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FULL SCALE COAL PREPARATION RESEARCH ON HIGH SULFUR IOWA COAL

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February 1, 1978

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IS-ICP-53

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Abstract. A 63.5 metric tons per hour (70 TPH) demonstration coal preparation plant was constructed on the Iowa State University campus, Ames, Iowa, as a part of the Iowa Coal Project funded by the state of Iowa and administered through the Energy and Minerals Resources Research Institute. Processing equipment in the plant circuit includes a heavy media separator, concentration tables, separating and dewatering screens, and conveying equipment. Coal samples of size 907 metric tons (1000 tons) with sulfur contents ranging from 2.5 to 8.75% sulfur from seven mines in the state of Iowa have been processed in the plant. Sulfur reductions have averaged 35% with ash reduction averaging 45%. Equipment for advanced fine coal beneficiation research is currently being installed in the plant to include a slurry pretreatment circuit, froth flotation, oil agglomeration, pelletization, hydrocyclones, advanced design thickener and disc filtration.

I. Background

The Iowa Coal Project was funded by the Iowa Legislature for $3 million over a three year period beginning in May of 1974. The major thrust of the project was to research Iowa coal and determine courses of action that could make the State of Iowa more energy self-sufficient through greater use of its own reserves. The state has considerable coal reserves and up until the 1940's had supported an active coal industry. However, the development of Iowa coal involves two major obstacles: (1) it exists under some of the world's richest farm land and (2) it is high in sulfur content. Realizing these problems, the two major goals of the Iowa Coal Project were formulated:

1. To establish methods for surface mining of Iowa coal with return of land to the same or better productive use and to demonstrate these methods on a sufficiently large scale to permit reasonable estimates of their cost.
2. To establish methods of refining Iowa coal so that is can be burned in conformance with environmental standards and to demonstrate these methods on a sufficiently large scale to permit reasonable estimates of their cost.

In addition, significant research work was accomplished under the following secondary or supporting goals:

1. To characterize Iowa coal including character alteration during processing.
2. To develop new methods for chemical desulfurization and physical processing of coal.
3. To analyze the environmental impact of surface mining in Iowa.
4. To provide an economic analysis of the mining, restoration, beneficiation, transportation, and use sequence for Iowa coal.

In addition to these goals much work was done on the legal/ownership aspect of Iowa coal mining and on the sociological impact of a possible expanded Iowa coal industry. Both primary goals state clearly that research is to be carried out on a scale "sufficiently large to permit reasonable estimates of costs". Therefore, both the mining and beneficiation activities were full scale and as such were initially demonstration as well as research projects.

The state funded project was administered through the Energy and Minerals Resource Research Institute (EMRRI) of Iowa State University, Ames, Iowa. Administration and personnel were supplied through the University and the Ames Laboratory which is a federally funded national Laboratory on the Iowa State University campus. Personnel included administrators, researchers, and students from the University and administrators, scientists, engineers, technicans and construction personnel from the Ames Laboratory.

To achieve the first goal, the University leased land and operated a 141 645 m^2 (35 acre) experimental strip mine. This site contained two coal seams of .91 m (3 ft.) and 1.5 m (5 ft.) thicknesses totaling approximately 99 773 metric tons (110,000 tons) with up to 15.2 m (50 ft.) of overburden. The land was initially suitable for pasture only and was partially eroded. Overburden removal was accomplished with scrapers instead of draglines and topsoil, unconsolidated clays, and shales were stockpiled separately. Through the use of an integrated mining/restoration plan, the site was restored by constructing terraces suitable for row crop farming. Agronomic research is currently being conducted on this site to determine short term and long term effects of this form of mining and restoration on agricultural land. This is the only full scale mining and restoration project of its type to be successfully conducted by a university and various research papers are available covering results of this portion of the Iowa Coal Project.

The state of Iowa has reserves of seven billion tons of coal underlying approximately the southern one half of the state. The coal rank is high volatile "C" bituminous. Heating values of raw coal range between 23.26 and 24.42 J/μg (10,000 and 10,500 BTU/lb.), ash content between 15 and 20%, and sulfur content between 2.5 to 9%. There are currently two operating shaft mines and six strip mines in the state producing approximately 634 900 metric tons (700,000 tons) per year. Iowa coal is very high in sulfur content and the coal industry in the state is rather small compared to other coal producing regions in the U.S.

This paper deals primarily with the full scale coal beneficiation research as outlined in goal #2 and a glimpse of future fine coal beneficiation activities. The initial step in the implementation of goal #2 was the collection of channel and run-of-mine coal samples from all operating mines in the state. A coal washability laboratory was established and washability studies were performed on coals from all existing Iowa mines. These initial washability studies indicated that sulfur reductions of up to 40% and ash reductions of up to 50% were theoretical achievable.

No coal preparation work has been done in the state in recent years. It was felt therefore, that initial needs could best be served by determining on a full scale basis what could be achieved by applying the best of current physical coal cleaning technology to high sulfur Iowa coals. The resulting coal preparation plant utilizing heavy media and concentration tables was designed and constructed by EMRRI engineers and construction personnel. In its present form, the plant represents an investment of $1.1 million of the total $3 million alloted for the Iowa Coal Project. Initial planning and research (washability studies, etc.) consumed approximately one year and actual design and construction of the facility took one year. Since construction was completed the plant has cleaned 907 metric ton (1000 ton) samples of coal from seven Iowa mines, as well as processing approximately 45 350 metric tons (50,000 tons) of coal from the Iowa Coal Project demonstration mine. The project is currently funded by the State of Iowa (Iowa Coal Project Phase II) and the Department of Energy for advanced fine coal beneficiation research. Several experimental plant studies have been completed to date and this paper presents an overview of the results of these activities.

Plant Circuitry and Design

A configuration diagram of the existing plant as well as planned additions is shown in Figure 1. Circuits currently in operation include crushing and screening, cone type heavy media, concentration table and the settling basin. The heavy media separator utilizes a cone type vessel and has a complete media recovery circuit integrated into a compact five module movable package. Media specific gravity can be accurately controlled in the 1.30 to 1.70 range. The concentration table is placed in the circuit such that the entire -9.5 mm (-3/8") feed can be processed or the -.3 mm (-48M) portion (slimes) can bypass the table.

An impact type crusher is used to reduce ROM coal to processing size in a single pass. This unit produces slightly more fines than either a roll type crusher or Bradford breaker; however it is a very flexible unit in that processing top size can be readily changed by varying rotor speed or grate spacing producing top sizes between 101.6 mm (4 in.) and 4.8 mm (3/16 in.)

