to extrude only part of the coal feed or all of it depends on the power requirements and on the cost of the extrusion equipment which, in turn, depends on the capacity of a given piece of equipment in pounds per hour/ft^2 barrel.

We have been developing the capability of the extruder along these lines and have achieved a significant increase in performance in scaling up from the one inch to the two inch extruder. This is due to design improvements in the barrel, screw, and die and also to more favorable surface to volume ratios obtained with the larger machine. At one atm., the specific power consumption of 200 lb/kw-hr and output of 11,000 lb/hr-ft^2 barrel represents a significant improvement over the one inch system. Higher numbers here are indicative of better performance and we are aiming for > 200 lb/kw-hr at a specific output of at least 20,000 lb/hr-ft^2 barrel on our pilot plant system. To put the power numbers in perspective, gas losses from a conventional lock hopper system at 23 atm. amount to ∿ 1.5%. The energy requirements to recompress and reinject this gas at 23 atm. is equivalent in energy terms to that required to extrude the coal. Furthermore, if one requires that the coal fines must be utilized in the lock hopper as is being done with the extruder, a briquetting operation will be required; the power requirements for this added to the lock hopper losses gives a rather high specific power consumption of ∿ 130 lb/kw-hr for the combination lock hopper briquetting operation.

We have continually been increasing the pressure to which we can deliver coal by extrusion and have successfully operated against pressures as high as 1100 psi at low delivery rates. Power requirement increases with increasing pressure as indicated by the extruder performance at 20 atm. This increase is greater than that suggested by the theoretical P-V work, however, and by judicious operation of the extruder and die, we feel we can bring these numbers down.

TABLE 1

Improved Performance With Extruder Scale-Up

EXTRUDER	HYDROSTATIC BACK PRESSURE (ATM)	SPECIFIC OUTPUT ($lb/hr/ft^2bbl$)	POWER CONSUMPTION (lbm/KWe - hr)
1"	1	2,700	17
2"	1	11,000	200
2" screw/ram	1	9,500	230
2"	20	9,000	120
6"	1	7,000	310
6"	20	5,00C	170

TWO INCH MACHINE WEAR

Machine wear has been a recurring problem with the process and harder materials have been employed to handle it. Coal is a very abrasive material and where there is sliding contact with the coal occurring under pressure, there is wear. On the two inch machine, both the barrel and die have held up exceptionally well and we are still using the same hardware after two years of test work. The screw is a different story, however.

We generally operate in the range of 3000 to 5000 psi on the coal, this being the pressure that the screw exerts on the coal to force it through the die against 20 atm. backpressure. Since the extrudate mix behaves almost as a solid in the barrel, it is not possible to gradually build up to this pressure over a section of the screw as can be done with a tapered compression zone on a plastics extruder. We are forced, instead, to develop the required pressures with only about the last two flights of the worm, and this is where our wear occurs. The rest of the worm while it does show some wear, is not subjected to nearly as severe conditions as the tip.

To combat the wear, we first tried flame spray coatings but these tended to chip and flake off. Stellite® on top of a heat treated 17-4 stainless steel got our wear down to more reasonable limits while providing the necessary strength.

We have recently switched to a machinable titanium carbide tip which is mechanically fastened to the extruder shank. This is our second effort using carbide; the first screw had a solid titanium carbide tip which was vacuum brazed to the shank. The fact that this tip could not be removed limited its flexibility, and the fact that it broke under load limited its usefulness. Wear with the carbide is down in the 5 ppm range, where we are expressing the lbs of screw metal lost per one-million lbs of mix extruded. We would like to see the wear rate below 0.1 ppm and are continuing to look at advanced materials and coating processes to accomplish this goal.

Table 2 summarizes our results to date.

TABLE 2

WEAR RATES OBTAINED ON EXTRUDER SCREW

SCREW MATERIAL	WEAR, PPM
Carbon Steel	> 100
4140 Chrome Plated	> 100
Flame Sprayed Coatings	Chipped
17-4 Heat Treated Stainless Steel	30
Stellite® #1	16
Titanium Carbide (Ferrotic® CS-40)	5
Hi Chrome Cast Steel	0.5
Advanced Coatings	?

