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Benefication and Drying of Mississippi Lignite

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Lignite Beneficiation and Drying

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LIGNITE BENEFICIATION AND DRYING

Final Report

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ABSTRACT

This report summarizes the research on lignite that was performed at Mississippi State University for the Mississippi Mineral Resources Institute during the period July 1, 1983 to June 30, 1984 The work was concentrated in the areas of lignite drying ash removal.

The drying effort was directed toward the evaluation of the permanent drying effect of combined micropulverization and drying of lignite in a fluid-energy mill. A new concept called hot-water drying was also investigated. Both techniques showed a significant permanent drying in the lignite product.

The ash removal effort was directed toward modification and use of a computer analyses of an air cyclone. The program was modified to represent an air classifier with a peripheral slit in the lower cone of a conventional air cyclone. This modification results in a system which can be operated so as to remove different size particles.

INTRODUCTION

The Mississippi lignite research program has been a cooperative effort among several state and private agencies including the Mississippi Department of Energy and Transportation (MDET), the Mississippi Mineral Resources Institute (MMRI), Mississippi State University(MSU), Ergon, Inc., and Mississippi Power and Light Co. (MP&L). The overall goal of the project is to develop an economically competitive fuel from lignite that can be used as a retrofit fuel for existing boilers at power plants, industries, and large institutions.

Since most of these units in Mississippi operate on natural gas, the lignite fuel needs to be one which can be used in a gas (or oil) designed boiler without major capital modifications.

Previous research work has shown that if coal is ground to an ultrafine powder prior to burning, then the resulting flame is quite similar to an oil or gas flame and the ash particles from the coal are so small that they do not cause significant slagging of the heat transfer surfaces in the boiler (References 1 and 2). Therefore to retrofit such a fuel into an existing plant, basically only new burners and a bag house type exhaust cleanup system are required (References 3 and 4).

The first phase of the MSU lignite program conducted during 1982 concentrated on the ultrafine pulverization of Mississippi lignite in a fluid-energy pulverizing system owned and operated by Ergon, Inc. This system had been used previously to micropulver ize coals and cokes. Since lignite has much more moisture and ash in the as-mined condition than higher grade coals have, it was not clear initially whether it could be pulverized in this system. However, it was found that it would break easily even in its as-mined, high moisture state. The results of these tests showed that lignite could be successfully pulverized in such an apparatus as the initial stage in the production of a microfine fuel (Reference 5).

Phase two of the project has concentrated on the beneficiation of the lignite or the increase in the heating vlaue through moisture and ash reduction. In order for lignite to be a viable fuel, its heating value must be increased from the as-mined value of about 5500 BTU/lb to

8,000 to 10,000 BTU/lb. This can be accomplished through a permanent reduction in the water content in the fuel and/or a reduction in the nonburnable impurities.

During 1983, the drying efforts concentrated on ways to permanently reduce the moisture content in the micropulverized lignite. Raw lignite has a moisture content of about forty-five percent by mass, but this water can be easily driven off by heating the material in an oven at 105°C for thirty minutes to an hour. However, as soon as this dried lignite is exposed to humidity or to water (as in a slurry), the moisture is quickly reabsorbed back to the original level.

It has been found that when lignite is dried at higher temperatures, some permanent drying takes place. The efforts at MSU have dealt with quantifying this effect. Initial tests with air drying were successful, but the temperatures that could be attained were limited by the ignition of the lignite. Other tests included combined micropulverization/steam drying in the Ergon pulverizer. These tests were conducted at various temperatures up to 240°C and a significant permanent drying effect was found (Reference 6). These results have been compared with similar results for conventional pulverized lignite that were obtained at the Grand Forks Energy Technology Center. The significant difference is that a permanent drying occurs at a much lower temperature with micropulver ized lignite than it does with conventional lignite.

These comparisons have continued into 1984 along with a new hot water drying effort. By heating a lignite water slurry to a high temperature, under high pressure, the permanent drying effect can potentially be improved with a reduced overall energy input. The equipment for these tests has been assembled, and testing was begun in August 1984.

The beneficiation efforts related to ash reduction have concentrated on the removal of the superfine particles (<5 microns) from the micropulverized lignite. These fine particles appear to be primarily ash. During the pulverization studies in 1982, an air classifier on the exhaust of the system allowed some of these very small particles to escape. A measurement of the ash content in the raw lignite and in the micropulverized product showed a ten percent ash reduction. This apparently resulted from the ash being blown out with the pulverizing fluid (air or steam).

Further investigation of the pulverized lignite with an optical microscope showed that the smaller particles appeared to be ash while the larger (>25 micron) particles appeared to be lignite with fine ash particles distributed throughout them. Therefore, only a partial ash reduction is possible by physical means.

During 1983, the ash removal efforts were directed toward heavy medium hyddrocyclone particle separation and toward chemical ash reduction. Bench tests showed that sulfuric acid would remove up to 20 percent of the ash from the lignite; however, significant cleanup procedures would be required for a full scale commercial operation based on this technique. The chemical cleaning work has been postponed while other, physical means are being investigated.

The heavy medium hydrocyclone studies used Freon 11 3 as the working fluid since it has a specific gravity between ash and lignite. The theory of the hydrocyclone is that the less dense lignite particles will leave with one flow stream and the more dense ash particles will leave with the other flow stream. However, this process was unsuccessful since the larger, lignite particles also contained ash causing too small of a difference in density with particle size.

The 1984 ash reduction studies have concentrated on the apparent size difference between the ash and lignite particles. Both electrostatic and aerodynamic particle classification techniques are being studied. The electrostatic separation theory is based on the probable charge difference on the ash and lignite particles caused by the grinding process in the pulverizer. Therefore a coupled pulverization, electrostatic cleaning process might be feasible.

The aerodynamic separation work is based on the observed ash reduction during the 1982 pulverization tests. Analytical work on this area is in progress and a bench test has been designed and fabricated.

The tasks identified for this contract were divided into the two categories of lignite drying and lignite ash reduction or beneficiation. These areas are described in the following sections. The MMRI grant was used to fund two graduate students, Mr. Robert Ross and Mr. Guy Spikes, who assisted in the research.

DRYING

Combined Micropulverization/Drying with Steam and Air

The purpose of the drying tests was to investigate methods of permanently drying the lignite. Small samples of the micropulverized lignite can be dried relatively quickly in 110°C air; however as soon as these samples are exposed to humid air or put in a water slurry they return to their original moisture levels. This hydrophilic nature is common to most lignites.

The problem is to remove the moisture and at the same time alter the lignite structure and chemistry so that the particles become hydrophobic. Work on steam and hot water drying processes that accomplish this permanent drying are ongoing at Grand Forks Energy Technology Center (GFETC) in Grand Forks, North Dakota (References 7 and 8). The results of these tests show that -40 mesh lignite dried for 15 minutes at 340°C has an inherent moisture of 10 percent compared to 35 percent for the original lignite. Some of the theories on why the moisture reduction takes place are decomposition of carboxilic acid groups, surface modifications which reduce the ability of the coal to bind water, and excess moisture being forced out of the pores.

As an alternative to air drying lignite, a combined steam (or air) pulverization and drying process was investigated. The pulverizer operates on the principal of colliding small coal particles into each other, thus causing a grinding action to take place between particles. This grinding is induced by forcing steam or air through a ring of nozzles turned in such a way as to produce a vortex flow field carrying the particles of coal. The pulverizer is designed so that the smaller particles can exit from the unit out of the top where they can be collected.

The lignite for these tests was obtained from a test pit opened by MSU on land leased by Phillips Coal Company in Panola County, Mississippi. The lignite was beneath approximately 13 feet of overburden. The seam was approximately 6 feet thick.

The pulverizer/drying tests consisted of steam pulverization at temperatures of 250°F, 325°F, 400°F and 460°F (the maximum steam temperature available for the unit). Air pulverization tests were run at 250°F and 325°F, however at 325°F the lignite began to ignite therefore data is only available for the 250°F runs. Particle size analyses were conducted on both the 250°F and 460°F steam ground samples at Ergon. The results of these analyses show that the mean particle size for the 250°F sample is 8.15 microns based on volume and 4.5 microns based on population and for the 460°F sample 7.4 microns based on volume and 3.8 microns based on population.

The data for the combined pulverization/drying tests are given in Table 1. the equilibrium moisture value given represents the inherent moisture that would be present in the lignite after it is mixed with water in a slurry. These data are also presented in graphical form (Figures 1-5). Each graph is shown with bands giving the scatter in the results. From Figure 1 it is seen that the majority of the equilibrium moisture reduction occurs at or before the 250°F point. After the 250°F point there appears to be little change in moisture. Figure 2 shows that the ash decreases somewhat with increasing steam temperature. Figure 3 shows that the heating value tends to increase with pulverizer temeprature particularly at temperatures above 400°F which is probably caused by the decrease in ash content. From Figure 4 it is seen that the volatile matter remains essentially constant until the 400°F and 460°F points where there is a slight decrease. Figure 5 shows the equilibrium moisture decrease with air pulverizing temperature. The 100°F point on Figure 5 was obtained with ambient air as the pulverizing medium.

TABLE 1. Results of Combined Pulverizing/Drying Tests

Sample Type	Dry-Basis Proximate			Dry-Basis Heating Value (BTU/lb)	*i* Equilibrium Moisture
	% Volatile Matter	% Ash	% Fixed Carbon		
As-Mined	47.2	27.4	25.4	9375.	37.5
Feed-Stock	46.8	26.6	26.5	8928.	37-7
250°F A.G.	47.6	25.5	26.9	9370.	15.7
250°F S.G.	46.6	26.4	27.0	9115.	16.7
325°F S.G.	46.9	26.4	26.7	9192.	13.5
400°F S.G.	45-5	26.2	28.3	9186.	14.6
460°F S.G.	45.8	25.9	28.4	9331 ·	13.7

S.G. = Steam Ground
A.G. = Air Ground
Volatile matter, ash, fixed carbon, and equilibrium moisture are based on a weight percentage.