Other processing equipment incorporated in these circuits includes belt conveyors, electronic weigh scales, a hopper, tramp iron magnet, separating screen, dewatering screen, flocculation equipment, front end loader, and a unique fine coal setting basin. The basin is formed concrete and is designed to be used in a "flip flop" fashion, i.e., one side is used to clarify processing water while the other side is being cleaned. External plant layout facilities include storage for approximately 907 metric tons (1000 tons) of incoming coal when delivered by truck and an immediate clean coal stockpiling capacity of 1360 metric tons (1500 tons). Approximately 454 metric tons (500 tons) of refuse can be accumulated prior to removal.

Operations

The plant has operated on a semi-production/demonstration/research basis for one and one half years processing a total of approximately 51 700 metric tons (57,000 tons) of coal. The operating staff at the plant consists of an operator, assistant operator and equipment operator. The plant is typically operated for 5 hours per production day, four days per week at 70 TPH for a total weekly production of 1400 tons. All raw coal to date has been trucked in; however, the plant is located adjacent to a rail spur such that rail shipments can be received. The plant is located adjacent to the Iowa State University power plant and all cleaned coal to date has been burned in this plant. Figure 4 is an aerial view of the preparation plant showing its location with respect to the Iowa State University power plant.

II. Optimal Cleaning of Seven Iowa Coals

The initial coal preparation research work at the Iowa State University coal preparation plant consisted of processing 907 metric ton (1000 ton) samples from each of seven operating Iowa mines to demonstrate optimum full scale washability of these Iowa coals. The coals tested varied from 2.51 to 8.74 percent in sulfur content and represented both deep and surface mined coal. Runs were made at several level of specific gravity for each coal. Initial test procedures attempted to relate previously taken laboratory washability studies for each coal to a best specific gravity of separation for plant operation. However, considerable time had lapsed between the laboratory studies and the actual plant runs such that the laboratory washability tests were no longer applicable. Later the procedure was changed to incorporate four runs per 907 metric ton (1000 ton) sample. Two levels of specific gravity (1.30 and 1.60) were established and the crusher was set to produce two top sizes of material. The concentration tables were adjusted to approximate the 1.30 and 1.60 gravity levels of the heavy media circuit. This was done by adjusting tilt and slope and observing the specific gravity of the product at the corner of the table (junction between "clean" and "refuse" products). Concentration tables do not operate effectively at gravities below approximately 1.50 and therefore, the -9.5 mm (-3/8) portion of the feed was separated at some value above the 1.30 and 1.60 levels as set in the heavy media circuit. This matter is further discussed under section III of this report where actual partition curves were constructed for both the heavy media and concentration table circuits.

Samples were taken according to ASTM standards from coal streams representing raw coal (plant input), heavy media feed, heavy media clean, heavy media refuse, concentration table clean, concentration table refuse, total plant clean, total plant refuse and settling pond tailings. A proximate analysis was performed on all samples and data were assembled on "plant performance analysis" forms similar to those in Figures 2 and 3. Flow rates of all streams were determined and plant yield and material and energy balances were then calculated. Comparison of the four runs was made to determine the best run for each coal considering sulfur and ash reduction, tonnage and thermal yields and sulfur dioxide emission level in the cleaned product.

The results of this study are shown in Table 1. The left hand portion of the table lists coals tested with their raw and cleaned proximate analyses. The right hand portion lists yields and various computed reduction factors. Also included are comparative data from The Bureau of Mines Report of Investigations

RI 8118 (1).

In general, the yields and the listed reduction factors compared quite favorably with values computed from BOM RI 8118 laboratory washability data on seventeen similar Iowa coals. The yield and reduction factors listed as BOM comparative data were computed from data on pages 83 through 91 of this report at the 1.40 level of specific gravity and were for particle sizes 38 mm X .15mm (1.5 in. X 100M). This was not an exact comparison with our work, as the smallest beneficiated particle size was 48M in our experiments and specific gravities varied considerably above and below the average 1.40 level. Nevertheless, the comparison of results was deemed worthwhile from a standpoint of laboratory versus full scale results. An examination of the ISU plant results for coal from the different Iowa mines on the basis of tonnage yield, BTU yield, ash reduction, pyrite sulfur reduction, total sulfur reduction, and SO_2 reduction shows close correlation with the BOM comparative data. This indicates that laboratory washability results may be very closely approximated with careful plant operation and control even with high sulfur coals. The best comparison of laboratory washability with plant results is direct comparison of these methods on a given coal at a given time. This method was used to evaluate results in Section III of this report.

Table 2 is a summary listing of the SO_2 emission standards to which each coal was beneficiated with respect to its raw sulfur content. The two deep mined coals were lowest in as-mined sulfur content and were beneficiated to the lowest emission standards of 1.72 and 2.15 $\mu g SO_2/J$ (4 and 5 lb SO_2/MMBTU) respectively. Strip mined coals in the 4.5 to 5.5 sulfur content range were beneficiated to meet a 2.72 $\mu g/J$ 6lb SO_2/MMBTU standard. One coal in the 6.5 to 8.75% sulfur range was beneficiated to meet a 3.63 $\mu g\ SO_2/J$ (8 lb SO_2/MMBTU standard) and others in this range could only meet a 4.54 $\mu g\ SO_2/J$ (10 lb SO_2/MMBTU) standard.

These are significant results for the state of Iowa since much of the surface mined coals exist in the 4 to 7% sulfur range and the state Department of Environmental Quality Implementation standards for existing power plants are in the 2.15 to 3.44 $\mu g\ SO_2/J$ (5 to 8 lb SO_2/MMBTU) range depending upon community size and location. Therefore, it appears that most deep coals and some but not all surface mined coals can be beneficiated to meet standards for existing power plants. No coals in the state can be beneficiated to meet federal new source standards of .51 $\mu g\ SO_2/J$ (1.2 lb SO_2/MMBTU) using existing commercial coal preparation technology.

An important part of the coal preparation research work, in addition to actual processing technology, has been a determination and analysis of processing costs. A study has been initiated and a brief summary of results to date is included. It is stressed that the costs presented are estimated costs and not actual selling prices. Also, transportation costs are specifically excluded from this study.

Table 4 illustrates the model or method by which basic cost components are assembled to arrive at a total cost to mine and beneficiate coal on a dollars per million BTU (cleaned coal) basis. It includes four basic elements, two of which are estimated and assumed to be constant (mining cost and processing cost). The other two components, plant yield and BTU content of the cleaned coals, are considered variables in the preparation plant process. Also included are basic assumptions upon which the coal preparation plant cost data are based.