TWO INCH SCREW/RAM

The ability of the extruder to survive on coal is of paramount importance to the success of the project and we felt that in view of the wear problem with the screw, we should investigate an alternative means of fuel injection which didn't put as much of the burden on the rotating screw. This resulted in the screw-ram concept which combines the best of both a screw and a ram extruder.

We had built a small ram extruder early in our work and while it showed little promise due to low potential throughputs and sealing capability, it did operate with very low erosion rates and was capable of developing high ram pressures.

After extensive design work, the existing two inch screw extruder was modified into what we feel is a very versatile piece of test equipment which can be run as a screw extruder, a ram extruder or a screw/ram. Fig. 4 shows the machine during off-line atmospheric testing.

Operation as a screw/ram is similar in concept to an injection molding machine. On the feed stroke the hydraulically powered screw rotates to feed the coal/tar mix forward while at the same time retracting from the barrel. At a preselected point, the screw stops rotating and hydraulic actuators ram the screw forward to compact the coal in the die area. Hydraulic pressure is then relieved on the actuators and the screw begins the feed cycle again. Wear was expected to be substantially reduced on the screw tip because during conditions of high face loading, i.e. when the coal is being forced through the die, the screw is non-rotating and hence there is no relative velocity between it and the coal. The adjustable circular die from the two inch machine is used and the axial force which can be developed on the coal is only limited by the size of the actuator.