FIGURE 1 EQUILIBRIUM MOISTURE US. TEMPERATURE FROM 1983 TESTS

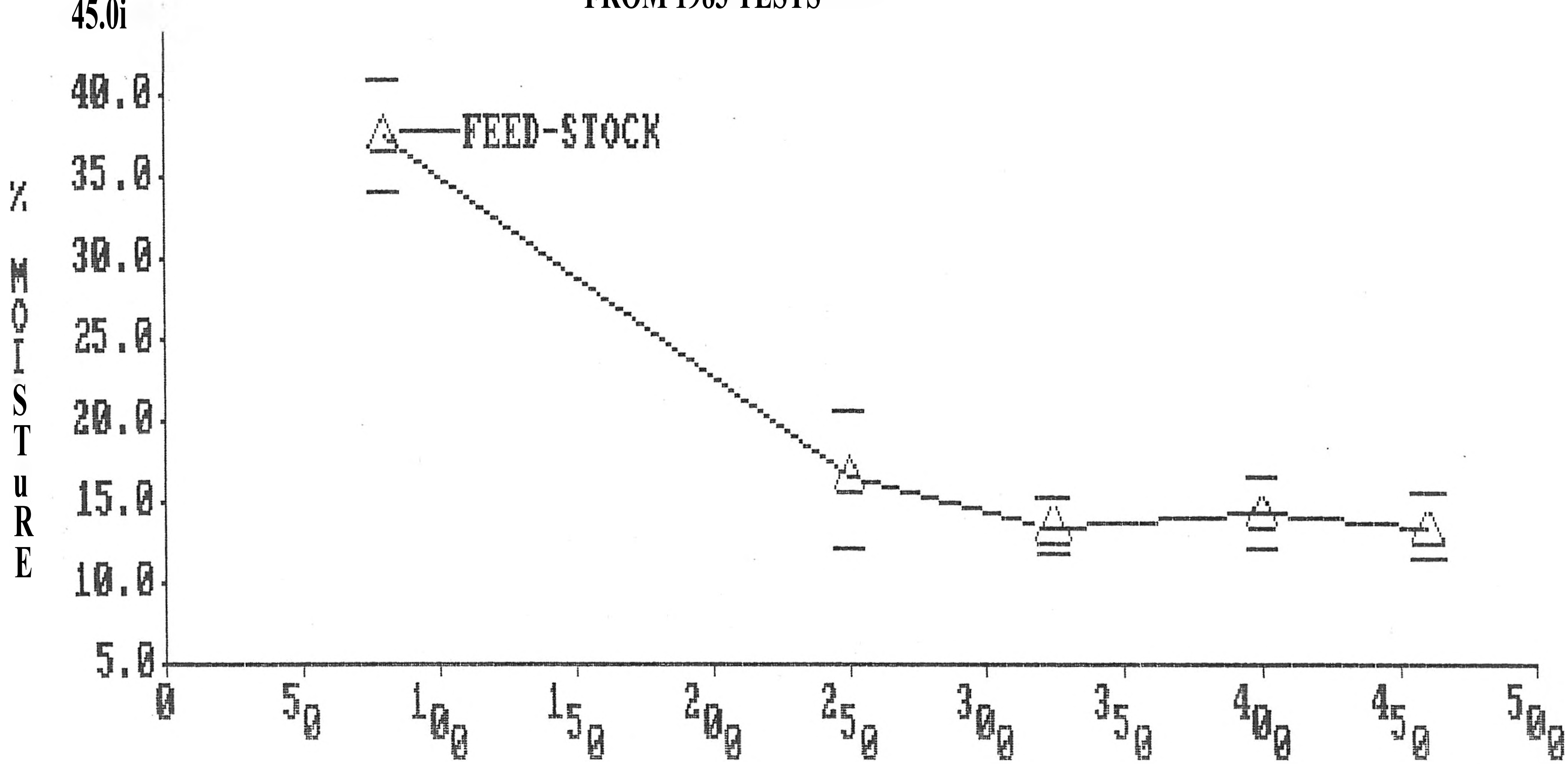

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FIGURE 2 DRY BASIS ASH VS. TEMPERATURE
FROM 1983 TESTS

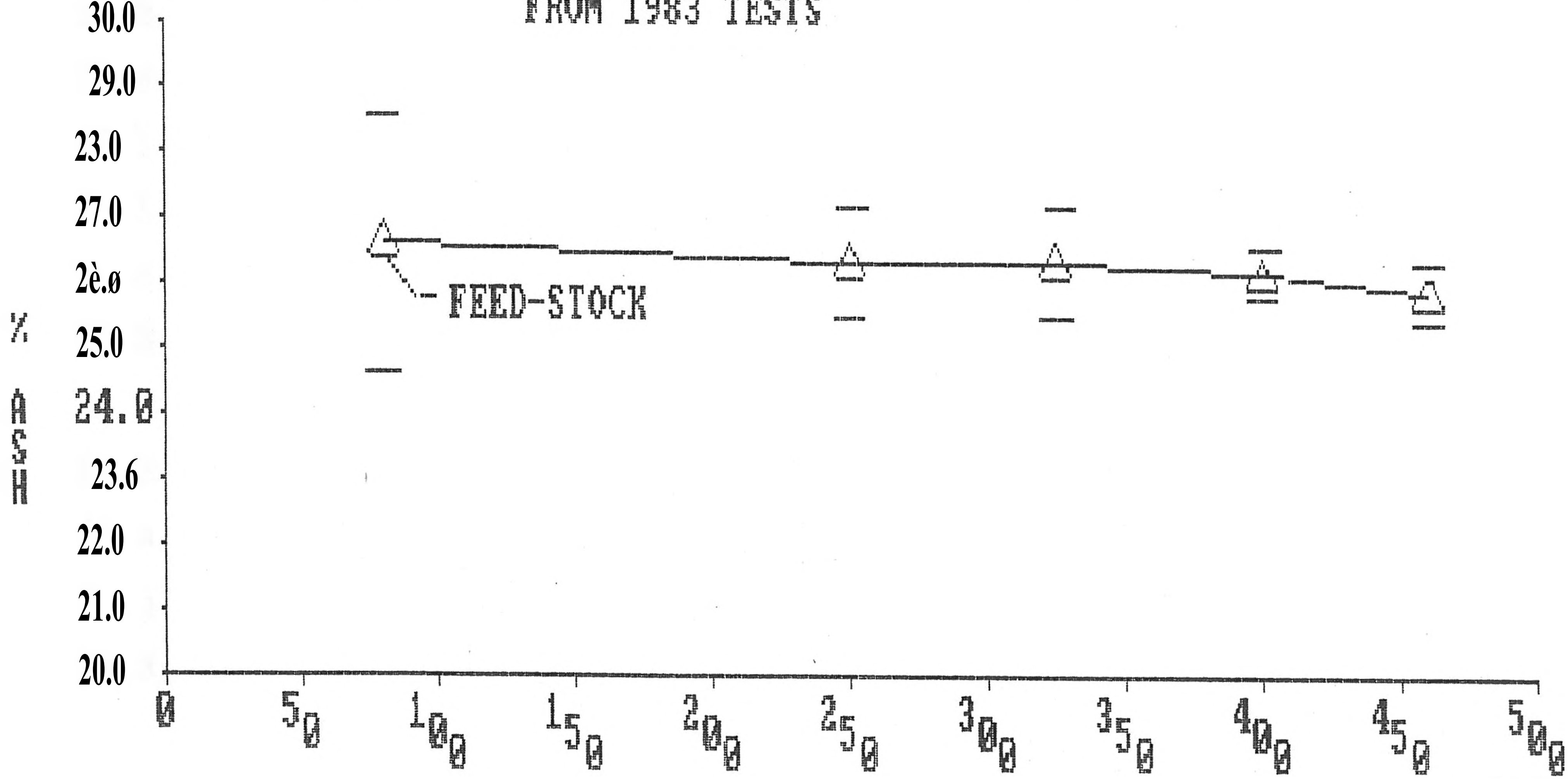

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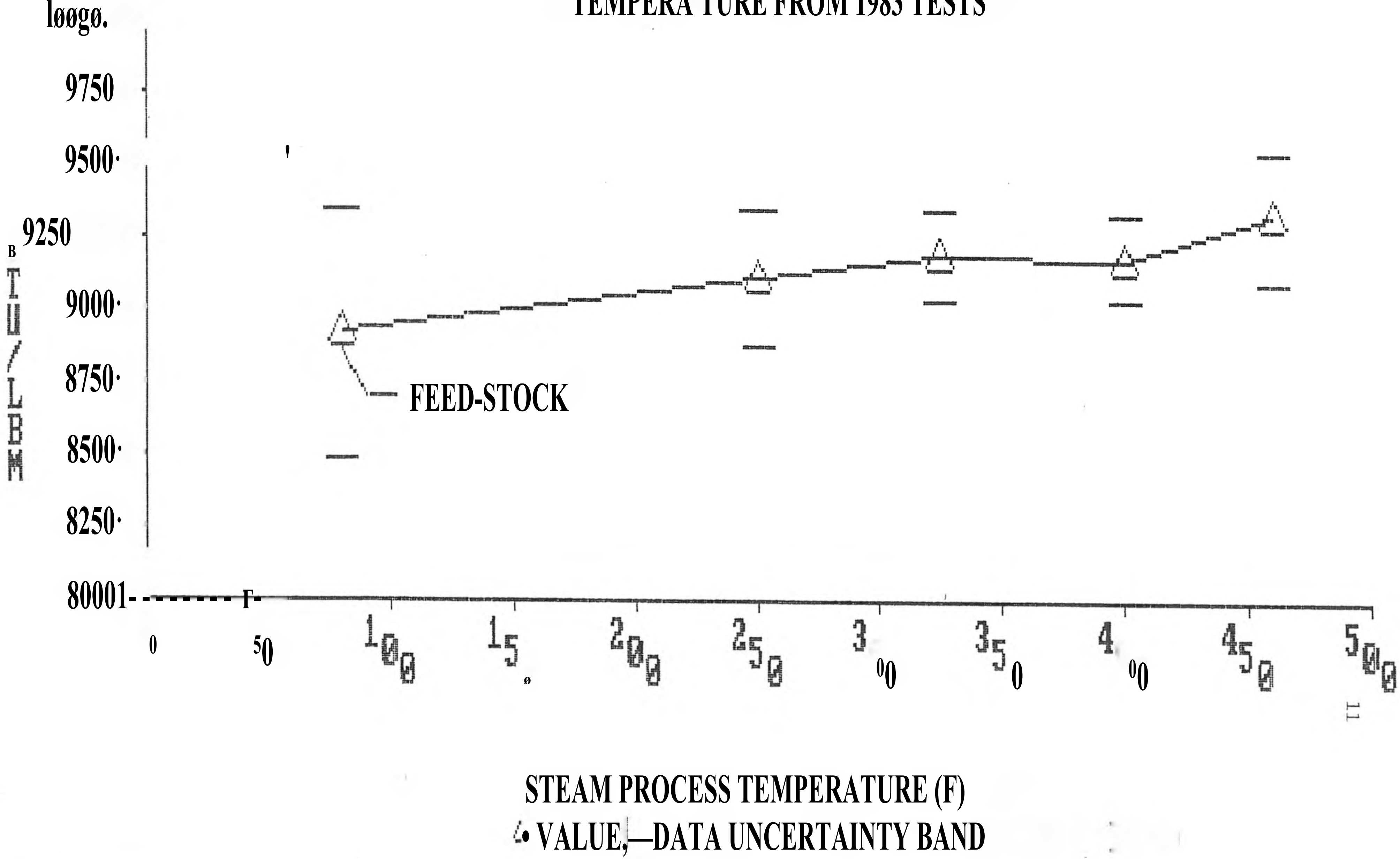
FIGURE 3

DRV BASIS HEATING UALUE US. TEMPERA TURE FROM 1983 TESTS



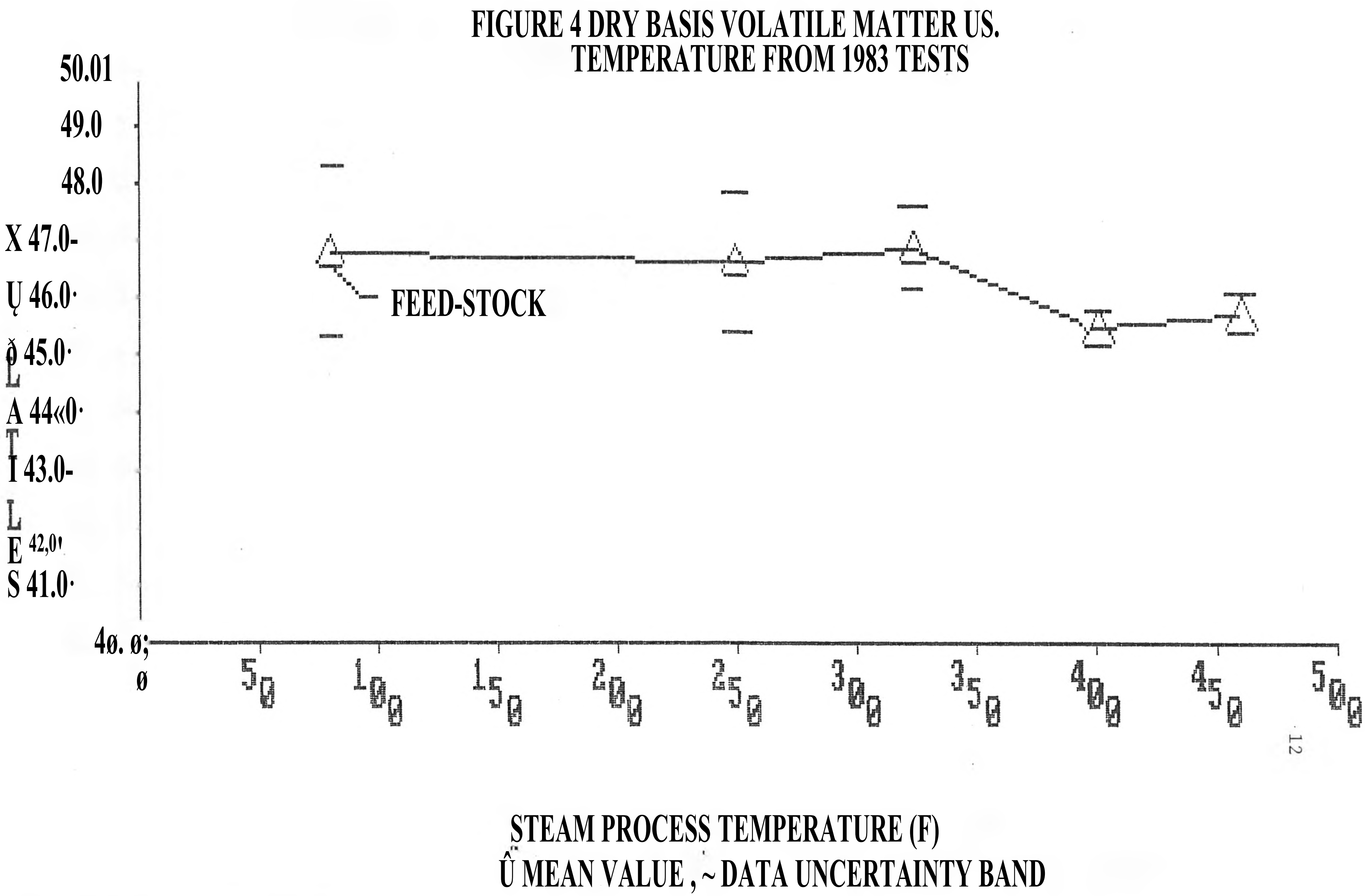


FIGURE 4 DRY BASIS VOLATILE MATTER US.
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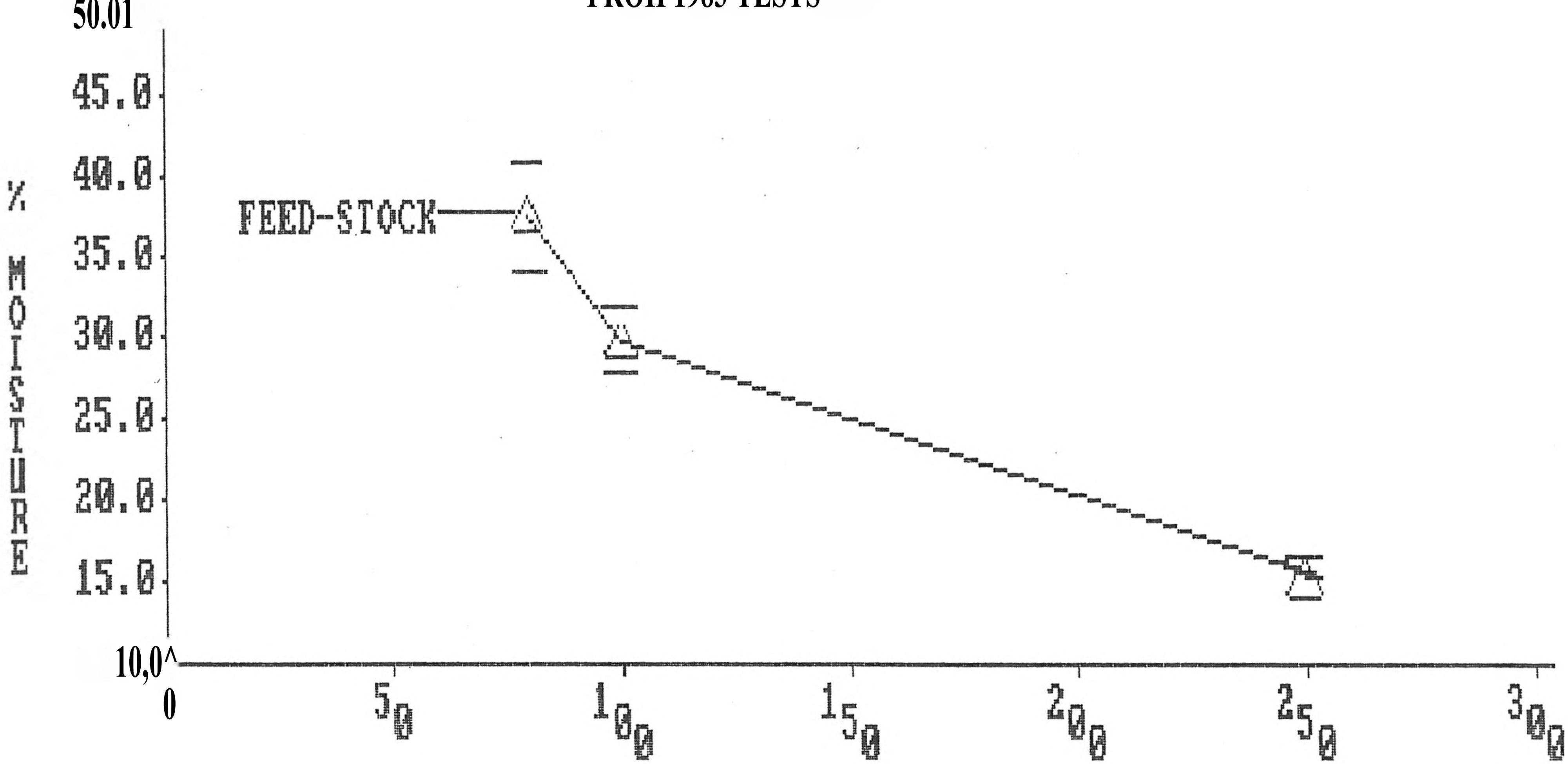
FIGURE 5 EQUILIBRIUM MOISTURE US. TEMPERATLRE FROH 1983 TESTS



AIR PROCESS TEMPERATURE í F)

û MEAN VALUE, “DATA UNCERTAINTY BAN»

The significant difference between these test results and those at the GFETC is that a permanent moisture content of about 15 percent was obtained at a drying temperature of 300°F while temperatures above 500°F were required in the North Dakota tests to reach this same moisture level. The lignite in these tests was -325 mesh as compared to the -40 mesh lignite used at GFETC.

Hot-Water Drying

Hot-water drying is a process for the removal of liquid water from high-moisture coal by heating a coal-water slurry under pressure. The lignite used in these tests was obtained from the same test pit in Panola county as mentioned earlier. The lignite was pulverized at Ergon with ambient air as the working medium.

A slurry is produced with the pulverized lignite by adding distilled water to the coal and agitating. A 150 ml slurry is then poured into a 300 ml autoclave which is then heated to a specified temperature for a set period of time.

Preliminary results of hot-water drying are shown in Table 2. It should be noted that these test results are initial runs without replication, therefore, multiple samples must be analyzed before the results can be used. The results indicate a singificant decrease in both ash and equilibrium moisture and an increase in heating value.

Potential Lignite Fuels and Future Work

The significance of this equilibrium moisture reduction is in the feasibility of using the lignite in a water slurry as an oil-like fuel. Consider the 460°F steam ground lignite for example. If enough water

TABLE 2. Results of Hot-Water Drying Tests

Sample Type	Proximate Vo1atile % Matter	Proximate Ash $	Proximate Fixed Carbon	Dry-Basis Heating Value (BTU/lb)	% Equilibrium Moisture
100°F A.G.	52.3	24.0	23-7	10203.	30.0
283°F H W.D.	52.0	21 .3	26.7	10464.	25.6
600°F H.W.D.	50.0	18.5	31 -5	11973.	4.2

A.G. = Air Ground
H W.D. = Hot Water Dried
Volatile matter, ash, fixed carbon, and equilibrium moisture are based on a weight percentage.

is added to this product to make a slurry of 40% water, 60% water-saturated lignite, then the total water content in the slurry will be 40% plus (0.137) times 60% or 48.2%. The resulting slurry will have a heating valaue of 4832 BTU/lbm, or a value very close to the heating value of the raw lignite. However, the form of the fuel has now been changed to an oil-like mixture that can be retrofit into existing boilers.

Further reduction in the equilibrium moisture or increased solids loading of the slurry will of course raise this heating value. This is illustrated by the hot-water dried lignite data in Table 2. If a 40% water, 60% water-saturated lignite slurry is made from the 600°F dried product, then the slurry heating value will be 6886 BTU/lbm. This is very close to the slurry-fuel heating values that can be obtained with bituminous coal. The hot-water drying technique appears to be the best method for generating a high heating value slurry.

These preliminary data indicate that there is a good possibility for using lignite as a retrofit boiler fuel. The air or steam ground lignite has an as-received moisture content of 2% to 5% giving it a heating value before slurrying of about 9500 BTU/lbm. One area for further research is the possibility of using this micropulverized product as a "dry" rather than a slurry fuel. The moisture reabsorption characteristics of this product in standard atmospheric conditions needs to be determined. Also the methods for transport, safe storage, and burning of this dry fuel need to be investigated.

BENEFICIATION

Analysis and Design of an Air Classifier

A computer analysis of the performance of an air cyclone has been generated by F. Boysen, et. al. of Sheffield University in England. A copy of this program has been obtained and made operational on the MSU owned UNIVAC computer. The computer program has been modified to represent an air classifier in which there is a peripheral slit in the lower cone of a conventional air cyclone through which auxiliary air is admitted in varying amounts. A sketch is shown in Figure 6. This modification results in a system which can be operated so as to remove different size particles.

The air cyclone or air classifier is based on the principle of centrifugal forces in comparison with drag forces to provide for larger particle removal out the lower cone or for smaller particles to be carried through with the outlet air stream.