Mining costs are estimated at \$14.21 per metric ton (\$12.89 per ton) of raw coal which represents actual Iowa Coal Project Demonstration Mine #1 costs modified for continuous production. Plant processing costs are estimated at \$1.80 per metric ton (1.63 per ton) of cleaned coal under the assumptions as listed. These cost items are not truly constant but in reality will vary with annual production. However, if these values are considered and plant yield percentages and clean coal BTU values as listed in Table 1 are used, estimated total costs will average \$7.77 X 10^{-10}/J (\$0.82/MMBTU) of cleaned coal produced for the mines tested. Of this amount approximately \$5.78 X 10^{-10}/J (\$0.61/MMBTU) will represent the cost to mine raw coal and \$1.99 X 10^{-10}/J (\$0.21/MMBTU) will represent the cost of beneficiation including processing costs and the cost of material that must be rejected to produce cleaned coal.

If a profit of 15%or \$1.14 X 10^{-10}/J (\$0.12/MMBTU) and a transportation cost of \$2.37 X 10^{-10}/J (\$0.25/MMBTU) are assumed, the resulting delivered price in Iowa of \$11. 28 X 10^{-10}/J (\$1.19/MMBTU) appears to be competitive (1976 dollars) with out of state coals at small-to-medium sized plants in central Iowa which are not able to utilize unit train shipments. Therefore, it appears that the cost of beneficiation in itself will not be a deterant to the development of a coal beneficiation industry in the state of Iowa.

III. Two Stage Processing Experiment

This experiment was set up to compare the effectiveness of a two stage cleaning process against a conventional single pass process. All full scale coal preparation work to date at Iowa State University has been based upon a single pass through the plant at one predetermined specific gravity setting. Results have been satisfactory with respect to sulfur and ash reduction and yield when plant performance was compared to washability studies. However, the coal being tested was very high in sulfur and it was felt that additional pyrite could be liberated through recrushing in a second stage and should be tried. This experiment was designed to first process the 38 m X .3 mm (1.5 in. X 48M) coal at 1.30 specific gravity, keep the float as clean coal then recrush the middling refuse to 19 mm X .3 m (.75 in. X 48M) and refloat at 1.60 specific gravity. The -.3 mm (-48M) material was not beneficiated in this experiment. Refuse from the last step would be the total refuse for the process and the float product would be combined with the 1.30 float to produce the total process cleaned coal. The object was to increase the sulfur and ash reduction factors through increased pyrite and ash liberation during recrushing and to also increase the tonnage yield and thermal yields. Appropriate samples were taken and results recombined in the flow sheet shown in Figure 3. The control or "base" run at one level of specific gravity (1.60) consisted of three replications of a single stage process applied to coal from the same mine. A block diagram of this run is shown in Figure 2.

Actual gravity separation values were determined through the construction of partition curves. The cone type heavy media separator was found to separate quite sharply at the desired specific gravity. Actual gravity levels for the concentration tables however, were considerably above what was actually desired and separation was not as sharp as that produced by the heavy media process.

Results of this experiment are shown in Table 3, which compares the two stage process with the single stage process. At the outset it was realized that the sulfur and ash reduction factors for this experiment (single or two stage) were considerably less than those presented in Section II of this report which dealt with optimal cleaning of seven different Iowa coals. The coal in this experiment came from a mine adjacent to the ISU demonstration site and was quite high in sulfur content (8.20%). Washability curves plotted from data taken during plant operation for this particular coal showed that it would be particularly difficult to clean, which was a factor in the low sulfur and ash removal effectiveness.

Another reason for the relatively low sulfur and ash reduction factors was poor control of the effective specific gravity at which the concentration table operated. The experiment was set up to clean at specific gravity levels of 1.30 during the first stage and 1.60 during the second stage. Actual partition curves showed that the heavy media circuit did in fact operate at these levels but the concentration tables were functioning at specific gravities of 1.73 during the first stage and 1.91 during the second stage. In addition, most of the coal (percentage wise) was cleaned by the concentration table circuit. This meant that most of the experiment was conducted at considerably higher gravities than was intended. The initial experiments comparing the seven Iowa coals were conducted at an average specific gravity of 1.40 which should and did produce cleaner products.

However, valid comparisons can be made between the base run single stage and two stage processes. Sulfur reductions (both sulfur and SO_2) as well as ash reductions were improved with two stage cleaning of this coal. This was undoubtedly due to increased pyrite and ash liberation effected during the intermediate recrushing stage where the first stage refuse was recrushed to approximately 19 mm (.75 in.) top size prior to the second stage. Both thermal and tonnage yields were increased with two stage cleaning although the effects were not dramatic.

The only apparently detrimental effect of two stage processing was the increased production of fines caused by the second stage recrushing. In this experiment it was felt that both processes tended to produce excess fines which was partly caused by the impact type crusher. At any rate two stage crushing would greatly increase the desirability of a fine coal circuit to beneficiate this size fraction. This is a separate subject and is covered in Section V of this report.

IV. Ashing Properties of Raw v.s. Cleaned Coals

The ashing properties of both raw and cleaned coals were compared to determine what effects beneficiation could have on boiler slagging and fouling characteristics of Iowa coals. Raw and cleaned samples were gathered for four Iowa coals presented in Section II of this report. Three of these coals were from strip mines and one was from a deep mine. The coals differed greatly in their sulfur contents which ranged from 7.1% to 11.52% (raw) for strip mined coal and 2.23% for the deep mined coal. The deep mined coal was probably hand picked prior to beneficiation and its sulfur content was lower than normally would be expected from this mine.

A complete chemical analysis was performed on the ash from these coals and from this information the base content, acid content, base/acid ratio, silica/alumina ratio, silica value, iron ratio and dolomite percentage were calculated using standard (ASTM) procedures. From these values both a fouling index and slagging index were calculated. The fouling index was computed by multiplying the base/acid ratio times the per cent sodium and the slagging index by multiplying the base/acid ratio times the percent dry sulfur. These indexes were than evaluated with respect to classification values presented by R. S. Attig and A. F. Duzy (2). This information is presented in tabular form in Table 5 which includes the classification categories with respect to low through severe fouling or slagging types.

The most significant result in this study was the considerable reduction in the base/acid ratio during beneficiation. The average per cent reduction in this parameter for all coals was 36% with the largest reductions occurring in the coals with the greatest sulfur and ash reduction during beneficiation. The deep mined coal with little sulfur and ash reduction showed very little reduction in base/acid ratio. The considerable reduction in base/acid ratio of the three other coals coupled with the reduction in sulfur content during beneficiation combined to produce a drastic reduction in the cleaned coal slagging index when compared to raw coals. The slagging index numbers are quite high for all of the strip mined coals (even in the beneficiated state) when compared to the "severe" slagging category of "over 2.6" and this is undoubtedly due to the very high sulfur contents of these coals. However for the strip mined coals a dramatic decrease in this index was observed following beneficiation.