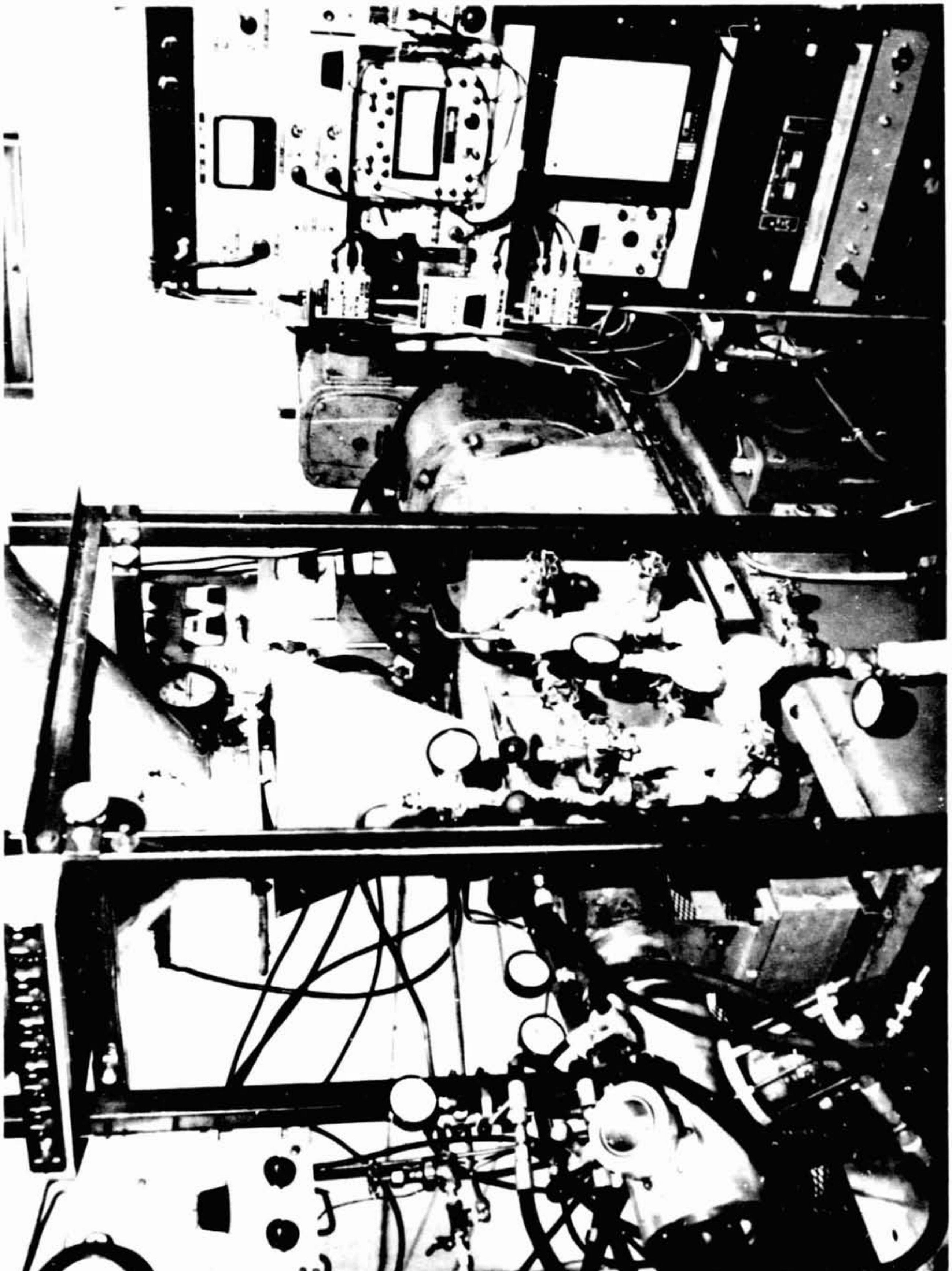

Figure 4. Two-Inch Screw/Ram Coal Extruder

SCREW/RAM PERFORMANCE

The performance of the machine at one atm. was better than expected. Smooth steady operation was the rule rather than exception on a sampling of ten different coals run. Screw wear was reduced by almost 30%, power consumption was 230 lb/kw-hr, and specific deliveries approached 10,000 lb/hr per ft^2 of barrel area. While axial pressures as high as 20,000 psi could be exerted on the coal, best results were obtained in the 3000 to 5000 psi range. Pressures much higher than this caused surface degradation of the extrudate, resulting in a weaker rather than stronger briquette.

Operation at pressure with the screw/ram proved to be a problem. We could not reliably maintain a gas seal against backpressures greater than 23 atm. Leakage through or around the coal plug would begin to develop as the screw started its feed stroke. The loosely compacted coal being fed in front of the screw did not provide enough support for the compacted coal plug in the die. A tapered die with a slightly diverging cross-section was tried in an effort to force the coal plug to act more like a cork, but we still could not continually maintain a seal on the back stroke at pressures higher than about 20 to 25 atm.

By restricting the rearward movement of the screw during feed, however, we were able to seal at pressures in excess of 40 atm, but because of the additional work being required of the screw, both power and wear increased to the point where the advantages of the screw ram concept over the straight screw began to diminish.

SIX INCH EXTRUDER

General Electric is currently engaged in a joint gasification program with E.P.R.I. as part of a contract to build and operate a stirred fixed bed gasifier capable of processing 2000 lb/hr of coal at 23 atm pressure. The facility is located at the General Electric Research and Development Center in Schenectady, New York.

To feed coal to the gasifier, both a lock hopper system and an extruder will be used. Incoming run of mine coal will be screened to remove the size fraction below 1/8". These fines will be sent to the extruder while the above 1/8" will be lock-hoppered into the gasifier. Both feed systems are sized such that they can each handle the full output of the gasifier independently of each other.

The GEGAS-D extruder is a six inch heavy duty screw type powered by a 60 hp SCR drive. It is nominally rated at 2000 lb/hr but on the basis of our results so far, we feel this is a conservative number. The hopper of the machine is equipped with two counter-current packer wheels which help cram the hot mix into the screw cavity. The screw itself is of the segmented auger type with individual cast sections stacked along a central drive shaft to give a continuous worm. With this design, screw geometry can be varied quite easily and worn areas of the screw can be replaced without removing the entire screw. L/D of the machine is 4:1 and the barrel is made up of two steam jacketed sections each equipped with a hardened and ribbed steel barrel liner. The die is a scaled up version of the two inch and is a combination variable area-variable length. Die material is stainless steel.

For off-line pressure testing, a 700 psi chamber is used as an extrudate receiver and is isolated from the extruder with a high speed knife gate valve in the event that the pressure seal is lost in the extruder die. During on-line testing against gasifier pressure, this receiver will be connected to the pressurized coal feed auger on the gasifier and will house a hydraulically powered chopper. Curved teeth on a rotating flywheel are used to break the solid 6" logs into pieces small enough to be fed by the auger. A 10" Everlasting® slide gate valve mounted between the gasifier auger and receiver isolates the extrusion system from the gasifier during start-up and during emergency shutdowns.