The centrifugal force is related to the mass of the particle. Buoyancy forces are present in the air cyclone; however, due to the large differences in density of the particles and to air, the buoyancy force may be neglected. Using a spherical shape as an approximation for the shape of the micronized lignite particles of interest, then the centrifugal force is proportional to the density times the radius cubed.

The drag force is related to the projected cross sectional area of the particle and a coefficient of drag. If the spherical shape approximation is used, then the drag force is proportional to the coefficient of drag times the radius squared. If the flow is such that the particle Reynolds number in the cyclone or classifier is less than

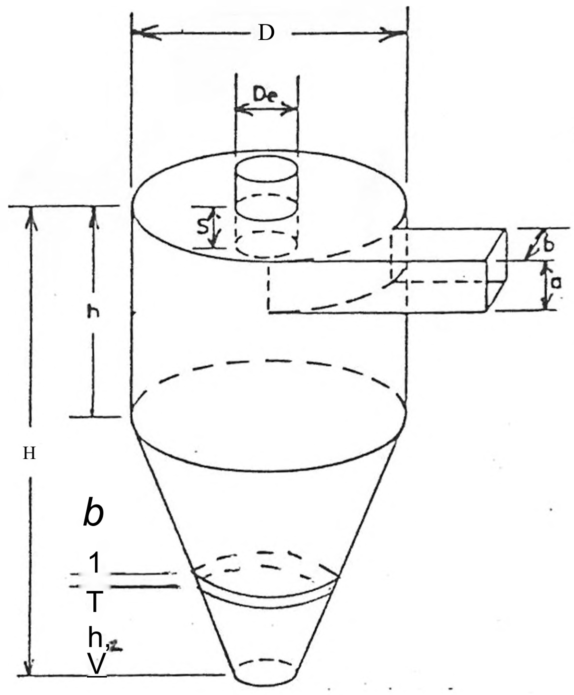


Figure 6. Classifier Geometry

one, then the particle is said to be in the Stokes flow regime where the drag coefficient is proportional to the inverse of the radius of the particle.

Considering the ratio of the centrifugal to drag forces on a particle, then the ratio is proportional to the density times the radius squared. The density range on the micronized lignite particles is approximately 1.2 - 1.5, or a factor of 1.25 to one. The radius variation is from about 1 to 20 microns or a factor of 20 to one. Thus, it is anticiapted that the air classification of the micropulverized lignite particles would be principally a particle size related phenomenon.

Based on this preliminary analysis and the observation of optical microscope pictures of the micropulver ized lignite particles which showed an apparent ash particle as the smaller particles and an apparent hydrocarbon paricle as the larger particles, it was expected that an air classification system would separate out the smaller particles, thus reducing the ash content of the micropulverized lignite.

The Computer Program

The computer program simulates the fluid flow and particle motion in axially symmetric confined turbulent vortex flows with special emphasis on cyclone separators. The mathematical model on which the computer program is based consists of the fundamental equations of the conservation of mass and momentum. The turbulence is modelled by approximate transport equations for the pair correlations of the fluctuating velocity components. This enables the prediction of 3 velocity components for the fluid pressure and 7 turbulence quantities.

The particle trajectories are predicted by solving the equations of motion of solid particles of various sizes. The particle trajectory predictions then allow predictions of particle residence times and particle density in the fluid.

The cyclone geometry is specified based on the typical design variables depicted in Figure 6. These are the barrel height, the total height with the lower cone, the overall diameter, the diameter of the exit, the distance which the exit tube extends into the barrel, and the height and width of the rectangular inlet. It is assumed that the fluid density and laminar viscosity values are constant and are known inputs to the program.

A modification to the original program has been executed which allows for admission of additional or supplemental air through a circumferential slit in the lower cone as shown in Figure 6. This provides for a variable operating characteristic air classifier with a constant air/particle volume input. Additional computations are required to assure appropriate solutions with the supplemental air flow. Limited funding for variations of design have limited the amount of calculations which could be executed under this project for this modification.

A sample output for the base case of the classically designed hydrocyclone is presented as Figure 7. For a final design

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Figure 7. Computer Program Base Case Output

configuration, it may be possible to design a particular air cyclone without the benefit of the air classification supplemental air slit in the lower cone.

Conclusions and Recommendations

If micropulverized lignite has the appropriate properties of a very fine ash particle size which is distributed among relatively larger particles which are principally hydrocarbon, then successful beneficiation of the micropulver ized lignite would be expected through the use of an air classifier which is used to separate out the smaller ash rich fraction.

The computer program which simulates the flow in an air cyclone or air classifier with supplemental air circumferential slit should provide design information much more economically than would be required for a strictly experimental development program. The computer program does require significant amounts of computer time and consequently does require substantial expenditures for each case studied; however, it is expected that it would lead to more efficient designs more rapidly and economically than with the experimental trial and error approach.

In order to corroborate the predicted results of the modified program for the prediction of the performance of the air classifier, it is recommended that an experimental model be fabricated and tested at several operating conditions. Also, additional samples of micro-pulverized lignite from different formations should be evaluated for ash distribution according to particle size fraction.

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APPENDIX 3

Paper Presented at the 6th International Coal Utilization Exhibition and Conference, Houston, TX, November 15-17, 1983.

1

"EVALUATION OF THE MICRÜPULVERIZATICN, DRYING AND BENEFICIATION OF LIGNITE"

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EVALUATION OF THE MICROPULVERIZATION, DRYING AND BENEFICIATION OF LIGNITE

by

C. W. Bouchillon, W. C. Steele, J. A. Clippard, and J. D. Burnett

INTRODUCTION

Lignite has been mined and utilized as a boiler fuel on a regional basis for several years, primarily in North Dakota and Texas. The major U. S. lignite deposits occur in the Fort Union Region (North Dakota and Montana) and the Gulf Region (Texas, Louisiana, Arkansas, Tennessee, Mississippi, and Alabama) (1,2). The Gulf Coast lignite resources have been estimated at thirty-five billion tons with the majority of this in Texas and Mississippi (3). Typical as-received analysis of Mississippi lignites is given in Table 1.

' The research reported here is from a cooperative program among the Mississippi Energy Research Center, Mississippi State University, the Mississippi Department of Energy and Transportation, the Mississippi Mineral Resources Institute, Mississippi Power and Light Company, and Ergon, Inc. The objective is to develop processes which will allow effective expansion of the use of lignite as an energy source. The three major areas of research under development are micropulverization, drying and benefication. Each of these three general processes has potential to improve lignite as a fuel.

The first area of this research program concerntrated on the micropulver ization of lignite in a fluid-energy pulverizing system. Tests have been conducted with various operating parameters for the pulverization system. The samples from these tests have been analyzed for particle size, ash content, and heating value. Preliminary results show that lignite can be pulverized successfully in a fluid-energy apparatus as the initial stage in the production of a microfine lignite fuel for boilers currently using oil or gas.

Related work on ultrafine pulverized coal (4,5) has shown that micropulverized coal (1007 less than 44 microns) will cause less slagging than conventional pulverized coal when used in an oil or gas boiler. Figure 1, similar to the illustration presented by Margulies, et.al. (4), illustrates the basic concept favoring micropulverization. Other work on slag reduction of Canadian lignites has been reported (6). The tubes in oil and gas boilers are generally spaced closer than those in conventional coal-fired boilers. Because of this increased tube surface to flow area ratio, the larger ash particles in conventional pulverized coal will impact the tubes and cause slagging. 'However, the very fine ash particles in the micropulverized coal or lignite tend to follow the flow streams around the tubes resulting in less slagging and erosion. These small particles can then be collected by a scrubber, a baghouse or a precipitator.

An oil or water slurry is one of the primary methods being considered for transport and end use of pulverized coal. With regular pulverized coal slurries, either the boiler must be modified to minimize fouling or the coal must be beneficiated to reduce the ash content. The coal slurry technology is progressing at a rapid rate and preliminary commercialization efforts are underway (7,8,9).

Work hnn been performed in Australia on tho uao of ultraflna brown coal to make a conl-o11 mixture to repince dicaci fuel for engines (10). Aino micropulverized xoal-oll mixtures made by Ergon, Inc. have been successfully burned with no significant ash deposits forming in the boiler (11).

The primary result of the pulverization tests reported here was that lignite with its high moisture content could be micropulverized. The fluid-energy mill used for micropulverization was described by Taylor (12). Basically, a ring of inward facing jets directed slightly off-center causes a vortex flow to be established and the particles grind or impact against each other to generate a lignite product with a mean diameter of 5 to 7 microns based on population and 15 to 25 microns based on volume.

The second area of research concentrated on the drying of lignite. The purpose of the drying tests was to investigate methods for permanently drying the lignite. Small samples of the micropulverized lignite can be dried relatively quickly in 110'C air; however, as soon as these samples are exposed to humid air or put in a water slurry they return to their original inherent moisture levels. This hydrophilic nature is common to most lignites.

The problem is to remove the moisture and at the same time change the lignite structure and chemistry so that the particles become hydrophobic. Work on steam and hot water drying processes that accomplish this permanent drying are described in detail (13, 14) for North Dakota lignites. The results of these studies show that If the lignite is heated to a temperature of about 310"C for 15 minutes, the inherent moisture reabsorbed will be only about 10 percent as compared with the 35 percent for the original lignite used in the studies. It was also found that temperatures greater than 310"C have only a small additional drying effect.

The third area of research concentrated on beneficiation or ash removal processes. With processes which have been used successfully in coal cleaning as a starting point for consideration, attention was given to gravimetric, agglomeration, particle size separation, and ion-exchange methods.

Comparison of the ash characteristics of various lignites was presented by White (15) and is presented in Table 2. The Gulf Coast lignites generally have a much higher silicate content and a significantly lower sodium content than the North Dakota lignites. This suggests that a mechanical separation may be more important than a chemical or ion-exchange process for the Gulf Coast lignites.

Previous work in gravimetric methods applied to mlcropulverlzcd coals Indicated that hydrocyclones may be effective for ash removal. The results are highly dependent upon the washability—or the ash distribution with specific gravity. Recent work by Keller and Simmons (16) indicates that for coals with good washability characteristics, that good cleaning of -325 mesh coal in a true heavy liquid medium of Freon—113 can be accomplished in a 2 inch cyclone with an 85 psi pressure drop. Washability studies (17) indicate that some Gulf region lignites do have reasonably good washability characteristics while some exhibit almost no ash content variation with specific gravity.

In an effort to reduce the sodium content of North Dakota lignites Paulson, ct.al. (18) have done extensive work in ion-exchange processes which result in a reduction in the sodium content of the ash--apparently the predominant ash component contributing to tube fouling problems in boilers.

MICROPULVERIZATION

The lignite used in these teats was obtained from n ncnm in Γηηοΐη County, Mississippi which is relatively close to the surface. The samples were stored in polyethylene bags in barrels prior to the pulverization studies at the Ergon laboratory.

Tests were performed with both as-mined and air-dried moisture levels and with various conditions of pulverizer operation. The air-drying consisted of cracking the lignite into large chunks and spreading it out in a sunlit area in an attempt to remove some of the surface moisture. The eight test runs are given in Table 3. Both steam and air were used as fluid-energy pulverization mediums and the pressure at the inlet nozzle to the fluid-energy mill was set at either 40 psi or 65 psi. The lignite was successfully micropulverized in all of the runs.

A proximate analysis was performed on some of the pulverized samples, and the moisture, ash, volatiles, fixed carbon, and heating value for these samples are given in Table 4. A significant result of the air driven micropulverization was the reduction in the moisture. It is our opinion that this was accomplished primarily by the significant increase in surface area caused by the micropulverization. This allowed much of the surface moisture and some of the inherent moisture to be removed by the heated (200'F) air driving fluid. Another significant observation is that the air predrying of the raw lignite had no effect on the moisture content of the samples studied. Additional tests are discussed later concerning lignite moisture reduction.

It is also of interest to note the reduction in ash content during the micropulverization process. The ash content was reduced by approximately 10 percent in the samples which were evaluated. This reduction is attributed to the very small particle size observed for some of the ash particles and the resultant blow-by of these fine particles in the separation apparatus of the laboratory micropulverization equipment. A venturi scrubber followed by an air cyclone separator was used for removal of the micropulverized particles from the air stream.

An optical microscope was used to observe, measure and photograph the micropulverized samples from both as-mined and alr-dryed pretreatment. Typical particles sizes for the hydrocarbon particles were 15-30 microns and 2-5 microns for the ash particles. Figure 2 is a photograph of the micropulverized lignite as taken with an optical microscope camera system. Similar results were observed with a scanning electron microscope except that more individual particle surface detail could be observed as is shown in Fig. 3. The apparent matrix of ash and carbon in the larger particles is seen in this picture.

Particle size analyses were conducted by PETC-DOE on a Bausch and Lomb automatic image analyzer and by Mississippi Power and Light Company on a HIAC particle analyzer. The results of the particle analysis done on the Bausch and Lomb automatic image analyzer as reported by Killmeyer (19) are presented in Fig. 4. For the two samples evaluated by PETC-DOE the arithmetic mean sizes on a number basis were 5.24 and 4.14 microns with geometric mean sizes on a weight basis of 22.54 and 14.79 microns respectively. These results are comparable with the optical microscope observations discussed above.

Typical results of the particle size analysis performed on the HIAC particle analyzer (20) showed that the mean particle sizes based on population ranged from 6.4 to 5.1 microns and the particle size based on volume ranged from 24.6 to 15.7 microns in the six test runs. These results are also comparable with the optical microscope evaluation and the automatic image analyzer results discussed above. The particle sizes observed for the samples taken suggest that micropulverization of Mississippi lignites can produce a resultant

particle size in a desirable range—even with the high moisture content in the as-mined material.'

DRYING

The current work was focused on the drying characteristics of Mississippi lignites. Preliminary work was conducted with air as the drying medium. The results of these tests are given in Table 5. The samples for the nir drying tests were taken from the 1982 micropulver f zed product. The equilibrium moisture values given in Table 5 are the moisture levels of the lignite after it has been exposed to a humid environment under a vacuum for 72 hours. This moisture level is representative of the final inherent moisture of the lignite.

As seen in the table, the air-dried lignite did undergo some permanent drying. However, the problem with air drying is the oxidization of the lignite. At a temperature of about 400*F in the natural draft oven, the lignite began to burn and the tests were discontinued.

As an alternative approach, a combined steam (or air) pulverization and drying process was investigated. These tests were conducted at Ergon's Vicksburg facility with their research pulverizing unit. The purpose of these tests was to determine the drying effectiveness for various operating conditions of the pulverizer.

The lignite for these tests was obtained from a test pit opened by MSU on land leased by Phillips Coal Company in Panola County, Mississippi. The lignite was from the Claiborne group and was beneath approximately 13 feet of overburden and the seam was approximately 6 feet thick.

The pulverlzlng/drylng tests consisted of steam pulverization at 250"F, 325'F, 400'F and 460°F (the maximum value that could be obtained). An air pulverization test was run at 250°F, but the lignite ignited at 325'F and the rest of the air tests were deleted. This result is consistent with the findings in the air drying tests in the natural convection oven.

The data for 'the combined pulverlzatlon/drylng tests are given in Table 5. These results are consistent with the previous work and show that the 460°F steam pulverization reduced the inherent moisture of the lignite from 40.9 percent to 14.1 percent. This result Indicates that the pulverized lignite product could be used to make a water slurry without unacceptable moisture reabsorption.

Analyses of the particle sizes for the pulverized product from the 250'F and 460'F steam ground lignite were made with Ergon's Coulter counter. The 250"F steam pulverized lignite had a mean diameter based on population of 4.5 microns and a mean diameter based on volume of 8.15 microns. The 460'F steam pulverized lignite had a mean number basis size of 3.8 microns and a mean volume-basis size of 7.4 microns.

Electron microscope pictures of the 460'F and the 250'F steam pulverized product are shown in Figs. 5 and 6. The product ground with the higher temperature steam has a much smoother, less porous surface. This is a significant factor in the difference in the equilibrium moisture for the two products as noted in Table 5.

BENEFICIATION

The first evaluation of the micropulverized samples included optical microscopic examination. A typical picture is shown in Fig. 2. This suggested that the smaller particles were probably silicates and the larger particles were mostly hydrocarbons.

Л hyd Гиcy ('.lotte (J" x 5) vuo tilit o Ined und modli lcd lor une ntt n irne heavy liquid medium device. Freon-113 was selected ns tbc fluid becnuse of Its low viscosity (^{s}0.6 cp) nnd high specific gravity (^{5}1.5). The modifications were made in an effort to provide significant flows to the underflow so as to carry out the smaller, heavier particles and allow the larger lighter particles to "float^{5}' out the overflow. The results of these tests were not successful—largely because of the poor washability characteristics of the particular lignite samples being used.