The other factor evaluated was the fouling index which measures the tendency of the coal to coat the upper regions of the boiler tubes. This undesirable property is caused primarily by a high sodium content in the coal. Fortunately Iowa coals are very low in sodium content and therefore are not fouling type coals. The fouling indexes as computed from the chemical composition of the ashes did show reduction during beneficiation due primarily to a reduction in the base acid ratio.

The reliability of these data was evaluated by interviewing the manager of the I.S.U. Power Plant who, though not familiar with this form of analysis, has experienced the burning of both very high sulfur Iowa coals in past years and more recently beneficiated coals as produced at the Iowa State University coal preparation plant. In general, little or no fouling of boiler tubes has been experienced with Iowa (or any other Midwestern) coals as they contain very little sodium. This was accurately predicted in the computed fouling index and in practice no problem exists in this area. The slagging indexes however, did indicate coals that in the past had caused a great deal of slagging problems. Iowa coals that had been burned in the past and were in the high sulfur range (over 6%) had caused severe slagging problems. When these coals were burned it was customary to shut the units down periodically for slag removal. Lower sulfur coals did slag but were manageable. It was felt, therefore, that the beneficiation process in addition to reducing the sulfur and SO_2 content of the cleaned coal, greatly reduces boiler slagging problems through a reduction in the base/acid ratio of the ash product.

V. Advanced Fine Coal Beneficiation Circuits

The recovery of coal fines -.3 mm (-48M) normally lost in the coal beneficiation process is currently a very important research area. As the value of coal continues to increase, it becomes increasingly more attractive to install equipment that will recover, beneficiate, dewater, and reconstitute coal fines. Equally important is the elimination of coal/refuse settling ponds which pose an environmental problem. Fine coal recovery is a very important area both from a commercial as well as a research standpoint. In addition to addressing current fine coal recovery problems, research in this area ties in with total fine coal beneficiation and chemical desulfurization which are possible future alternatives in advanced coal beneficiation, conversion, and utilization.

For these reasons the EMRRI at Iowa State University has an active research/demonstration program in fine coal beneficiation and chemical desulfurization. Considerable laboratory scale fine coal work has been done in the areas of froth flotation and oil agglomeration from the standpoint of sulfur reduction. Froth flotation has proven to be an effective method of ash reduction but in its conventional use has not offered much advantage with regard to sulfur reduction. The oil agglomeration process with chemically pretreated coal has the advantage of offering significant sulfur reduction as well as providing a product needing little if any dewatering and which is set up for pelletization. The primary disadvantage to this process at its current state of development is high reagent (oil) cost. Finding suitable reagents remains an active research area. A unique pretreatment process is being developed and will enhance the performance of both froth flotation and oil agglomeration. This involves fine pulverization, heating, and chemical treatment of the coal slurry prior to beneficiation.

In addition, laboratory work on several other basic processes is underway. Considerable work has been done combining various physical and chemical desulfurization processes to maximize sulfur reduction. A unique chemical desulfurization process in alkaline solution is being developed in the laboratory that will eliminate many problems associated with acidic chemical processes. High gradient magnetic separation is also under investigation as a fine coal beneficiation technique.

As a follow-up and extension of the above and to recover, beneficiate, and dewater coal fines currently being lost at the Iowa State University coal preparation plant several fine coal beneficiation circuits are being designed and installed in the existing facility. Figure 1 is a configuration diagram illustrating the various circuits as labeled either existing, under construction, or in the planning stage at the Iowa State University coal preparation research plant. The crushing and screening, cone type heavy media, and concentration table circuits have been described previously in Section I. The pretreatment, oil agglomeration, froth flotation, and pelletization circuits are Federally funded and are currently under construction. Completion of these circuits is scheduled for late spring 1978. The pretreatment circuit includes facilities for storing, mixing, size reduction, heating, and particle classification of a coal water slurry. This circuit can provide feed stock for other advanced fine coal beneficiation circuits, i.e., oil agglomeration, froth flotation, high gradient separation and chemical desulfurization circuits at the rate of 45.4 kg (100 lb) to 227.0 kg (500 lb) per hour.

Also under construction is the hydro cyclone fine coal beneficiation circuit including dewatering cyclones, advanced type thickener, and filters. This circuit is designed to beneficiate and dewater all -.3 mm (-48M) fines produced by the existing plant.

Also in the planning/design stage is a heavy media cyclone circuit designed to beneficiate medium to fine sized coal. This circuit will be an alternative to the concentration table circuit and in conjunction with the existing heavy media cone type vessel will enable the plant to process the entire feedstock down to fine sized coal using heavy media.

Figure 5 is an internal photograph of the existing plant showing the pretreatment, oil agglomeration, froth flotation, and pelletization circuits under construction.

VI. Conclusions

Full scale beneficiation research at Iowa State University has demonstrated that some coals in the state can be economically beneficiated to meet state SO_2 emissions standards for existing power plants. It has also been shown that some additional increase in both sulfur and ash reduction may be achieved through the use of a two stage beneficiation process utilizing intermediate refuse recrushing. The slagging properties of some strip mined Iowa coals were shown to have been improved by both sulfur reduction and the reduction of the base/acid ratio in the ash of those coals. The results of this full scale research and complementary laboratory research has shown the desirability of continued research in fine coal beneficiation. Continued research in this area is being persued at Iowa State University and implemented at the coal preparation research plant.