As a safety interlock, valve actuation is protected by a logic system which prevents an operator from opening the valve unless the pressure in the receiver and gasifier are equalized. Pressure equalization is handled by a small line using high pressure N_2, allowing the operator to test the extruder seal before exposing it to full operating conditions by opening the valve. Both the Everlasting® valve and the emergency 10" knife gate valve mounted between the extruder die and receiver are designed to close against a column of extrudate. With both these valves closed and the receiver vented,

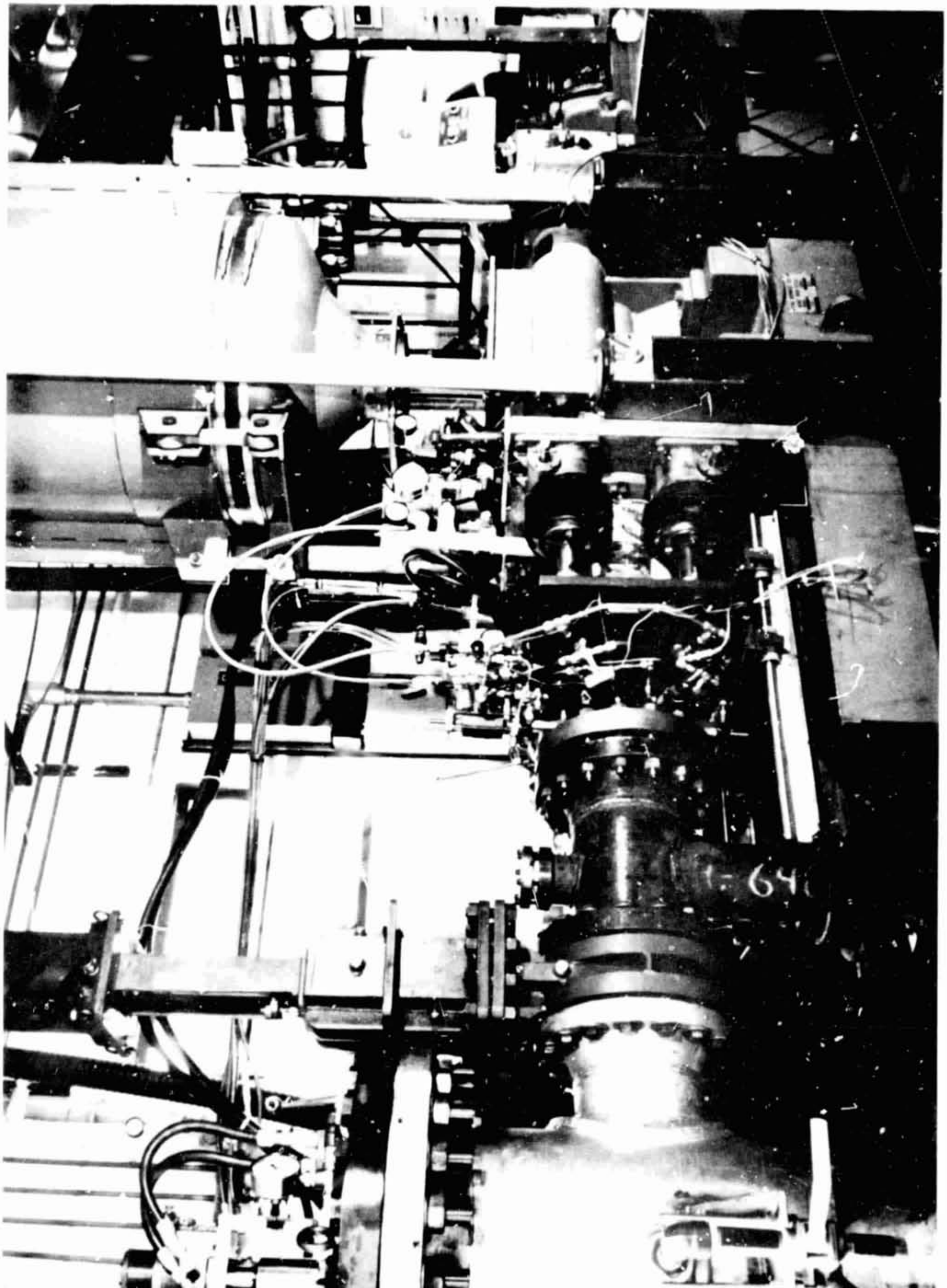

Figure 5. Six-Inch GEGAS-D Coal Extruder Connected to Pressure Receiver

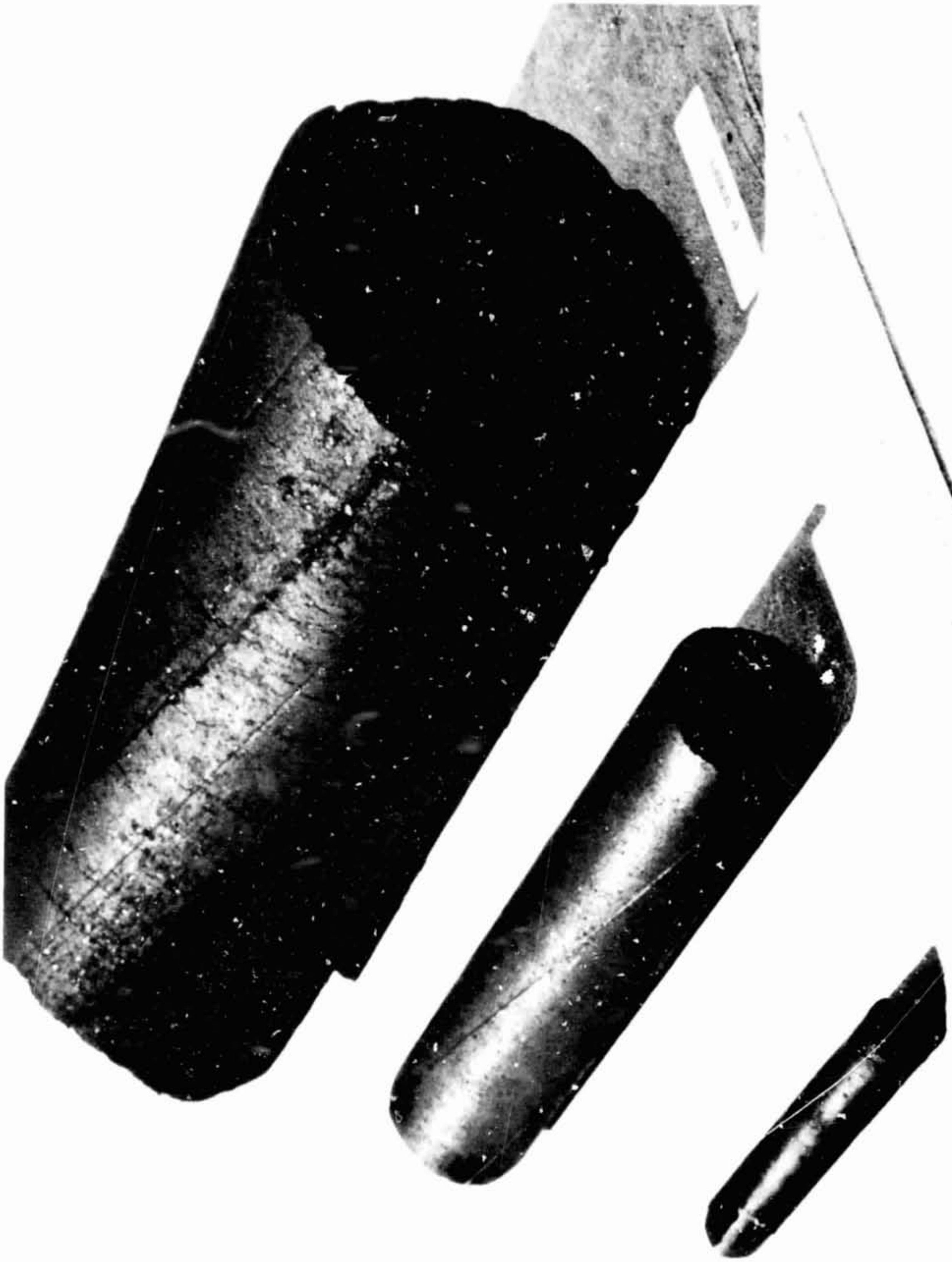

Figure 6. One-Inch, Two-Inch, Six-Inch Coal Extrudate

the extruder can be isolated at essentially atmospheric conditions while the gasifier remains at operating pressure.