A gravimetric analysis of the samples was obtained. The results of gravimetric testing of the micropulverized lignite samples which were performed by PETC-DOE as reported by Killmeyer (19) are presented in Table 6. The following observations relative to the gravimetric data may be made. The difference in final cumulative weights and initial sample weights is attributable in part to the very small particles which passed through the filter paper and formed a sort of paste or film on the pan after evaporation of the heavy liquid as reported by Killmeyer (19).

One result of these tests which is surprising—yet significant—is the large concentration of ash which remains with the lighter fractions as shown in Table 6. If this result is because the ash is embedded within the particle material—even at this small size—then it will be difficult to provide significant beneficiation through gravimetric or inertial means. Conversely, if there are significant surface forces on the small sized ash particles which overcome the body forces of gravity or the inertial forces experienced in the centrifuge, then it may be possible to introduce some controlling surface force such as would occur with surfactants or electrostatics.

The pyritic sulfur is a small fraction (only about six percent) of the total sulfur and nearly all of that is contained in the particles with specific gravity greater than 1.8. In that the specific gravity of pyrite is approximately five, this result is not surprising.

The total sulfur content of the samples examined is *oí* the order of 0.5 percent which is encouraging from an applications point of view. As with the ash content, the total sulfur is evenly distributed throughout the gravimetric range for the samples tested.

Further evaluation in an electron microscope indicated that there are indeed very small particles of ash material embedded in the 20-25 micron particles as shown in Fig. 3. The lighter surfaces in the figure indicate a different characteristic of that surface—cither due to higher surface reflectivity or to a different plating characteristic. This corroborates the results of the gravimetric analyses.

A preliminary evaluation of the removal of metals by acid ion-exchange has been made. A 2 Normal sulfuric acid solution was used on several micropulverized samples. Preliminary results indicate that approximately 20 percent of the ash may be readily removed by this technique. Continuous processes—perhaps accelerated by electrolysis—may Improve these results.

SUMMARY AND FUTURE WORK

In summary, fluid energy micropulverization of lignite to a product with a mean diameter of about 5 microns on a population basis and about 8 to 25 microns on a volume basis was successfully accomplished. Some drying did accompany the air-driven micropulverization at moderate temperatures (^{2} 200'F), however, this did not affect the equilibrium moisture of the product.

Simultaneous mlcropulverlzntlon and permanent drying did result when steam at moderately high (> 400"F) temperature was used. This process resulted in a change in the particle surfaces from hydrophylic to hydrophobic with the resultant permanently reduced inherent moisture absorption characteristic. Gravimetric and visual observations indicated that the ash was somewhat uniformly distributed throughout the specific gravity ranges, thereby making beneficiation by mechanical means very difficult.

Based on information gained to date, further work is planned in all three of the major areas of micropulverization, drying and beneficiation. Continued developments on improved designs for the fluid energy micropulverizer are planned in order to further optimize the operational efficiency of the process.

Further work will continue on the drying techniques which produce permanent equilibrium moisture reduction. These'will include combined micropulverization and drying processes as well as other continuous drying processes.

Additional studies planned for the beneficiation processes include further evaluation of the ash distribution relative to particle size distribution for possible air classification techniques. Further work will also be done on ion-exchange methods to remove the organically bound metal ash content.

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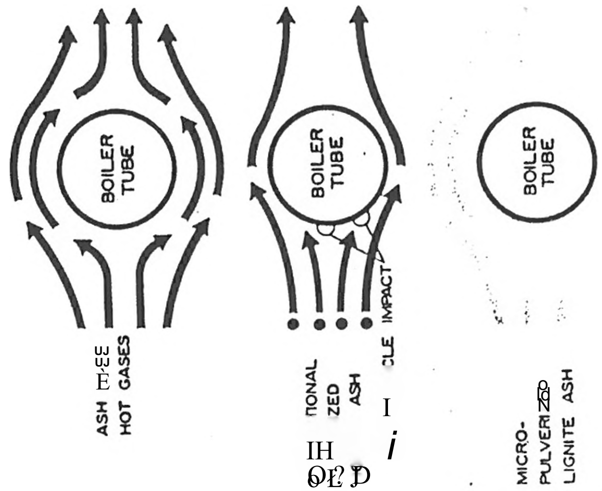

Figure 1. COMPARISON OF GAS STREAMLINES AND ASH TRAJECTORIES WHEN FIRING CONVENTIONAL VS. MICROPULVERIZED LIGNITE

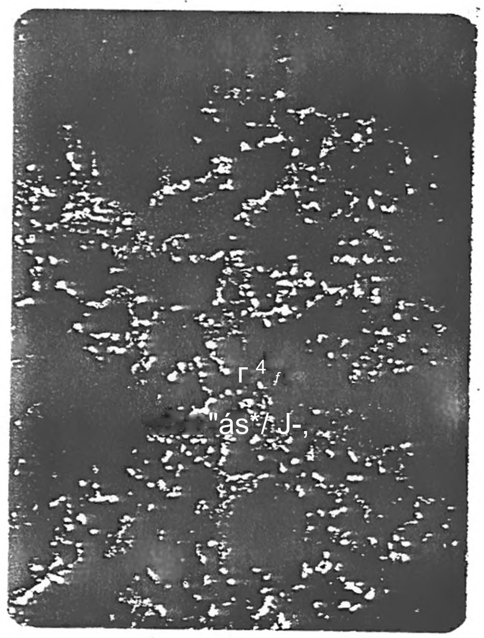

Figure 2. Micropulverized Lignite

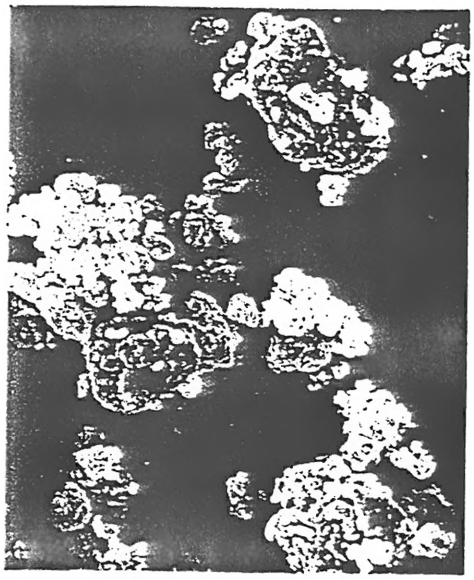

Figure 3. Scanning Electron Microscope View of Micropulverized Lignite

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305

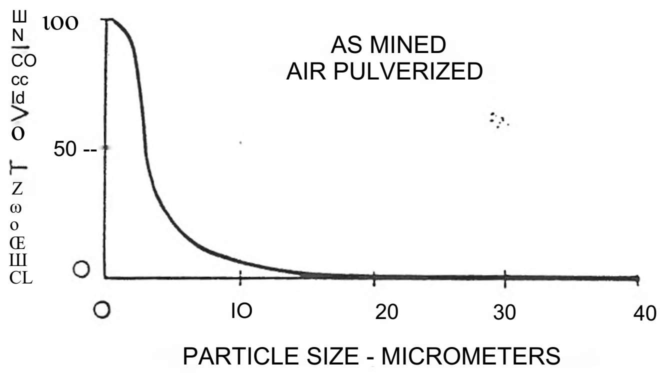
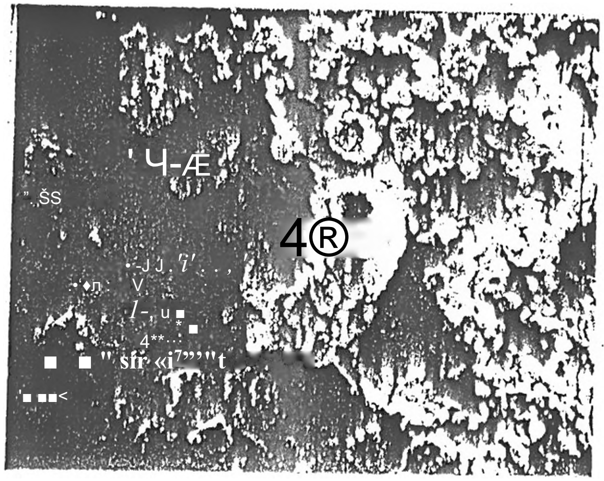
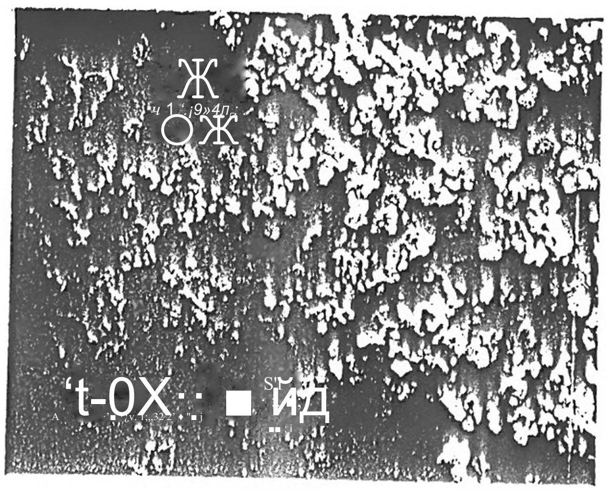


Figure 4. Results of the Bausch and Lomb Particle Size Analysis on a Population Basis for a Sample of Mississippi Lignite

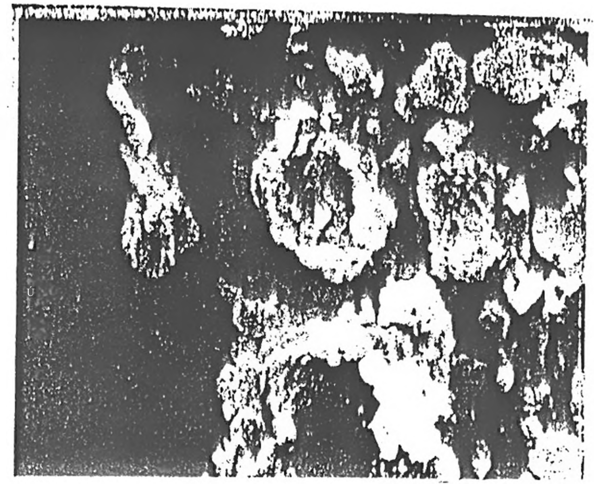


a. 25O°F Steam Dried

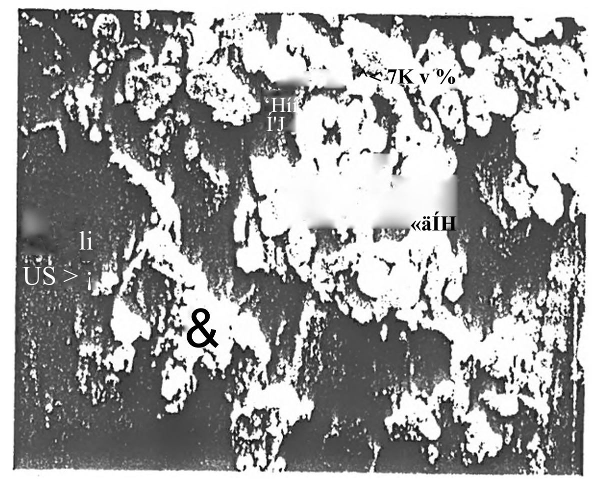


b. 660'F Steam Dried

Figure 5. Electron Microscope Pictures (2000 x)
of Micropulverized/Drled Lignite



a. 250°F Steam Dried



b. 460°F Steam Dried

Figure 6. Electron Microscope Pictures (5000 x)
of Micropulverized/Drled Lignite

TABLE 1

Typical As-Received Analysée of Mississippi Lignites (3)

	North Wilcox	South Wilcox	Claiborne
Moisture, Z	44.0	43.0	42.0
Ash, Z	12.0	12.0	14.0
Volatile Matter, Z	25.0	24.0	30.0
Fixed Carbon, Z	19.0	21.0	14.0
Sulfur, Z	0.5	1.2	0.5
Higher Heating Value, Btu/lbm	5396.0	5509.0	5585.0

TABLE 2

Comparison of Ash Characteristics for Mississippi, Texas, and North Dakota Lignites and an Eastern Bituminous Coal (15)

	Mississippi Claiborne	Texas Wilcox	Texas Claiborne	North Dakota	Eastern Bituminous
SiO_2	54.1	44.5	53.6	19.7	40.0
Al_2O_3	17.0	11.4	15.0	11.1	24.0
Fe_2O_3	6.9	7.4	6.6	9.1	16.8
TiO_2	1.0	1.1	0.8	0.4	1.3
P_2O_5	0.1	0.1	0.1	0.3	0.1
CaO	9.6	13.7	9.9	24.6	5.8
MgO	2.0	2.6	1.8	6.9	2.0
Na_2O	0.3	0.6	1.2	6.5	0.8
K_2O	0.5	0.6	1.2.	0.4	2.4
SO_3	6.9	10.9	8.9	19.5	5.3
Ash Fusion Tempera ture (Softening)	2,340	2,280	2,200	2,290	2,250
Hardgrove Grindability .	101	52	n.a.	35-70	55
Base/Acid Ratio	0.27	0.44	0.30	1.53	0.43

TABLE 3

Lignite Sample Description

Run ID#	Sample #	Sample Location	Feedstock Condition	Grind Medium	Nozzle psi	Pulverizer Temp (avg)	Moisture %	Ash %
1	82-123	Feedstock	as-mined	air	40	200°F	43.70	13.04
	82-126	Cyclone					30.44	13.36
	82-127	Tank					33.33	13.97
2	82-135	Cyclone	air-dried	air	40	200°F	31.32	12.04
	82-137	Feedstock					45.59	11.02
3	82-141	Feedstock	as-mined	steam	40	277°F	44.99	9.38
	82-143	Tank 1					14.44	17.80
4	82-157	Tank 2	air-dried	steam	40	221°F	17.69	15.08
	82-159	Feedstock					46.71	9.51
5	82-161	Tank 2	as-mined	air	65	200°F	28.57	14.12
	82-162	Feedstock					43.95	10.77
6	82-152	Tank 2	air-dried	air	65	200°F	20.15	20.84
	82-153	Feedstock					40.68	15.08
7	82-148	Tank 1	as-mined	steam	65	224°F	56.63	6.87
	82-149	Feedstock					46.63	10.70
8	82-146	Tank 1	air-dried	steam	65	218°F	65.91	8.06
	82-155	Feedstock					33.25	12.12

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TABLE 4

Results of Study of Micropulverization of Mississippi Lignite

Sample Number	82-124	82-136	82-125	82-135
Description	As-rained	Air-dried	As-mined, air-pulverized	Air-dried, air-pulverized
As-received basis:				
Moisture, X	42.9	44.0	29.5	26.6
Ash, X	13.1	12.1	13.7	13.8
Volatiles, X	30.6	28.1	37.2	37.8
Fixed Carbon, X	13.4	15.8	19.5	21.8
Higher heating value, Btu/lbm	5300	4966	7452	7561
Dry basis:				
Ash, X	22.9	21.6	19.4	18.8
Volatiles, X	53.6	50.2	52.8	51.5
Fixed Carbon, X	23.5	28.2	27.8	29.7

TABLE 5

Resulte from Drying Tests for Lignite Samples

Lignite Condition	Moisture (weight %)	Equilibrium Moisture (weight %)	As-Received Higher Heating Value (Btu/lbm)	Dry-Basis Higher Heating Value (Btu/lbm)
as-mined (P[illegible]la Co., 1983)	44.2	40.3	5080	[illegible]
micropulverized (1982)	28.6	29.8	6790	9510
air-dried at 250°F	5.8	18.8	8950	9500
air-dried at 300°F	3.0	16.8	9320	9610
air-dried at 350°F	2.4	15.2	9310	9550
ground (pulverizer feedstock)	42.5	40.9	5330	9260
steam dried/pulverized at 250°F	22.8	18.1	7130	9340
steam dried/pulverized at 325°F	8.5	14.4	8400	9180
steam dried/pulverized at 400°F	3.8	14.4	8890	9240
steam dried/pulverized at 460°F	2.7	14.1	9180	9430
air dried/pulverized at 250°F	3.4	16.0	9310	9640

TABLE 6

Micropulverized Mississippi Lignite Centrifuged Float-sink Results

Specific Gravity	Weight, Grams	Weight, X	Ash, X	Pyrltic Sulfur, X	Total Sulfur, X
Sample 03 (Starting Weight 202 g)					
1.30 FL	16	8.5	13.8	.03	.64
1.30 x 1.40	32	17.2	14.9	.01	.51
1.40 x 1.60	116	61.4	17.6	.01	.45
1.60 x 1.80	17	8.9	23.5	.01	.45
1.80 SK	8	4.0	59.3	.49	.54
	189	100.0	19.0	.03	.52
Sample 04 (Starting Weight 199 g)					
1.30 FL	6	3.7	11.7	.02	.39
1.30 x 1.40	30	18.6	13.5	.01	.44
1.40 x 1.60	92	56.4	16.4	.02	.48
1.60 x 1.80	29	17.4	23.9	.01	.35
1.80 SK	6	3.9	61.3	.39	.67
	163	100.0	18.7	.03	.45

NOTE: Particles that escaped through the filters after float-sink testing were left on the pan as a film after evaporation of the heavy liquid. This material was not recoverable.