References:

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Table 1 Iowa Coals Processed At Iowa Coal Project Preparation Plant
Data Represents Best Run Made On Each Coal

Coal Processed	Specific Gravity	Size		BTU/lb	Total Sulfur (%)	Pyritic Sulfur (%)	Ash (%)	Moisture (%)	Lbs SO_2/ MMBTU	Tonnage Yield (%)	BTU Yield (%)	Ash Reduction (%)	Pyritic Sulfur Reduction (%)	Total Sulfur Reduction (%)	SO_2 Reduction (%)
ISU #1	1.5	1½" X 48M	Raw	10,572	6.95	----	16.21	9.24	13.15	80.0	85.7	33.7	----	29.2	34.0
			Clean	11,312	4.91	----	10.73	9.39	8.68						
ICO	1.35	1" X 48M	Raw	10,690	5.48	----	11.55	12.9	10.25	73.6	78.3	39.4	----	40.4	43.9
			Clean	11,724	3.37	----	7.22	10.2	5.75						
Lovilia[1]	1.50	1½" X 48M	Raw	9,839	2.51	1.77	17.16	11.74	5.10	74.9	86.7	46.5	37.0	23.6	33.9
			Clean	11,868	2.0	1.16	9.57	8.0	3.37						
Mich	1.40	1½" X 48M	Raw	10,222	8.74	6.66	24.51	3.26	17.10	72.7	82.9	40.8	55.7	36.3	44.2
			Clean	11,434	5.46	2.89	14.22	5.12	9.55						
Shinn	1.35	1½" X 48M	Raw	10,558	4.56	3.25	15.99	8.65	8.64	66.3	74.0	46.4	44.1	27.0	34.8
			Clean	12,058	3.40	1.86	8.77	6.49	5.63						
Big[1] Ben	1.60	1½" X 48M	Raw	9,368	4.76	3.90	21.34	18.32	10.16	78.5	86.9	48.8	51.3	42.6	48.2
			Clean	10,511	2.50	1.58	9.84	15.57	4.76						
Jude	1.45	1½" X 48M	Raw	8,070	7.84	6.11	29.96	9.04	19.43	70.8	96.4	56.9	70.2	44.8	59.4
			Clean	10,709	4.22	1.77	12.58	11.39	7.88						
Average of all Coals Tested	1.40	1½" X 48M	Raw	9,903	5.83	4.34	19.53	10.45	11.98	73.8	84.4	44.6	51.7	34.8	42.6
			Clean	11,374	3.69	1.85	10.42	9.45	6.52						
							B.O.M. Comparative Data (1) 1½" X 100M @ 1.40 S.G.			72.3	78.8	46.5	59.5	38.0	43.3

[1]Deep Mine. All others surface mines.
[2]Losses in yield computations include fines (-48M) losses.

All proximate analysis - Air dried basis.
All reduction factors - Moisture free basis.

Table 2. Iowa Coals Cleaned at ISU Coal Preparation Plant Using Mechanical Beneficiation Techniques

	Coals Tested	Raw Coal Sulfur Content	Emissions Standard Attained LB. SO_2/MMBTU
Deep Mined Coals	Lovilia	2.51%	4
	Big Ben	4.45%	5
Strip Mined Coals	ICO	5.48%	6
	Shinn	4.56%	6
	Jude	7.84%	8
	ISU #1	6.95%	10
	Mich	8.74%	10

Coals processed at specific gravity producing maximum sulfur reduction with highest possible yield.

Heavy media and concentration table separations.

Particle size: $1\frac{1}{2}$" X 48M

Table 3. Comparison of Single Stage with Two Stage Beneficiation Coal from Childress Reclamation Site

	Single Stage	Two Stage
Sulfur Reduction Factor	12.61%	17.01%
SO_2 Reduction Factor	17.91%	22.99%
Ash Reduction Factor	26.21%	31.27%
*Tonnage Yield	92.73%	93.67%
*Thermal (BTU) Yield	97.25%	100.00%
Fines Loss (-48M)	22.95%	28.46%

*Yields calculated based upon material beneficiated i.e.; fines losses (-48M material) are not considered in these calculations.

Table 4. Basic Cost Model

$$\text{Cost \$/MMBTU Cleaned Coal} = \frac{\left[\frac{MC}{PY} + PC\right] 500}{(BTU)}$$

WHERE:

MC = Mining Costs in $/ton raw coal
Includes: earthmoving, mining, royalties and restoration

PY = Plant Yield: tons clean coal/ton raw coal input

PC = Plant Processing Costs: $/ton of clean coal produced
Includes: capital recovery, labor, utilities, supplies, maintenance, refuse handling and overhead

BTU = BTU/lb cleaned coal

Basic Assumptions

1. Preparation plant located near mine site

2. Production Rate: 70 TPH, two shifts, 14 hours per day
240 working days per year
40 six-day work weeks

3. Maintenance and Downtime: 12 weeks total shutdown time (winter)
Maintenance during third shift and Sundays
Major mechanical reconditioning during winter shutdown

4. Resulting Production Rates: 235,200 tons raw coal per year
188,160 tons clean coal per year (with 80% yield)

5. Labor: 3 men first shift
2 men second shift

6. Utilities: Current rates

7. Repairs and Maintenance: 5% of machinery cost per year

8. Overhead and Benefits: 83% of direct labor

9. Capital Recovery: 10-year life, 30% salvage value, 10% interest
Discounted cash flow method

Table 5. Comparison of Ashing Properties of Raw v.s. Beneficiated Coals

	ISU (strip mined)		Lovilia (deep mined)		MICH (strip mined)		ICO (strip mined)	
[1]Coal Proximate Analysis	RAW	CLEANED	RAW	CLEANED	RAW	CLEANED	RAW	CLEANED
% Sulfur	11.52	5.42	2.23	2.17	8.74	5.46	7.10	4.94
% Ash	17.86	11.84	12.06	10.40	24.51	14.22	18.28	8.94
BTU	11,384	12,484	12,534	12,901	10,222	11,434	10,896	11,794
Specific Gravity								
Ash Analysis								
[2]Ash Fusion Temp (F°)	2,087	2,110	2,107	2,150	2,037	2,073	2,147	2,153
Base Content	52.63	35.01	40.39	39.35	53.99	46.78	76.10	65.01
Acid Content	34.41	60.61	50.24	49.74	33.17	36.98	14.82	31.16
Base/Acid Ratio	1.53	.58(62%)[3]	.80	.79(1%)[3]	1.63	1.27(22%)[3]	5.13	2.09(59%)[3]
Silica/Alumina Ratio	1.83	1.67	2.03	2.34	2.09	1.95	1.35	2.01
Silica Value	30.39	50.78	47.20	48.66	29.59	35.14	10.11	24.69
Iron Ratio	2.49	4.51	1.48	1.12	3.07	1.51	4.90	8.95
Dolomite Percentage	27.61	17.15	37.39	43.76	24.15	38.26	16.77	9.77
[4]Fouling Index	.20	.09	.29	.33	.09	.02	.13	.03
[5]Slagging Index	17.63	3.14	1.78	1.71	14.72	7.32	38.17	11.24

Fouling Type

Low	Less than 0.2
Medium	0.2 - 0.5
High	0.5 - 1.0
Severe	Greater than 1.0

Slagging Type

Low	Less than 0.6
Medium	0.6 - 2.0
High	2.0 - 2.6
Severe	Greater than 2.6

1. Air dried basis
2. Average of Initial Deformation, Fusing, and Fluid Temperature under reducing atmosphere conditions
3. Percent reduction from raw coal.
4. (Base/acid ratio) X (%Na)
5. (Base/acid ratio) X (Dry %s)