Hot mix is supplied to the extruder via a batch paddle mixer and a conveyor system. Preheated 250°F mix is being used instead of the cold milled tar and coal used previously, because with the larger cross-sectional area of the six inch and the deeper screw flights, the heat transfer between the walls and mix is insufficient to melt and spread the tar binder. Using a separate mix system also gives us more system flexibility and allows us to separate the extrusion problems from the mix prep problems. Tar injection into the mixers is handled hot on a weight percentage basis. Figure 5 shows the extruder connected to the receiver/chopper in preparation for air backpressure tests on the gasifier. Figure 6 shows the comparative size of the extrudate produced from the one inch, two inch and six inch machines.

Six Inch Performance

To date about 30,000 lbs. of mix have been extruded in a series of off-line tests at backpressures ranging from 1 to 33 atm. This new system has gone through check-out runs and operating results so far suggest better than anticipated performance at one atmosphere. Extrudate has been delivered at 1 atm. at a rate of 7000 lb/hr-ft^2 bbl at > 310 lb/kw-hr. power consumption, with a projected maximum delivery in excess of 4000 lb/hr. or 20,000 lb/hr-ft^2 bbl area specific delivery.

By increasing operating rpm of the screws, the output per machine could be increased still further, but would be limited ultimately by the point where the feed screw begins to starve feed.

Several short duration tests have been made off line against hydrostatic heads up to 33 atmospheres. Although run times have been short due to the rather limited volume of the receiver/chopper housing, the operating data does show that the extruder can deliver extrudate against a 500 psig head. Water was used as the pressurizing medium in these tests for reasons of convenience and safety.

As Table I indicates, specific power consumption at pressure has been lower on the 6" machine than the 2" extruder (170 lb/kw-hr. vs 120 lb/kw-hr for the 2"), indicating that scale-up as well as equipment improvements have again been effective in lowering the process power requirements. The specific delivery of 5000 lbm/hr-ft^2 bbl shown for the 6" machine is artificially low due to the low delivery rates dictated by the limited volume of the off-line chopper housing/receiver. These power figures do not include the work required to heat and blend the tar-coal mixture.

Test results have indicated that the extruder density has a direct relation on the sealing capability of the machine. Satisfactory gas seals have been obtained against 33 atm. backpressure with effective coal plug lengths as short as 4.5". Power consumption is also a function of density however, and an operating trade-off has to be made. On the 6" machine this means densities of 73-78 lb/ft^3 to obtain gas seals at 33 atm. backpressure with reasonable power consumption.

Control of extrudate formation using the variable length variable area die scaled from the two-inch machine has generally been acceptable, although there are periods of instability where power and density fluctuations occur. These are most prevalent during start-up and shut-down and hopefully will not present a major problem during long term running.

Six Inch Wear

Wear on the auger parts has been below 0.5 ppm, which represents a ten fold decrease over measured wear on the two-inch screw. Auger material is a high-chrome, cast steel with a R_c hardness of 60-67. This is not a particularly hard or exotic material and the wear reduction obtained is felt to be a combination of both materials and more favorable geometric factors obtained from scale-up. The die has also held up well and the original hardware is still in service with no wear problems as yet. Long term testing involving several hundred tons of extrudate will ultimately be needed, however, to determine wear rate projections.

Current Tests

The extruder is presently connected to the GEGAS fixed bed gasifier. Unfired air tests are in progress now using the gasifier as a backpressure vessel. Based on the success of these tests, several long term runs with the gasifier operating at 20 atm. on 100% extrudate feed are anticipated. These tests will supply not only critical data needed to determine the viability of the extrusion process but will also determine how the extrudate behaves as a gasifier feed stock. Gasification rates, fines carryover and tar mass balances are parameters to be measured. Success of these tests would pave the way for development of a commercial sized ten or twelve inch extruder by supplying the critical reliability and operating cost data needed to compare this approach with other feeding systems. Based on current data, three of the twelve inch extruders would supply the 20 tph feed data to a commercial gasifier of twelve foot internal diameter.