As reported by R. Killmeyer of DOE-PETC, January, 1983.

Summary Report

Beneficiation and Drying of Mississippi Lignite

Performed under
METB Contract No. 83-250-255

Submitted by

C. W. Bouchillon
W. G. Steele

Mechanical and Nuclear Engineering Department
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November 1984

ABSTRACT

This report summarizes the research on lignite that was performed at Mississippi State University for the Mississippi Department of Energy and Transportation during the period August 1983 to August 1984. The work was concentrated in the three areas of lignite drying, ash removal, and test facility instrumentation.

The drying effort was directed toward the evaluation of the permanent drying effect of combined micropulverization and drying of lignite in a fluid-energy mill. A new concept called hot-water drying was also investigated. Both techniques showed a significant permanent drying in the lignite product.

The ash removal effort was directed toward identifying the processes available for beneficiation of lignite. The two primary areas investigated were an air classification technique and an electrostatic separation apparatus. Little ash removal was accomplished with the lignite used because the ash is distributed as superfine particles throughout the lignite structure. However, these techniques may be very useful for other lignite formations.

The test facility instrumentation effort concentrated on developing a data measurement system for the fluid-energy mill. Such a system is needed so that more accurate data related to lignite fuel processing costs can be determined. This system will be used on future tests with the fluid-energy mill.

INTRODUCTION

The Mississippi lignite research program has been a cooperative effort among several state and private agencies including the Mississippi Department of Energy and Transportation (MDET), the Mississippi Mineral Resources Institute (MMRI), Mississippi State University(MSU), Ergon, Inc., and Mississippi Power and Light Co. (MP&L) . The overall goal of the project is to develop an economically competitive fuel from lignite that can be used as a retrofit fuel for existing boilers at power plants, industries, and large institutions. Since most of these units in Mississippi operate on natural gas, the lignite fuel needs to be one which can be used in a gas (or oil) designed boiler without major capital modifications.

Previous research work has shown that if coal is ground to an ultrafine powder prior to burning, then the resulting flame is quite similar to an oil or gas flame and the ash particles from the coal are so small that they do not cause significant slagging of the heat transfer surfaces in the boiler (References 1 and 2). Therefore to retrofit such a fuel into an existing plant, basically only new burners and a bag house type exhaust cleanup system are required (References 3 and 4).

The first phase of the MSU lignite program conducted during 1982 concentrated on the ultrafine pulverization of Mississippi lignite in a fluid-energy pulverizing system owned and operated by Ergon, Inc. This system had been used previously to micropulverize coals and cokes. Since lignite has much more moisture and ash in the as-mined condition than higher grade coals have, it was not clear initially whether it could be pulverized in this system However, it was found that it would break easily even in its as-mined, high moisture state. The results of these tests showed that lignite could be successfully pulverized in such an apparatus as the initial stage in the production of a microfine fuel (Reference 5).

Phase two of the project has concentrated on the beneficiation of the lignite or the increase in the heating vlaue through moisture and ash reduction. In order for lignite to be a viable fuel, its heating value must be increased from the as-mined value of about 5500 BTU/lb to 8,000 to 10,000 BTU/lb. This can be accomplished through a permanent reduction in the water content in the fuel and/or a reduction in the nonburnable impurities.

During 1983, the drying efforts concentrated on ways to permanently reduce the moisture content in the micropulverized lignite. Raw lignite has a moisture content of about forty-five percent by mass, but this water can be easily driven off by heating the material in an oven at 105°C for thirty minutes to an hour. However, as soon as this dried lignite is exposed to humidity or to water (as in a slurry), the moisture is quickly reabsorbed back to the original level.

It has been found that when lignite is dried at higher temperatures, some permanent drying takes place. The efforts at MSU have dealt with quantifying this effect. Initial tests with air drying were successful, but the temperatures that could be attained were limited by the ignition of the lignite. Other tests included combined micropulverization/steam drying in the Ergon pulverizer. These tests were conducted at various temperatures up to 240°C and a significant permanent drying effect was found (Reference 6). These results have been compared with similar results for conventional pulverized lignite that were obtained at the Grand Forks Energy Technology Center. The significant difference is that a permanent drying occurs at a much lower temperature with micropulverized lignite than it does with conventional lignite.

These comparisons have cont nued into 1984 along with a new hot water drying effort. By heating a lignite water slurry to a high temperature, under high pressure, the permanent drying effect can potentially be improved with a reduced overall energy input. The equipment for these tests has been assembled, and testing was begun in August 1984.

The beneficiation efforts related to ash reduction have concentrated on the removal of the superfine particles (<5 microns) from the micropulverized lignite. These fine particles appear to be primarily ash. During the pulverization studies in 1982, an air classifier on the exhaust of the system allowed some of these very small particles to escape. A measurement of the ash content in the raw lignite and in the micropulverized product showed a ten percent ash reduction. This apparently resulted from the ash being blown out with the pulverizing fluid (air or steam).

Further investigation of the pulverized lignite with an optical microscope showed that the smaller particles appeared to be ash while the larger (>25 micron) particles appeared to be lignite with fine ash particles distributed throughout them. Therefore, only a partial ash reduction is possible by physical means.

During 1983, the ash removal efforts were directed toward heavy medium hyddrocyclone particle separation and toward chemical ash reduction. Bench tests showed that sulfuric acid would remove up to 20 percent of the ash from the lignite; however, significant cleanup procedures would be required for a full scale commercial operation based on this technique. The chemical cleaning work has been postponed while other, physical means are being investigated.

The heavy medium hydrocyclone studies used Freon 11 3 as the working fluid since it has a specific gravity between ash and lignite. The theory of the hydrocyclone is that the less dense lignite particles will leave with one flow stream and the more dense ash particles will leave with the other flow stream. However, this process was unsuccessful since the larger, lignite particles also contained ash causing too small of a difference in density with particle size.

The 198Д ash reduction studies have concentrated on the apparent size difference between the ash and lignite particles. Both electrostatic and aerodynamic particle classification techniques are being studied. The electrostatic separation theory is based on the probable charge difference on the ash and lignite particles caused by the grinding process in the pulverizer. Therefore a coupled pulverization, electrostatic cleaning process might be feasible.

The aerodynamic separation work is based on the observed ash reduction during the 1982 pulverization tests. Analytical work on this area is in progress and a bench test has been designed and fabricated.

The tasks identified for this contract were divided into three categories: (1) lignite drying, (2) lignite ash reduction or beneficiation, and (3) test facility design and instrumentation. These areas are described in the following sections along with a summary of the proposals prepared and trips conducted by the principal investigators.

DRYING

Combined Micropulverization/Drying with Steam and Air

The purpose of the drying tests was to investigate methods of permanently drying the lignite. Small samples of the micropulverized lignite can be dried relatively quickly in 110°C air; however as soon as these samples are exposed to humid air or put in a water slurry they return to their original moisture levels. This hydrophilic nature is common to most lignites.

The problem is to remove the moisture and at the same time alter the lignite structure and chemistry so that the particles become hydrophobic. Work on steam and hot water drying processes that accomplish this permanent drying are ongoing at Grand Forks Energy Technology Center (GFETC) in Grand Forks, North Dakota (References 7 and 8). The results of these tests show that -40 mesh lignite dried for 15 minutes at 340°C has an inherent moisture of 10 percent compared to 35 percent for the original lignite. Some of the theories on why the moisture reduction takes place are decomposition of carboxilic acid groups, surface modifications which reduce the ability of the coal to bind water, and excess moisture being forced out of the pores.

As an alternative to air drying lignite, a combined steam (or air) pulverization and drying process was investigated. The pulverizer operates on the principal of colliding small coal particles into each other, thus causing a grinding action to take place between particles. This grinding is induced by forcing steam or air through a ring of nozzles turned in such a way as to produce a vortex flow field carrying the particles of coal. The pulverizer is designed so that the smaller particles can exit from the unit out of the top where they can be collected.

The lignite for these tests was obtained from a test pit opened by MSU on land leased by Phillips Coal Company in Panola County, Mississippi. The lignite was beneath approximately 13 feet of overburden. The seam was approximately 6 feet thick.

The pulverizer/drying tests consisted of steam pulverization at temperatures of 250°F, 325°F, ^OO°P and ^60°F (the maximum steam temperature available for the unit). Air pulverization tests were run at 250°F and 325°F, however at 325°F the lignite began to ignite therefore data is only available for the 250°F runs. Particle size analyses were conducted on both the 250°F and 460°F steam ground samples at Ergon. The results of these analyses show that the mean particle size for the 250°F sample is 8.15 microns based on volume and 4.5 microns based on population and for the ^60°F sample 7.Д microns based on volume and 3.8 microns based on population.

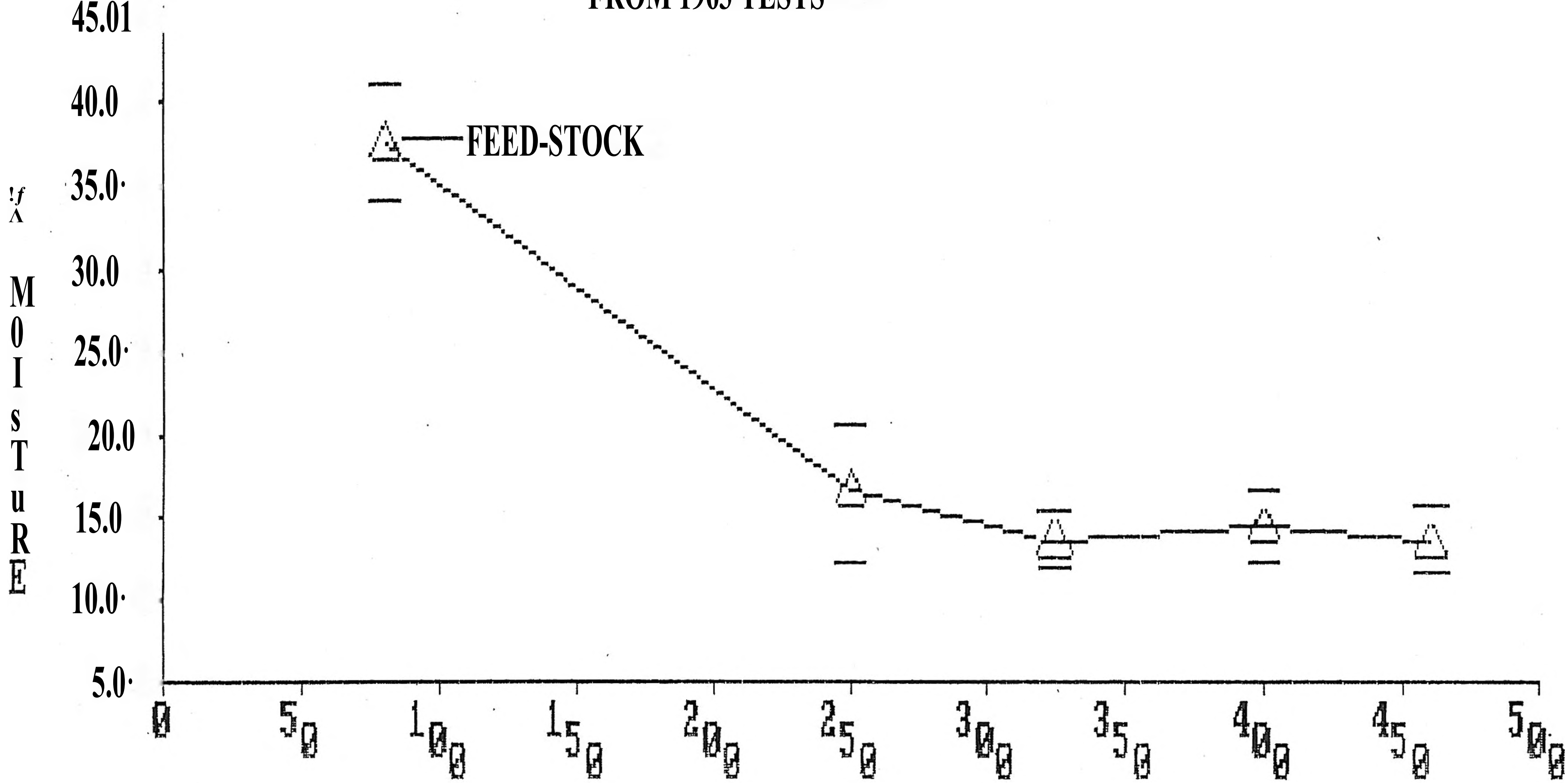
The data for the combined pulverization/drying tests are given in Table 1. the equilibrium moisture value given represents the inherent moisture that would be present in the lignite after it is mixed with water in a slurry. These data are also presented in graphical form (Figures 1-5). Each graph is shown with bands giving the scatter in the results. From Figure 1 it is seen that the majority of the equilibrium moisture reduction occurs at or before the 250°F point. After the 250°F point there appears to be little change in moisture. Figure 2 shows that the ash decreases somewhat with increasing steam temperature. Figure 3 shows that the heating value tends to increase

TABLE 1. Results of Combined Pulverizing/Drying Tests

Sample Type	Dry-Basis Proximate % Volatile Matter	? Ash	% Fixed Carbon	Dry-Basis Heating Value (BTU/lb)	% Equilibrium Moisture
As-Mined	47.2	27.4	25.4	9375.	37.5
Feed-Stock	46.8	26.6	26.5	8928.	37.7
250°F A.G.	47.6	25.5	26.9	9370.	15.7
250°F S.G.	46.6	26.4	27.0	9115.	16.7
325°F S.G.	46.9	26.4	26.7	9192.	13.5
400°F S.G.	45.5	26.2	28.3	9186.	14.6
460°F S.G.	45.8	25.9	28.4	9331 .	13.7

S.G. = Steam Ground
A.G. = Air Ground
Volatile matter, ash, fixed carbon, and equilibrium moisture are based on a weight percentage.