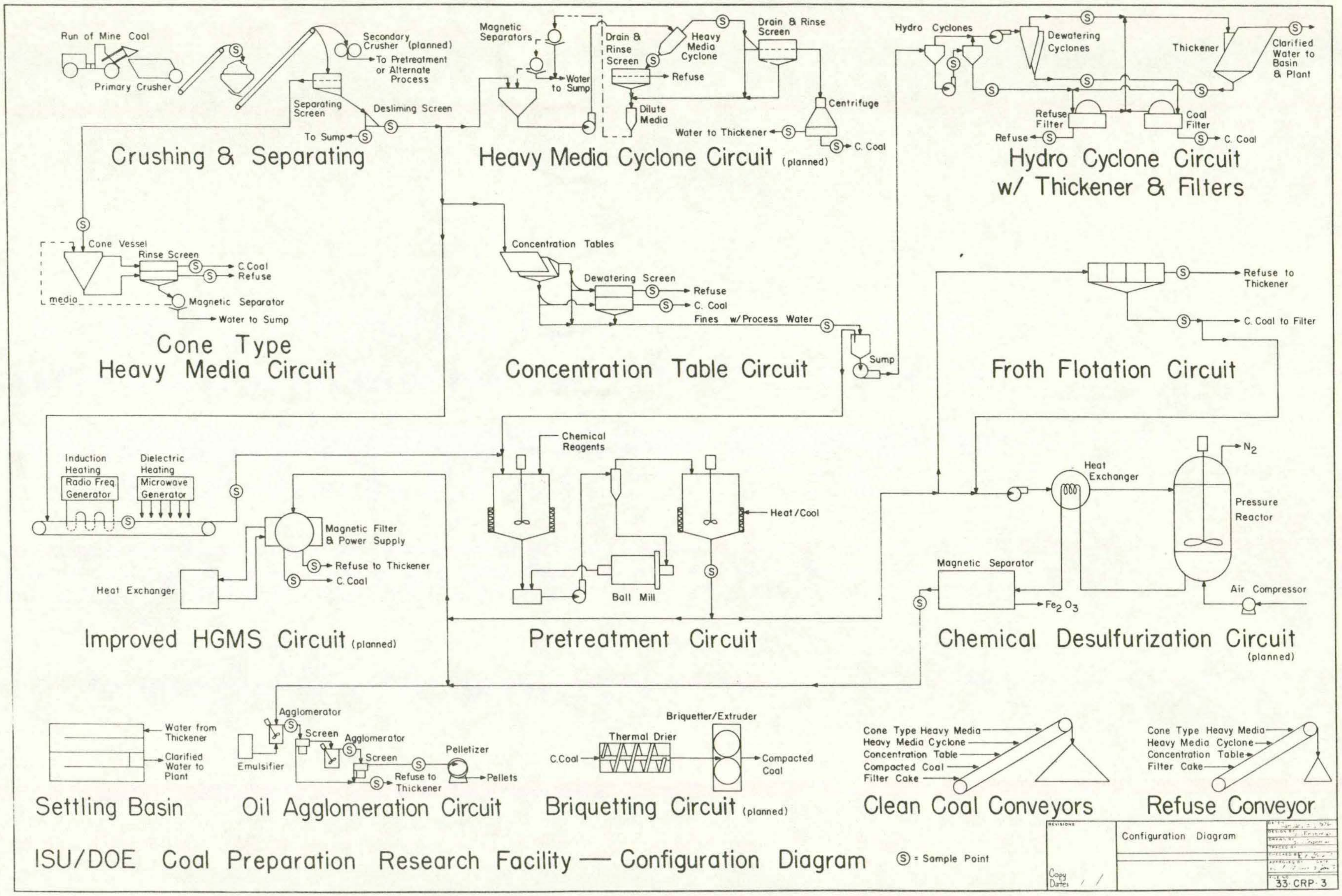
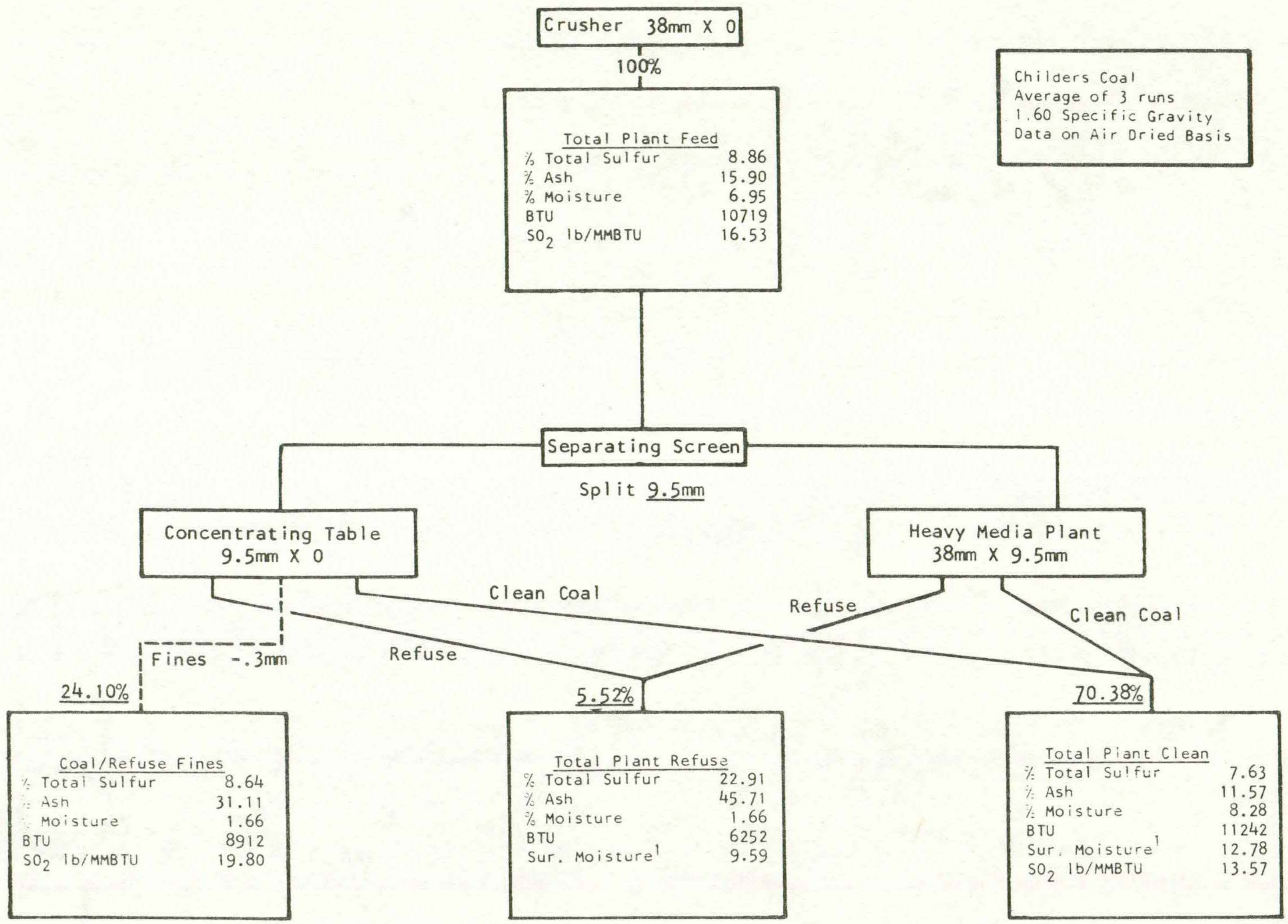