DISCUSSION

Process Variables

Coal's variability even within seams is legendary. This has contributed to the large fraction of art in the business of coal utilization. Each coal behaves differently when burned or gasified and in our extrusion work, we have found that no two coals extrude exactly alike. While the best way to determine how a particular coal will behave is to actually extrude it, there are certain variables which give us a clue to a coal's performance. These are the rank of the coal, the particle size distribution of the coal and the moisture content of the coal. Two other important variables, not a function of the coal type but directly related to the process, are the amount and type of binder used and the addition of other components to the extrudate mix.

It has been our experience that the higher rank coals are generally easier to extrude, anthracite being the easiest and some of the sub-bituminous and lignites being the most difficult. There are most likely exceptions to this rule, but with the coals we have run, this has proven to be the case. As for the reason we don't have a clear cut answer. Electron micrographs taken of the different coals show differences in the surface structures which could account for some of the differences in extrudibility.

The size distribution of the coal mix is an important variable. One would theoretically like a bell shaped distribution curve to give an optimum packing density to the extrudate. Unfortunately, in using screened run-of-mine coal, we take everything below 1/8" and are therefore unable to control our size distribution. This distribution in turn varies with the mining technique used and type of coal being mined. In general, too little fines and a weak extrudate is obtained because of poor density; too high a fines percentage and the binder content must be increased to compensate for the increased surface area.

Moisture content effects the handling of the coal, the strength of the extrudate and the power required to extrude it. We generally like to see the moisture content in the 3 to 5% range. Handling problems with screening and conveying the coal arise with moisture contents above this. Drying to below 3% on the other hand, penalizes the process unnecessarily because power is being wasted to excessively dry the coal. Also, more power is required to extrude the drier mixes. The moisture in the coal has the added advantage of helping to spread the tar binder during the heating stage.

The amount and type of binder used is a critical variable in the process for both economic and physical reasons. Coal tar pitch obtained from the spray quench system of the gasifier will be used in our pilot plant system. This use of tar as a binder provides a means for recycling what is otherwise a difficult disposal problem. Whether the system will be self sufficient in tar will depend on the type of coal being gasified and the amount of tar required for the extrusion process.

Ideally, we would like to see neither a surplus nor a deficiency of tar. Presently, we are using binder contents in the range of 6-12%, the actual percentage used being a function of the mix being extruded and the type of tar being used. In our lab work, we are presently using asphalt pitch because it is obtained locally, easy to work with, and does not represent a health hazard as do some of the coal tars. Other binders such as bentonite and sulfite liquor have also been used.

With the extrusion process, it is possible to blend coals with other components to obtain extrudate with specific properties. The use of ash as a diluent is a general technique to reduce the swelling tendencies of coal by separating the coal particles and reducing their tendency to stick together. In extruded coal, the ash appears to have a rather specific effect in reducing the measured swelling index of the extrudate and it does so by an amount greater than proportionate to the amount of ash used. Figure 7 shows the effect of added ash on FSI for a Pittsburgh #8 coal. This technique has allowed us to process highly caking coals in a convéntional fixed bed gasifier without stirring. The ash is, however, quite abrasive and does put an additional load on the extruder by requiring higher throughputs due to the dilution of the mix by the inert ash.