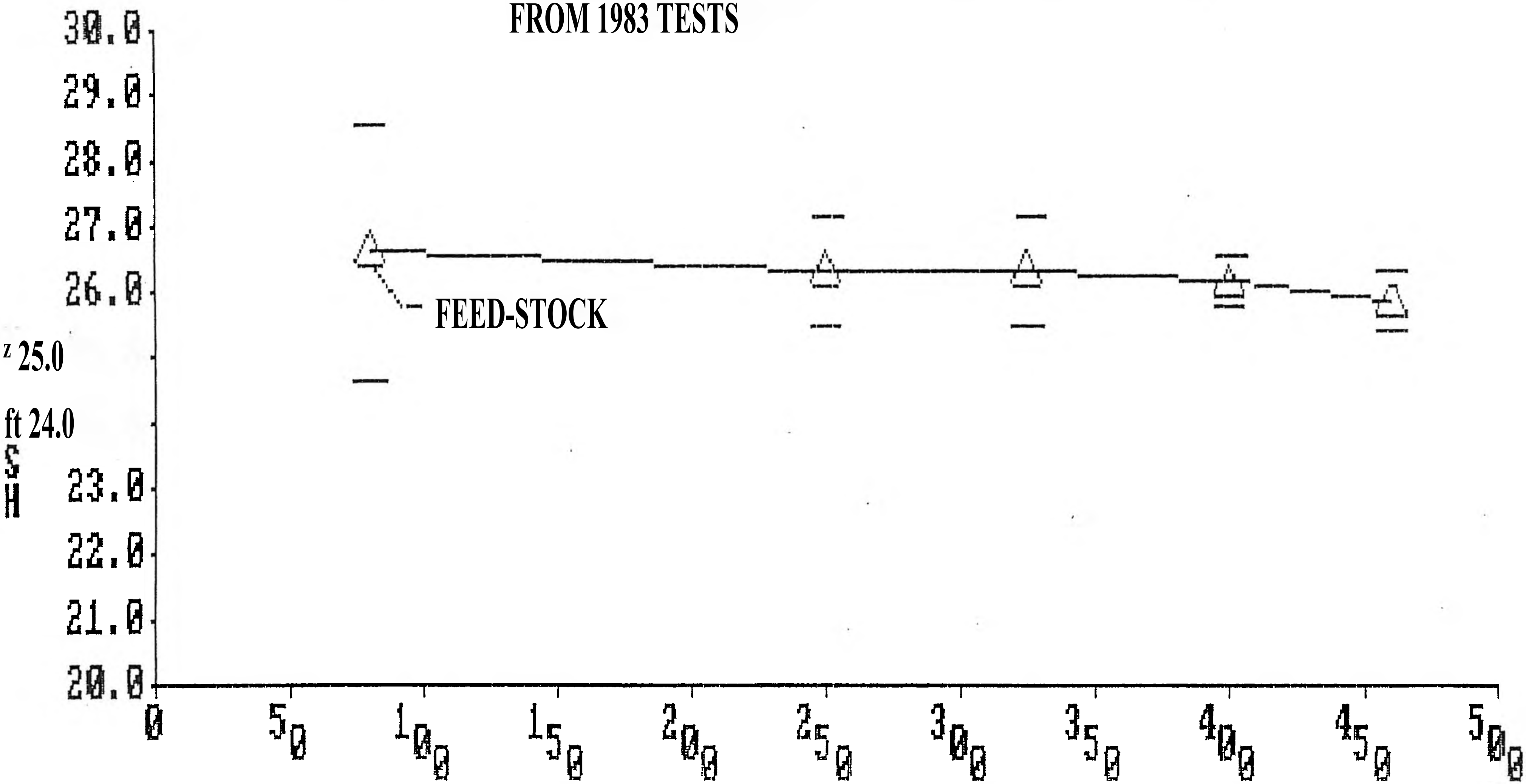
FIGURE 1 EQUILIBRIUM MOISTURE US. TEMPERATURE FROM 1963 TESTS



STEAM PROCESS TEMPERATURE (F)

A MEAN УШЕ, “ША UNCERTAINTY BAND

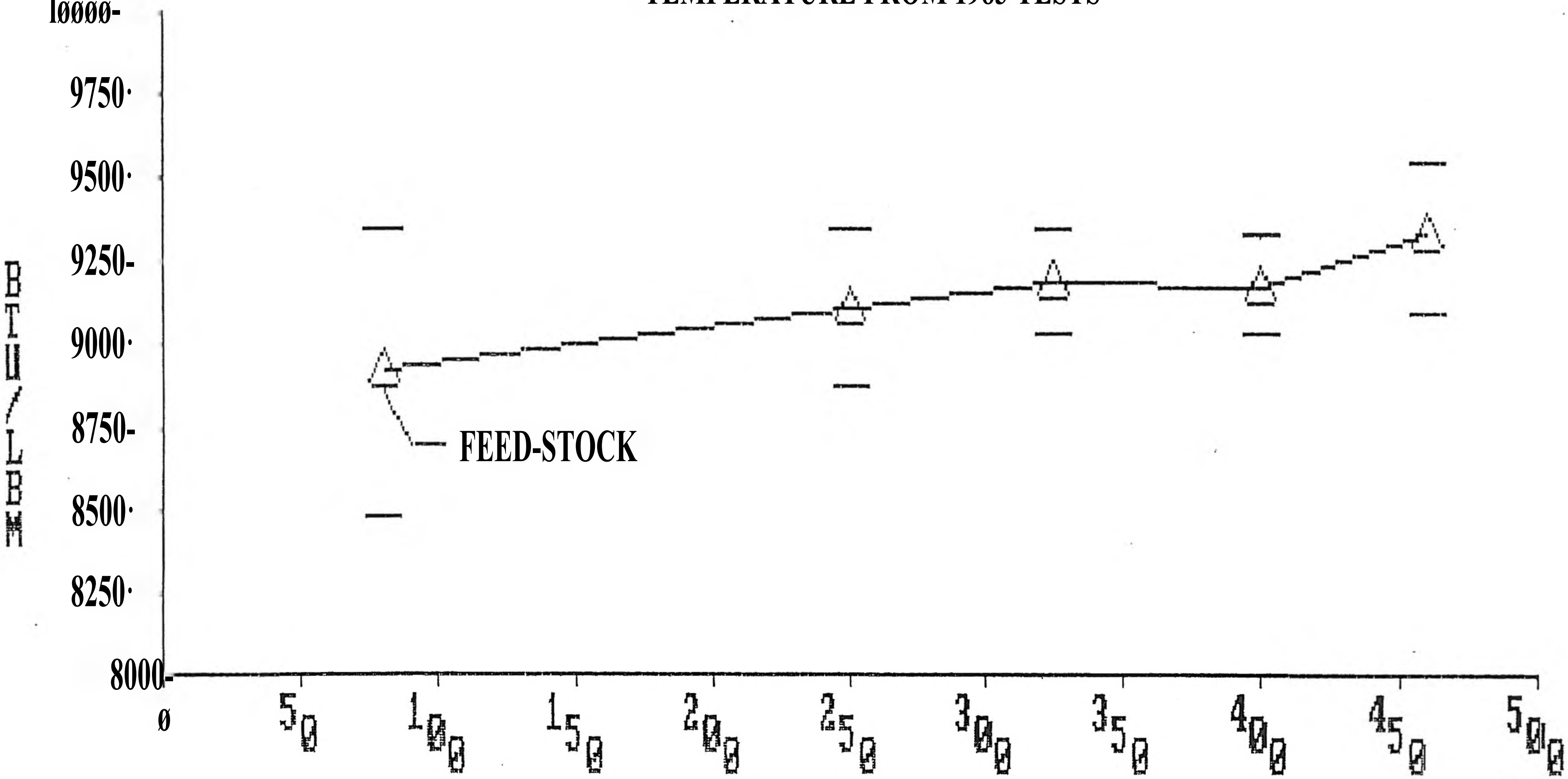
FIGURE 2 DRY BfiSIS ASH VS. TEMPERATURE
FROM 1983 TESTS



STEAM PROCESS TEMPERATURE (F)
Δ MEAN VALUE, - DATA UNCERTAINTY BAND

FIGURE 3

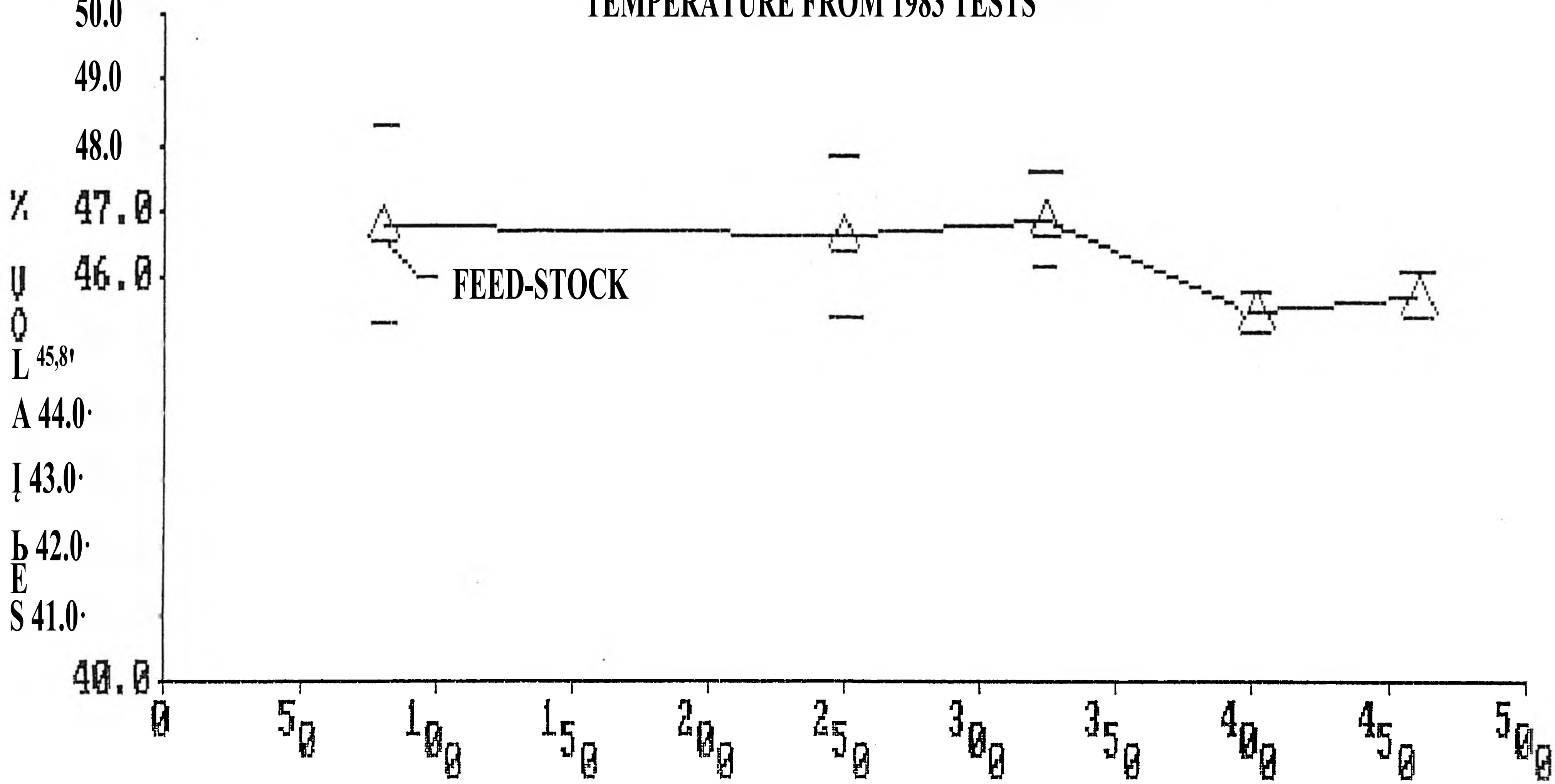
DRV BASIS HEATING VALUE US.
TEMPERATURE FROM 1983 TESTS



STEAM PROCESS TEMPERATURE (F)

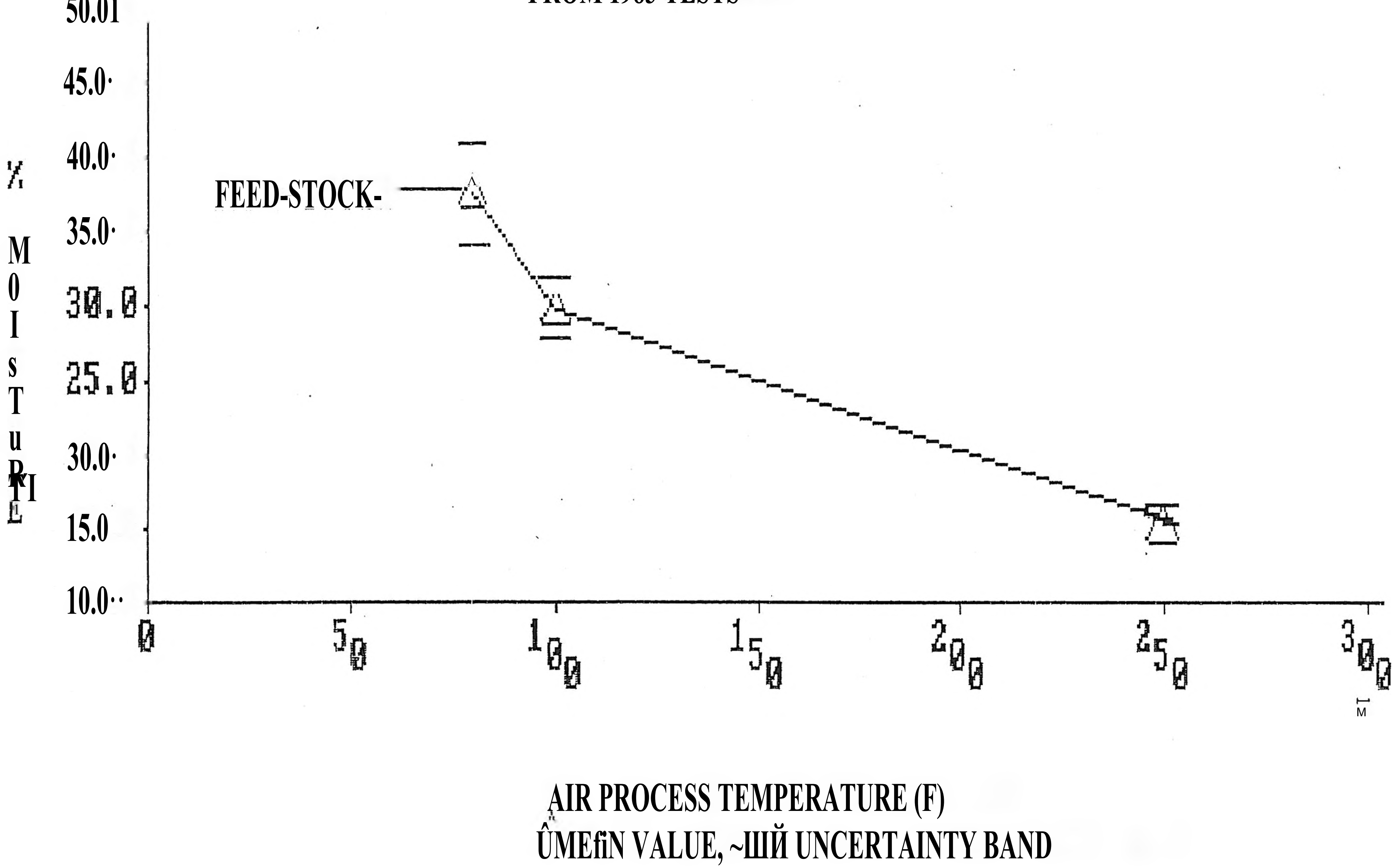
ûMEAN VALUE,—DATA UNCERTAINTY BAND

FIGURE 4 DRV BASIS VOLATILE HAПEB US.
TEMPERATURE FROM 1983 TESTS



STEAM PROCESS TEMPERATURE (F)
ü MEAN VALUE ," DATA UNCERTAINTV BAND

FIGURE 5 EQUILIBRIUM MOISTURE VS. TEMPERATURE FROM 1983 TESTS



with pulverizer temeprature particularly at temperatures above 400°F which is probably caused by the decrease in ash content. From Figure 4 it is seen that the volatile matter remains essentially constant until the 400°F and 460°F points where there is a slight decrease. Figure 5 shows the equilibrium moisture decrease with air pulverizing temperature. The 100°F point on Figure 5 was obtained with ambient air as the pulverizing medium.

The significant difference between these test results and those at the GFETC is that a permanent moisture content of about 15 percent was obtained at a drying temperature of 300°F while temperatures above 500°F were required in the North Dakota tests to reach this same moisture level. The lignite in these tests was -325 mesh as compared to the -40 mesh lignite used at GFETC.

Hot-Water Drying

Hot-water drying is a process for the removal of liquid water from high-moisture coal by heating a coal-water slurry under pressure. The lignite used in these tests was obtained from the same test pit in Panola county as mentioned earlier. The lignite was pulverized at Ergon with ambient air as the working medium.

A slurry is produced with the pulverized lignite by adding distilled water to the coal and agitating. A 150 mi slurry is then poured into a 300 ml autoclave which is then heated to a specified temperature for a set period of time.

Preliminary results of hot-water drying are shown in Table 2. It should be noted that these test results are initial runs without replication, therefore, multiple samples must be analyzed before the results can be used. The results indicate a singificant decrease in both ash and equilibrium moisture and an increase in heating value.

The significance of this equilibrium moisture reduction is in the feasibility of using the lignite in a water slurry as an oil-like fuel. Consider the 460°F steam ground lignite for example. If enough water is added to this product to make a slurry of 40$ water, 60% water-saturated lignite, then the total water content in the slurry will be 40$ plus (0.137) times 60$ or 48.2$. The resulting slurry will have a heating valaue of 4832 BTU/lbm, or a value very close to the heating value of the raw lignite. However, the form of the fuel has now been changed to an oil-like mixture that can be retrofit into existing boilers.

Further reduction in the equilibrium moisture or increased solids loading of the slurry will of course raise this heating value. This is illustrated by the hot-water dried lignite data in Table 2. If a 40$ water, 60$ water-saturated lignite slurry is made from the 600°F dried product, then the slurry heating value will be 6886 BTU/lbm. This is very close to the slurry-fuel heating values that can be obtained with bituminous coal.