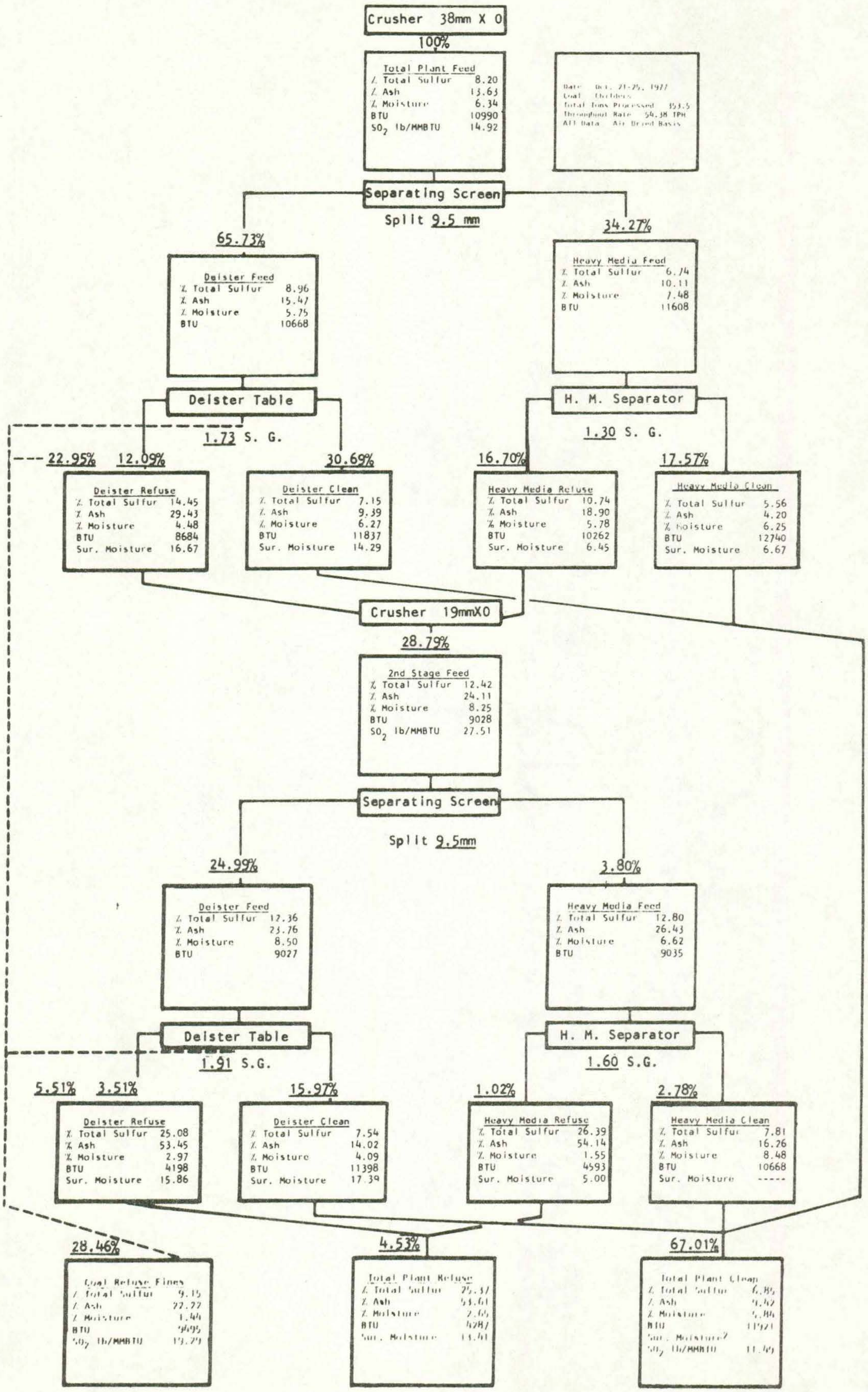
Figure 1. Configuration Diagram



[1] As Cleaned Basis

Figure 2. Single Stage Base Run at 1.60 Specific Gravity

Figure 3. Two Stage Run with Recrushing of 1st Stage Refuse



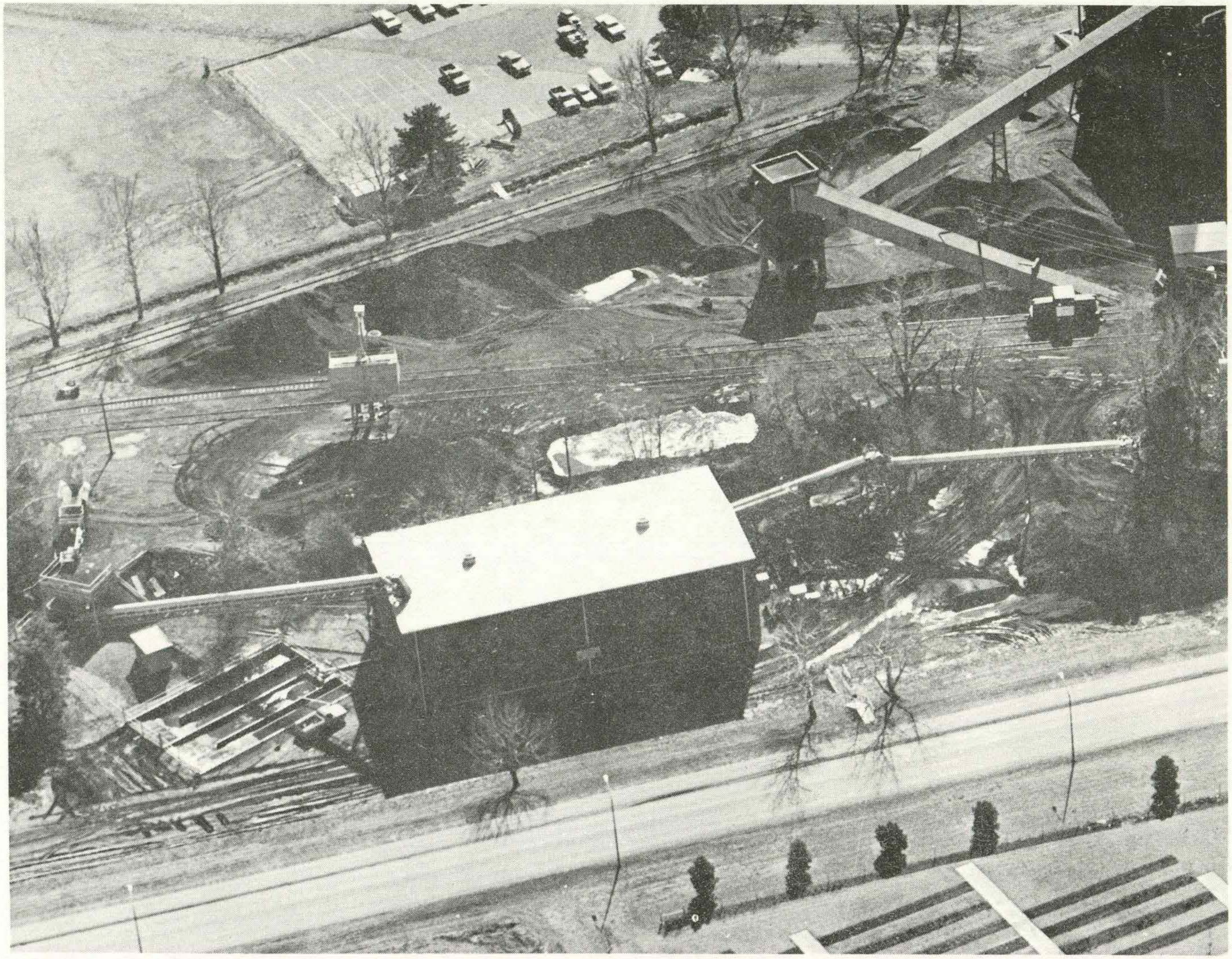