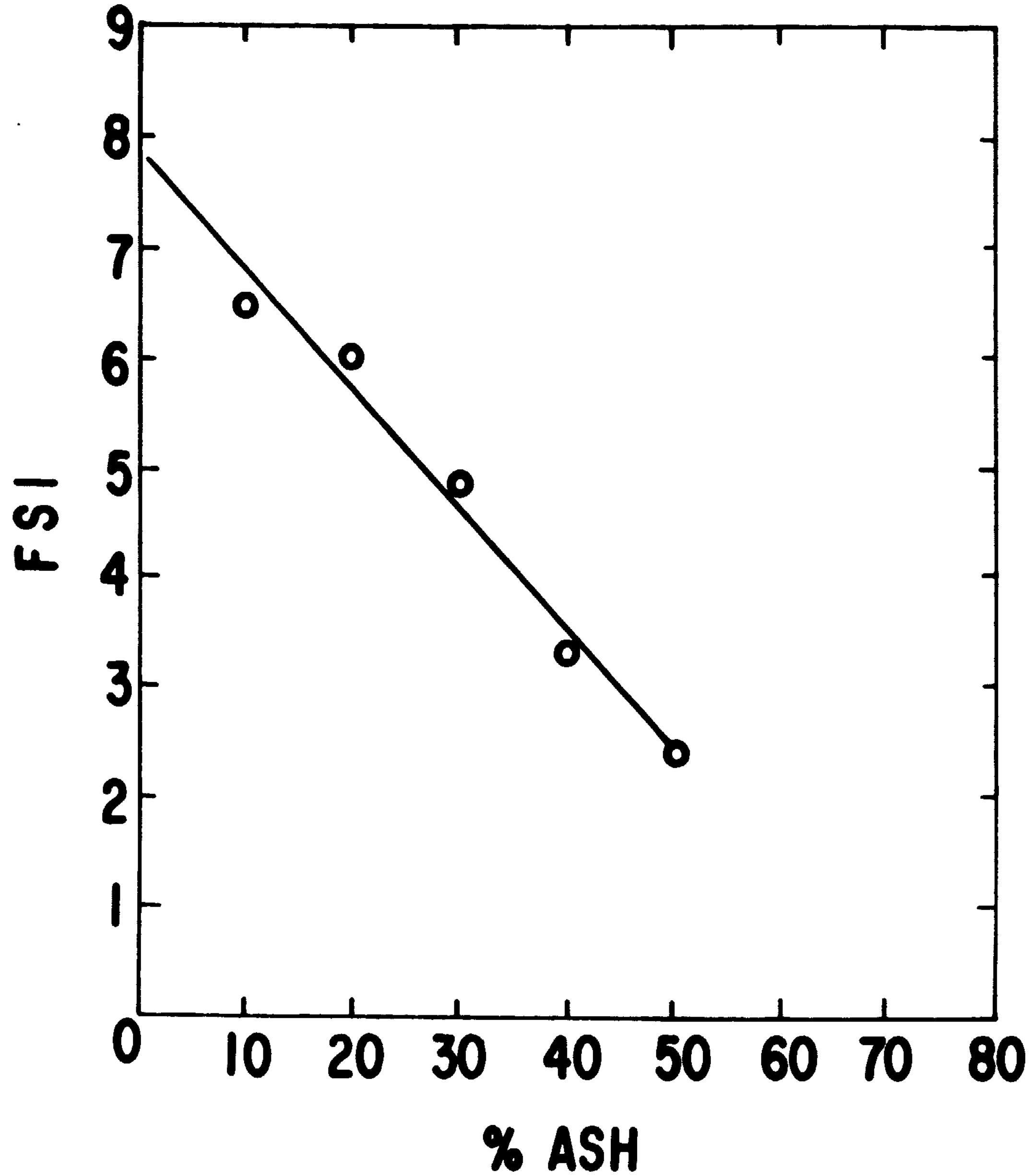

Figure 7. Effect of Added Ash on Free Swelling Index

TABLE 3

COALS EXTRUDED

COAL	MINE LOCATION
Anthracite	Pennsylvania
HVA Bituminous (Pitt. #8)	Pennsylvania
HVA Bituminous (Ill. #6)	Illinois
Bitumincus, M-V	Missouri
Bituminous, HVB	Kentucky
Bituminous	Japan
Subbituminous	Wyoming
Subbituminous	Japan
Lignite	Utah
Lignite	Texas
Lignite	Canada
Minewaste	Illinois

SUMMARY

In summary, we are developing the coal extrusion process as a means of compacting and feeding coal fines directly into a pressurized gasifier. We chose the "cold" extrusion process over a hot one and a screw machine over other types. We have seen economies of scale in going from smaller to larger machines and have demonstrated gas sealing capability at competitive power consumptions on the 2" machine. Wear and process control are continuing problems, but ones in which progress is being made. The next major hurdle is to demonstrate that the process parameters can be scaled up to the 6" extruder and to measure the four critical parameters of sealing, power, output and wear while operating on an actual pressurized gasifier.

ACKNOWLEDGEMENT

All experimental research on the six-inch extrusion system, and a portion of the work on the two-inch extruder, has been sponsored by the Electric Power Research Institute on Contract RP357-1.

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