These preliminary data indicate that there is a good possibility for using lignite as a retrofit boiler fuel. The air or steam ground lignite has an as-received moisture content, of 2$ to 5$ giving it a heating value before slurrying of about 9500 BTU/lbm. One area for further research is the possibility of using this micropulverized

TABLE 2. Results of Hot-Water Drying Tests

Sample Type ?	Dry-Basis Proximate Volatile Matter	% Ash	% Fixed Carbon	Dry-Basis Heating Value (BTU/lb)	% Equilibrium Moisture
100°F A.G.	52.3	2-4.0	23.7	10203.	30.0
283°F H.W.D.	52.0	21 .3	26.7	10464 .	25.6
600°F H.W.D.	50.0	18.5	31 .5	11973.	^.2

A.G. = Air Ground
H.W.D. = Hot Water Dried
Volatile matter, ash, fixed carbon, and equilibrium moisture are based on a weight percentage.

product as a "dry" rather than a slurry fuel. The moisture reabsorption characteristics of this product in standard atmospheric conditions needs to be determined. Also the methods for transport, safe storage, and burning of this dry fuel need to be investigated.

The hot-water drying technique appears to be the best method for generating a high heating value slurry. Limited work is continuing in this area with support from MSU and MMRI. Additional support is needed to continue a comprehensive study in the lignite drying and fuel preparation areas

Fuel Cost

Assistance has been obtained from Ergon, Inc. and Phillips Coal Co. in the estimation of a cost for a micropulver ized lignite fuel Phillips Coal Co. (Reference 9) has projected a mine mouth cost of their Antioch Project lignite (near Batesville, MS) of $1.39 per million BTU for 100,000 to 399,000 tons per year. Ergon, Inc. (Reference 10) has projected micropulverizing costs of $1.25 to $1.50 per million BTU. If slurrying costs of about $0.50 per million BTU and transportation costs of $0.25 per million BTU are also considered, then the cost of the lignite fuel delivered to the boile-· is approximately $3-6^ per million BTU.

This cost is competitive with current natural gas costs of $3.00 to $5.00 per million BTU and fuel oil costs of $^.00 to $6.00 per million BTU (Reference 11) This cost is also competitive with bituminous coal slurries. Such coal can be delivered to Mississippi power plants at $2.00 to $2.50 per million BTU. If a micropuvlverizing/slurrying plant is located at the power plant then the final fuel cost would be about $^.50 per million BTU. Thus lignite and bituminous coal slurries are comparable in cost.

Another consideration in a coal based fuel is the ash content. The lignite has a dry basis ash of 20$ to 26$ and the bituminous coal has a dry basis ash of 9$ to 12$. Considering the differences in the heating values of the two coals, a lignite fueled plant will have about three times as much ash to dispose of as a bituminous coal based plant However, if a use can be found for this ash then this problem might be alleviated. Research is being conducted in the Civil Engineering Department at MSU on the use of lignite ash as a lining material for chemical waste disposal.

It should be stressed that the above discussion on fuel costs is based on several assumptions. However, it does show that a lignite based fuel is not out of line with other hydrocarbon fuels.

The current DOE sponsored research at MSU will have as one of the results a better determination of the cost of the micropulverizing/drying of the lignite. These data can then be used to better predict the cost of a lignite retrofit boiler fuel.

BENEFICIATION

Review of Processes for Fine Coal Cleaning

Physical processes which have been successful in the cleaning of fine bituminous coals include oil agglommeration, heavy media cyclones, micro-bubble flotation, electrostatic separation, and air classification. The fine coals used were of such a nature that they exhibited good washability characteristics—that is the ash rich fraction was separable by gravimetric methods. Ash reduction via ion-exchange methods has also been successful on some low rank coals with low silicate contents. Hydrochloric acid or other ion-exchange materials were used to cause the more active metal ions to be removed from the coal/ash matrix.

One of the physical methods was studied during this effort. Because of the apparent ash rich fraction in the smaller particles of micropulverized Mississippi lignite as observed in optical microscope pictures, an air classification technique was examined.

Analytical Modeling of a Beneficiation Processes

The analysis of a continuous air classifier which is essentially a modified air cyclone was undertaken in considerable detail. Additional support for this activity was obtained from the MMRI funded Graduate Research Assistant and the MSU funded Graduate Student Research UNIVAC Computer usage. A description of the analysis is presented as Appendix 1 .

A batch air classifier was also designed and fabricated for future use on the lignite research project. A sketch of this apparatus is presented as Figure 6. It operates on the principle of higher particle drag due to interference with the flow in the fluidization region. This allows the smaller particles to be blown upward into a separation zone where the larger particles then fall back into the mixture. The smaller particles then continue out the outlet and are captured in a filter bag.

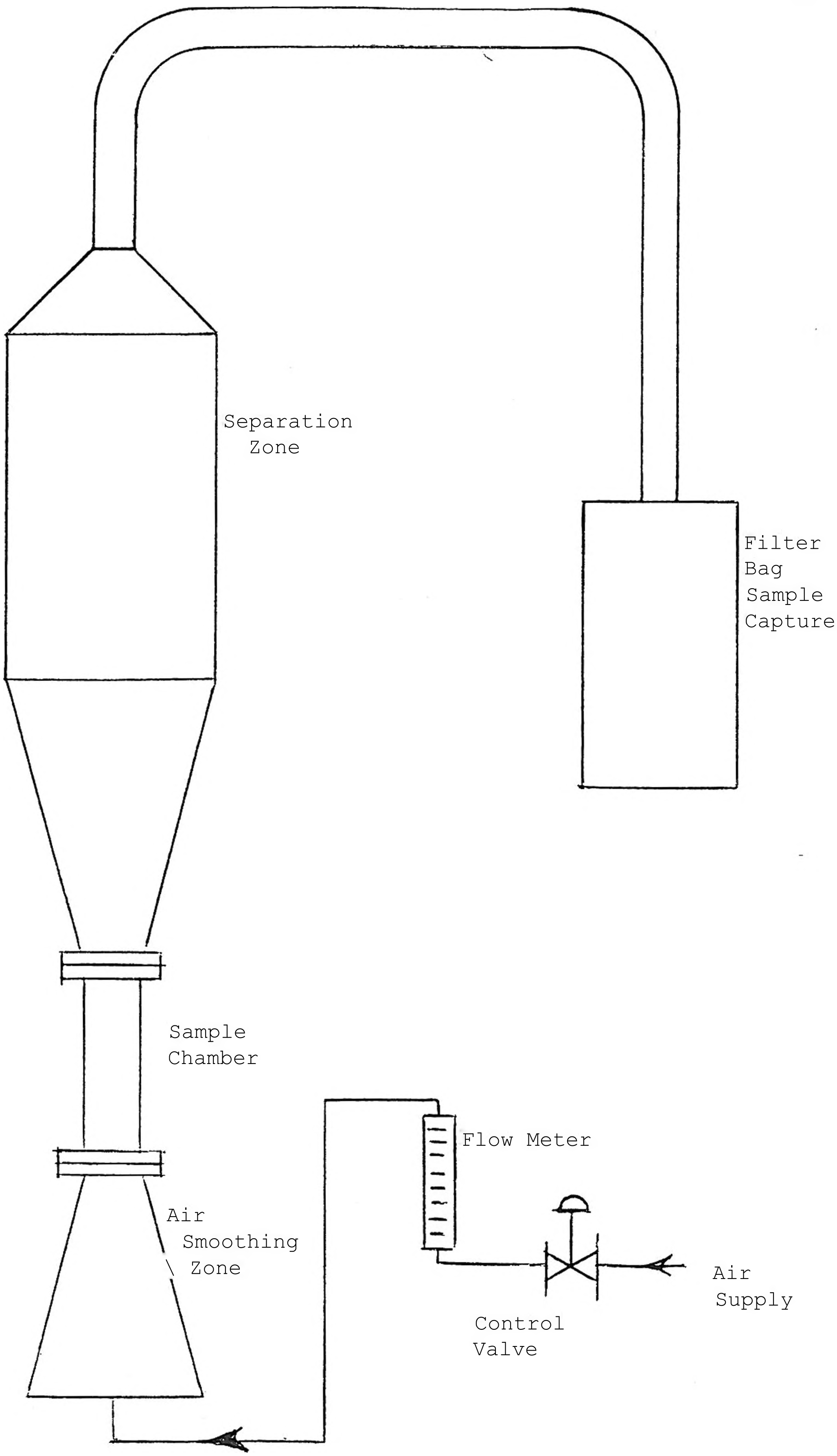


Figure 6. Schematic Sketch of Air Classifier.

Experimental Evaluation of Air Classification Beneficiation of Micropulverized Low Rank Coal

An experimental evaluation of air classification separation of the micropulverized Mississippi lignite from the Claiborne formation was also made. The results of this effort are given in Table 3.

The ash content of the larger aerodynamic diameter particles was higher than for the original total micropulverized sample. This may be explained by the observation that some of the very fine ash particles were removed in the micropulverization/collection process. An air cyclone was used in the collection from the micropulverizer. The ash content of the larger particles suggests that the mean mass particle size would have to be reduced greatly in order to afford air classification ash particle removal for this type of lignite.

Although only one sample was evaluated, the air classification method does not apepar promising for this lignite. Other deposits may have different characteristics and this method should be evaluated for use with other deposits.

Design and Fabrication of a Continuous Beneficiation Process

The second process considered was the electrostatic separation process which would be an ideal process to combine with the Ergon micropulverizer. The particles will experience triboelectrification—or changing due to friction—in the micropulverizer and thus will be prepared for separation in flow in a strong electric field.

TABLE 3. Results of Air Classification Tests

Sample No.	Aerodynamic Size (microns)	Volitiles $ Dry Basis	Ash 55 Basis	Heating Value Dry Basis Dry BTU/lbm
101-0	Original	50.5	20.8	9,389
1 01 —D	>11 .3	53.6	21 .1	8,945
1 01-F	>30.7	48.4	23.9	9,146
101-AM*	N/A	49.6	22.8	9,639

* As mined.

A preliminary system design has been made and some of the necessary equipment has been obtained for a laboratory scale proof of concept experiment. It is expected that a proposal will be submitted to USDOE-GFNDPO for further work on this process.

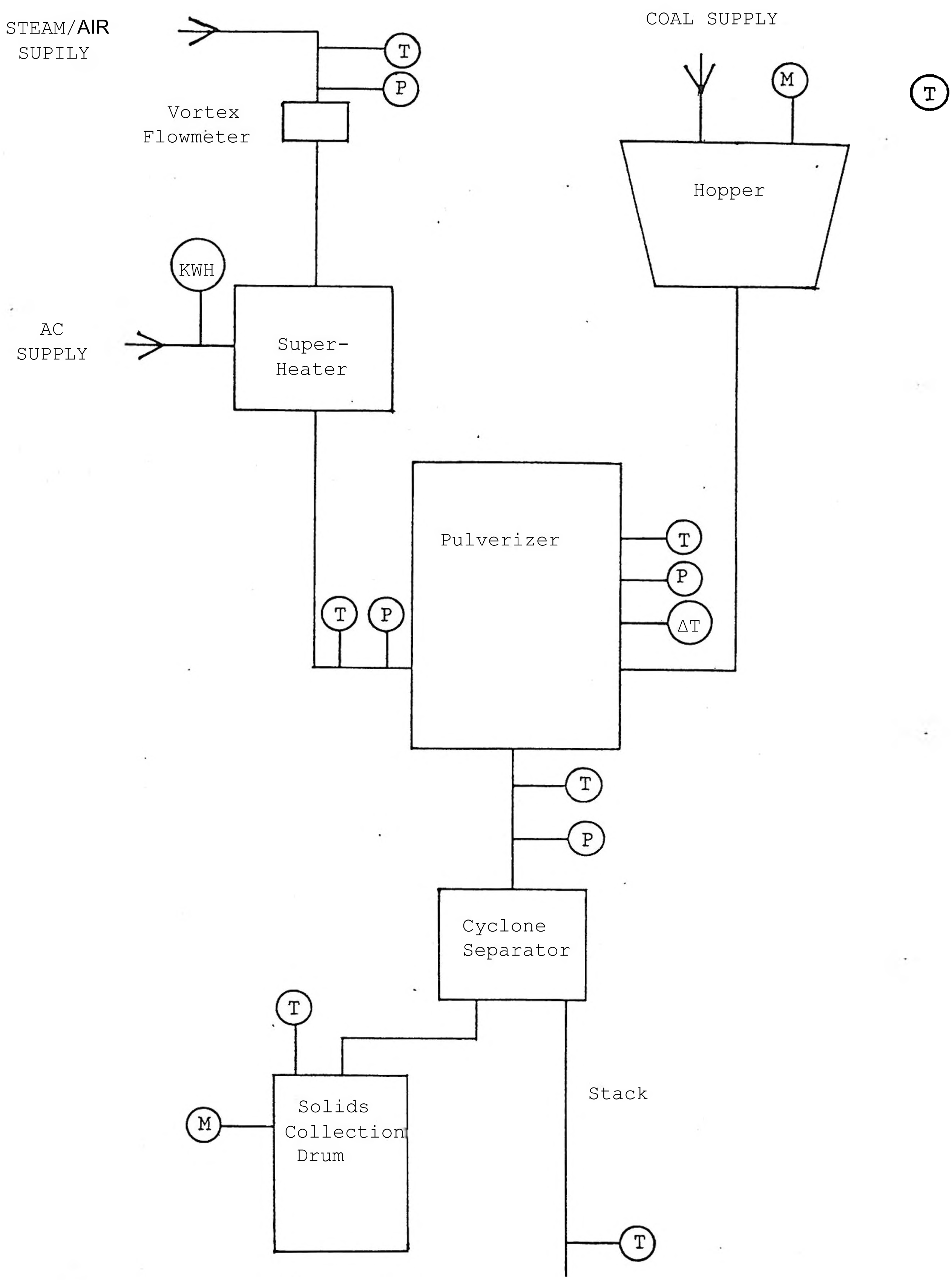
TEST FACILITY AND INSTRUMENTATION

Ergon's facilities in Vicksburg, MS are being used for the micropulverization of the lignite. They have a 100 pound per hour research unit which is ideally suited for the current effort. This unit is a fluid-energy mill which can be operated with either air or steam. The combined micropulverization/drying tests were conducted in this unit with superheated steam as the grinding fluid.

One of the key questions in the total cost of a lignite fuel is the cost increment for grinding and drying in the fluid-energy mill. An instrumentation plan has been developed for the pulverizer which can be used on future runs in orer to determine the energy requirements (and thus costs) for the pulverizing process. The flow chart and instrumentation locations are shown in Figure 7.

These data will be taken during the current DOE sponsored test. This should provide information for a better estimate of micropulverized lignite fuel costs.

Figure 7. Test Flow Chart and Instrumentation Locations



TRIPS AND PROPOSALS SUBMITTED

Trips

Bouchillon visited the Combustion Engineering, Inc. Laboratories at Windsor, Connecticut to review the design of their facilities for pulverized coal combustion research. He also visited the Massachusetts Institute of Technology to review a research project on the comminution of coal.

Steele attended the Sixth International Symposium on Coal Slurry Combustion and Technology in Orlando, FL. At this meeting the state-of-the-art technology in coal-water slurry preparation, testing, usage and economics was reviewed.

Proposals Submitted

The following proposals were submitted by the project personnel during the contract period:

MMRI - "Processes for Improving Lignite as a Fuel" (Graduate Student Funding)- $16,000.

MDET - "Continuation of Developmental Activities Related to the Use of Lignite as a Boiler Fuel" - $51,116.

USDOE - Grand Forks Project Office - "Ultrafine Grinding of Low Rank Coals" - $266 142.

USDOE - Grand Forks Project Office - "Preparation and Analysis of Low-Rank Coals for Combustion Applications" - $288,103.

USDOE - Pittsburgh Energy Technology Center - "Improving the Prediction of Solids Transport in Slurries" - $101,946.

The Grand Fork Project Office of the USDOE requested our assistance in preparing a revised five year plan for low-rank coals research. The list of topics submitted is included in Appendix 2.

CONCLUSIONS

The work performed under this contract was directed toward producing a transportable fuel from Mississippi lignite that could be retrofitted into existing boilers. The results from the drying and ash removal studies show that such a concept is feasible and is probably cost competitive with existing fuels.

The studies described in this report are the initial efforts toward producing a dry, reduced ash lignite fuel. These efforts need to be extended and quantified to provide the necessary data base for long range planning. Once the basic processes for producing a high grade lignite fuel are understood, then the next steps will be process optimization and scale-up to a commercial plant size.

The MSU lignite effort has been supported by the MDET and other state agencies and companies. This support has allowed us to develop data bases in certain areas so that we can be competitive for long range DOE research funding. The current contract on "Ultrafine Grinding of Low-Rank Coals" is an example. However, these contracts only provide funds to do a specific task. State or other funding is still needed to carry on the parallel tasks of hot-water drying, ash removal, slurry preparation, combustion and process evaluation. The principal investigators are actively seeking this support for the MSU lignite research program.

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10. Hartness, L. J., personal communication.

11. , "Energy User News," Vol. 8, No. 23, Monday, June 6, 1983.