Figure 4. Aerial View of Iowa State University Coal Preparation Plant (white roof) showing close proximity to University Power Plant (Upper R.H. corner of photo)

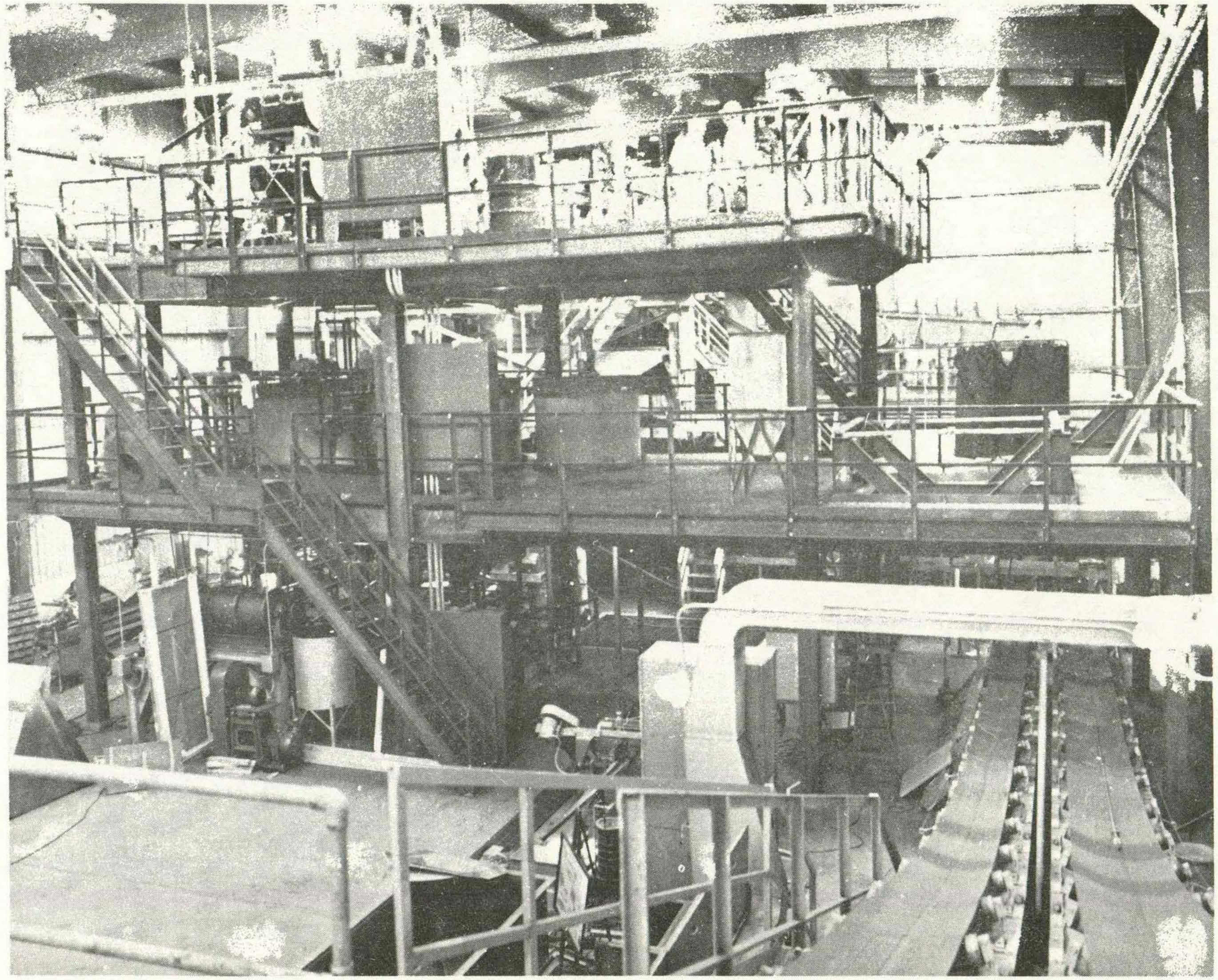


Figure 5. Equipment for cleaning fine-size coal is supported by structure in the foreground.