APPENDIX 1

Analysis of an Air Classifier for Micropulverized Lignite

A. Analysis and Design of an Air Classifier

A computer analysis of the performance of an air cyclone has been generated by F. Boysen, et. al. of Sheffield University in England. A copy of this program has been obtained and made operational on the MSU owned UNIVAC computer. The computer program has been modified to represent an air classifier in which there is a peripheral slit in the lower cone of a conventional air cyclone through which auxiliary air is admitted in varying amounts. A sketch is shown in Figure A-1. This modification results in a system which can be operated so as to remove different size particles.

The air cyclone or air classifier is based on the principle of centrifugal forces in comparison with drag forces to provide for larger particle removal out the lower cone or for smaller particles to be carried through with the outlet air stream.

The centrifugal force is related to the mass of the particle. Buoyancy forces are present in the air cyclone; however, due to the large differences in density of the particles and to air, the buoyancy force may be neglected. Using a spherical shape as an approximation for the shape of the micronized lignite particles of interest, then the centrifugal force is proportional to the density times the radius cubed.

The drag force is related to the projected cross sectional area of the particle and a coefficient of drag. If the spherical shape approximation is used, then the drag force is proportional to the

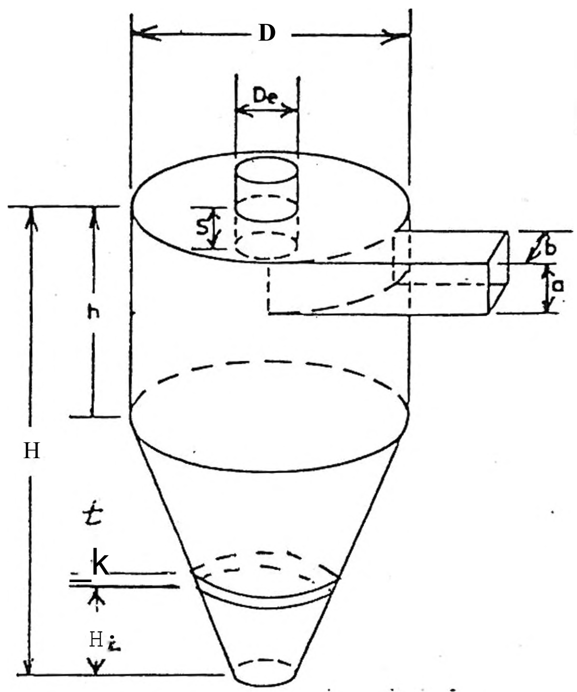

Figure A-l. Cyclone Geometry

coefficient of drag times the radius squared. If the flow is such that the particle Reynolds number in the cyclone or classifier is less than one, then the particle is said to be in the Stokes flow regime where the drag coefficient is proportional to the inverse of the radius of the particle.

Considering the ratio of the centrifugal to drag forces on a particle, then the ratio is proportional to the density times the radius squared. The density range on the micronized lignite particles is approximately 1.2 - 1.5, or a factor of 1.25 to one. The radius variation is from about 1 to 20 microns or a factor of 20 to one. Thus, it is anticiapted that the air classification of the micropulverized lignite particles would be principally a particle size related phenomenon.

Based on this preliminary analysis and the observation of optical microscope pictures of the micropulverized lignite particles which showed an apparent ash particle as the smaller particles and an apparent hydrocarbon paricle as the larger particles, it was expected that an air classification system would separate out the smaller particles, thus reducing the ash content of the micropulverized lignite.

B. The Computer Program

The computer program simulates the fluid flow and particle motion in axially symmetric confined turbulent vortex flows with special emphasis on cyclone separators. The mathematical model on which the computer program is based consists of the fundamental equations of the conservation of mass and momentum. The turbulence is modelled by approximate transport equations for the pair correlations of the fluctuating velocity components. This enables the prediction of 3 velocity components for the fluid pressure and 7 turbulence quantities.

The particle trajectories are predicted by solving the equations of motion of solid particles of various sizes. The particle trajectory predictions then allow predictions of particle residence times and particle density in the fluid.

The cyclone geometry is specified based on the typical design variables depicted in Figure A-1. These are the barrel height, the total height with the lower cone, the overall diameter, the diameter of the exit, the distance which the exit tube extends into the barrel, and the height and width of the rectangular inlet. It is assumed that the fluid density and laminar viscosity values are constant and are known inputs to the program.

A modification to the original program has been executed which allows for admission of additional or supplemental air through a circumferential slit in the lower cone as shown in Figure A-1. This provides for a variable operating characteristic air classifier with a constant air/particle volume input. Additional computations are required to assure appropriate solutions with the supplemental air flow. Limited funding for variations of design have limited the amount of calculations which could be executed under this project for this modification.

A sample output for the base case of the classically designed hydrocyclone is presented as Figure A-2. For a final design

```
ODATA.L FILE12.
DATA "9 RI S L7 ZT9 07/Y 5/84 "20 :"34 : 38 ~ (1 )
                                                        <------- OJLAFL------->
                                                           1... 20 +..00C
           13
                                                        ------------ I --------
^FLOWRATE:        1.67+000 M3/S --->                             I        I
SWIRL VEL. 1.12+001 M/S                                 ----  |  1        I
                                                              |
                                                              I     <---->
  - HEIGHTS     :                                             |   4.91 -OOT M
  TOTAL         :      4.25+000 M                             |
  VORTEX FINDER :      8.77-001 .M                            |
  INLET DUCT    :      6.3 SHDJD 1 M                          |^
  CONICAL SECT  :      2.44+000 M                             \
                                                               \     4.91-001 M /
  ************************                                      \  <---->  /
  * PRES SUR E NDROP     *                                        \      /
  *  3.55+003>N7M2 :*
  ************************

  NO. OF ITERATIONS     =  751

END DATA ETRO R ST"N"O"RE  TIME:   0.537 SEC.      ZMATE COUNT: 27
```

```
3 DATA.L FILE12.
DATA 9R1 SL74T9 C6/09/84 12:52:09 (1)

YCLR SCORE IS 108.0 OUT OF 3CG TRIES
   OVERALL EFFICIENCY          =    36.CC Z
T R-I ES^SO^EAR   :      TOCT

EFFICIENCIES ^F INDIVIDUAL SIZE RANGES              :
-------------------------------------------------------

DIAM (MICRONS)       EFFICIENCY (PERCENT)     NO. MISSED

   2.00                    3.33                   0
   4.89                    6.90                   1
   7.78                   16.67                   6
  10.67                   29.63                   3
  13.56                   36.67                   0
  16.44                   40.0C                   0
  19.33                   43.33                   0
  22.22                   50.0C                   0
  25.11                   62.?                    1
  28.00                   80.00                   0
END DATA. ERFCRS: NONETTI ME  :  0.533 SEC. IMAGE COUNT: 21
```

Figure A-2. Computer Program Base Case Output configuration, it may be possible to design a particular air cyclone without the benefit of the air classification supplemental air slit in the lower cone.

C. Conclusions and Recommendations

If micropulverized lignite has the appropriate properties of a very fine ash particle size which is distributed among relatively larger particles which are principally hydrocarbon, then successful beneficiation of the micropulverized lignite would be expected through the use of an air classifier which is used to separate out the smaller ash rich fraction.

The computer program which simulates the flow in an air cyclone or air classifier with supplemental air circumferential slit should provide design information much more economically than would be required for a strictly experimental development program. The computer program does require significant amounts of computer time and consequently does require substantial expenditures for each case studied; however, it is expeted that it would lead to more efficient designs more rapidly and economically than with the experimental trial and error approach.

In order to corroborate the predicted results of the modified program for the prediction of the performance of the air classifier, it is recommended that an experimental model be fabricated and tested at several operating conditions. Also, additional samples of micropulverized lignite from different formations should be evaluated for ash distribution according to particle size fraction.

APPENDIX 2

SUGGESTED RESEARCH TOPICS FOR LOW RANK COAL PROGRAM

1 . MICROPULVERIZATION

1.1. Process Evaluation

The evaluation of the fluid energy mill micropulverization technology is currently being investigated under an existing contract which will extend for thirty months. The energy requirements, scale up designs, product characteristics, and possible improvement suggestions will be evaluated.

1.2. Detailed Process Analysis

The evaluation of the detailed process of fluid energy mill communition of low rank coal (LRC) should reveal details of operation which could lead to design changes which could result in more efficient operations. For example, if numerical simulation of the jet mixing could be accomplished, particle acceleration, particle impacts, or in improved feeding conditions. This project would be a high level theoretical approach with some experimental observations in supersonic wind tunnels.

1.3. Detailed Communition Studies for LRC

The evaluation of the mechanism of communition of LRC should reveal techniques which could be used to more efficiently reduce the size of the particles. Classical engineering mechanics approaches to materials failure such as fracture mechanics could be applied. This would yield a means of predicting the minimum energy requirements for coinmunition of LRC.

1.4. Combined Steam Micropulverization/Drying

Combined steam micropulverization/drying is being evaluated to a limited extent in the current contract with HSU. A more detailed evaluation of the effect of particle sizes on the drying phenomenon should be undertaken. A theoretical model of the thermal energy transport processes should be made.

1.5. Combined Air Micropulverization/Drying

Combined air micropulverization/drying is being evaluated to a very limited extent in the current contract with MSU. A more detailed evaluation of the effect of particle sizes on the drying phenomenon should be undertaken. A theoretical model of the thermal energy transport processes should be made. This is very closely related to the combined steam micropulverization/drying process. Autoignition limits the level to which the temperature of the process may be carried.

1.6. Combined Stack Gas Micropulverization/Drying

Combined stack gas micropulverization/drying may be accomplished by using a steam turbine driven gas compressor to provide compressed stack gas at a reduced oxidant level which could be used to carry the drying process further than with air by the use of higher temperatures without autoignition in the micropulverizer. This system would have the added advantage of not requiring treated water from the main boiler for the working fluid as does the current steam micropulverization/drying process. A preliminary analysis of the process should precede the experimental program.

2. HOT WATER DRYING/BENEFICIATION

2.1. Hot Water Drying

Hot water drying of LRC is currently being evaluated both at UND and MSU. The effects of micropulverization on the hot water drying process should be evaluated further. Preliminary results indicate that much lower residence times are required for permanent drying effects with the micropulverized particle sizes. The potential for sodium removal with the micropulverized particles Should also be evaluated.

2.2. Hot Water Drying/Washing

The concept of hot water drying/washing of LRC should be evaluated. It is well known that the hot water drying can effect a removal of much of the sodium in LRC. Washing processes added after micropulverization and hot water drying should be evaluated to determine the effectiveness of sodium removal.

2.3. Dewatering Techniques for Micropulverized LRC

Dewatering techniques for micropulverized coal should be evaluated so that minimum energy levels are required for slurry thickening, drying for direct firing, or other processes. Because of the small particle sizes involved in micropulverization, it is expected that there will be difficulty in the use of classical processes such as vacuum filtering.. A surface tension separation process which has been developed for the paper industry has potential for use in dewatering of the micropulverized LRC.

3. ELECTROSTATIC SEPARATION (ESS) OF ASH FROM LRC

3.1. Triboelectrification ESS of LRC

Particles which experience rubbing or collisions experience triboelectrification (or develop differential electrical charges) due to the physical transfer of electrons from one particle to another. This phenomena is responsible for lightening in nature. Some preliminary work has been done in this area using a full stream laminar flow test section. The concept of using a convergent channel design to provide for stable flow at somewhat higher Reynolds numbers would allow the charged plates to be placed closer together, thus yielding a higher electrostatic field strength while limiting the necessary lateral distance which the particle should travel. This process should be evaluated both analytically and experimentally.

3.2. Combined Micropulverization with ESS

The nature of the fluid energy micropulverization mill is such that the particles should experience triboelectrification while being micropulverized because of the many collisions involved in the flow in the mill. If the electrostatic separation apparatus were applied at the exit of the micropulverizer, then the separation process should proceed with limited additional required equipment and energy for additional mixing. An experimental evaluation of the ESS combined with the fluid energy mill should be made.

3.3. Whole Stream Separation with Triboelectrification

Further evaluation of the whole stream .design suggested by the Canadians should be made with flow from the micropulverizer providing the triboelectrification of the particles.

3.4. Corona Discharge Charging with ESS

The classical use of corona discharge for the differential charging of the ash/coal particles should be evaluated. The use of an inert gas such as flue gas or supplied nitrogen would eieminate explosion hazards which would be anticipated with the potentially explosive stream of micropulverized LRC dust.

4. OTHER BENEFICIATION METHODS

4.1. Micro-bubble Flotation

Although the classical large bubble froth flotation techniques have not proven successful in fine coal separation, it may be possible to provide for micro-bubbles which could effect an appropriate separation of ash from the LRC. Experiments should be conducted with fluid energy micropulverized LRC using this method to ascertain if it could be successfully employed. Large scale micro-bubble generation is practiced in oxygenation systems in the paper pulp industry.

4.2. Oil Agglomeration

Classical oil agglomoration techniques have proven successful in the removal of ash from fine coals. These techniques should be examined for use with the micropulverized LRC.

^.3- Heavy Media Cyclones

True heavy media fluids such as Freon-113 have proven successful for fine coal cleaning when small cyclones and high pressure drops are used. These systems should be used to evaluate the effectiveness in ash removal in micropulverized LRC, especially with the steam dried system.

5. SLURRYING OF LRC

5.1. Preparation of Slurries of LRC

Preparation of slurries of micropulverized/dried LRC using various additives should be undertaken.

5.2. Determination of Flow Characteristics

An experimental flow loop should be used in addition to the immediate evaluation of the rheological properties of the slurries of the LRC after micropulverization, beneficiation and drying.

5.3. Determineation of Stability of Slurries of Micropulverized LRC

Experimental evaluation of the stability of slurries of various treatments of LRC should be made.

6. TRANSPORT OF TREATED LRC

6.1. Transport of Treated LRC in Dry Form

Several methods of transport of micropulverized/beneficiated/.dried LRC are available for consideration but require some experimental evaluation. Typical trucks or tank cars presently used for cement transport could be used provided that the product is sufficiently dry for this method. Dense phase pneumatic transport by pipeline may also be appropriate and should be evaluated further with the use of several gases.

6.2. Transport of Treated LRC in Slurry Form

The evaluation of the slurrying of the treated LRC should provide basic information for the design of pipeline transport of the slurried LRC. Tank trucks and railroad tank cars would also be viable means of transport and should be evaluated. The effects of vibration in transit on the stability of the slurries should be evaluated.

7. BURNING STUDIES OF TREATED LRC

7.1. Burning Studies of Slurried Treated LRC

The burning of slurried treated LRC may provide some different considerations for the final design of combustion chambers because of such factors as high residual ash content, small ash particle size, slurry particle size on exit from the burn nozzle or atomizer, nozzle wear, or other factors. Experimental evaluation of the treated LRC slurries should be made relative to these questions.

7.2. Burning Studies of Dry Treated LRC

The burning of the dry treated LRC may also provide some different considerations for the final design of combustion chambers because of some of the same factors mentioned above. Pneumatic conveyance into the furnace should be readily accomplished, however, experimental evaluation of the dry treated LRC samples should be made.

7.3. Burning Studies of Direct Fired Steam/LRC

Direct firing of the steam micropulverized LRC may be possible and desirable for some of the LRC with low sodium and sulfur content. Experiments have been conducted with direct fired steam/micropulverized coal in a conventional utility scale boiler with some success.

7.4. Slagging Studies with Micropulverized LRC

Several studies indicate that classical slagging problems typically experienced with LRC which is burned by conventional pulverization methods may not be present with micropulverized LRC because of the small ash particle sizes and the lack of fusion on the boiler tubes. Evaluation of the combustion and slagging characteristics of LRC should be made for micropulverized treated LRC.

8. COMBINED PROCESSES AND OPTIMIZATION

8.1. Mine Mouth treatment with Dirty Burner

In the event that fuel transport is economically viable with a treated LRC product, it may be appropriate to use the waste stream which would be high in ash content as the source of energy for the treatment proc-ess. In all cases, the thermal energy regenerative techniques should be employed optimally. Thus, a study of the various processes should be organized into an optimum configuration for mine mouth treatment and appropriate transport. This may mandate a dirty burner such as a slagging combustor to provide the energy necessary for mine mouth treatment.

8.2. Combined Micropulverization/Drying/Beneficiation of LRC for Product in Dry Form

The combined processes of fluid energy micropulverization, steam drying, and electrostatic separation would be an example of the types of combined treatment processes which should be evaluated. This should follow the evaluation of each of the processes in detail.

8.3. Combined Micropulverization/Hot Water Drying/Beneficiation of LRC for Slurry Preparation

The combined processes of fluid energy micropulverization, hot water drying, and micro-bubble flotation would be an example of treatments which would yield a liquid or slurry product. These processes should be evaluated in combination.