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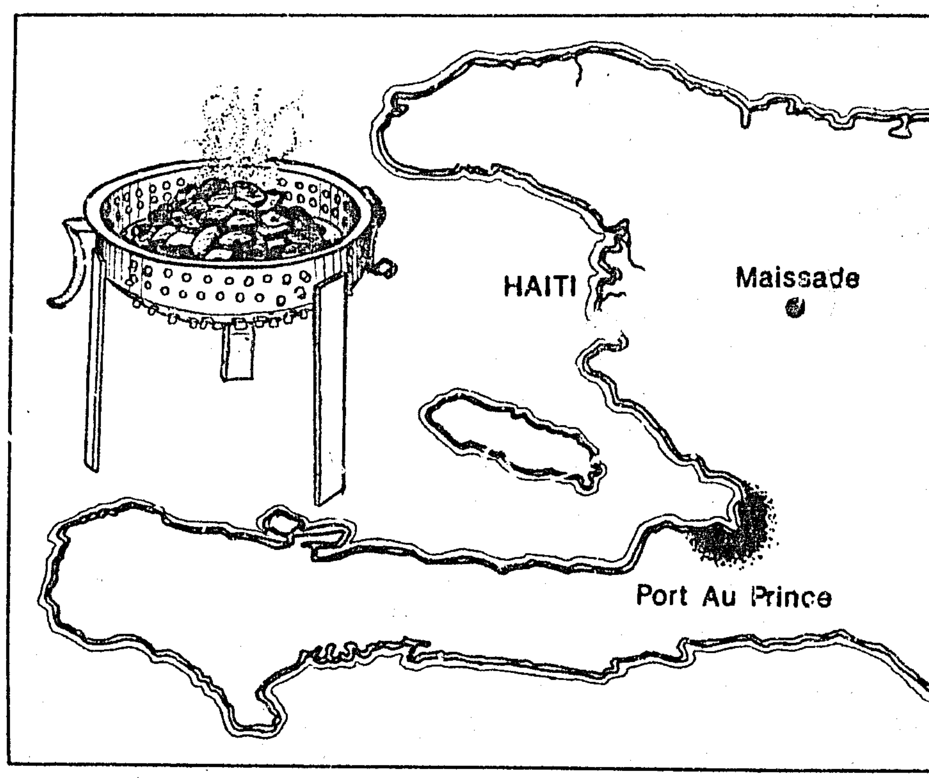
University of North Dakota
Energy Research Center

Box 8213 University Station Grand Forks, North Dakota 58202

PRODUCTION OF COOKING BRIQUETTES FROM MAISSADE (HAITI) LIGNITE:

Feasibility Study and Preliminary Plant Design



By

William B. Hauserman

Michael D. Johnson

Work Performed For

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William B. Hauserman and Michael D. Johnson
University of North Dakota Energy Research Center
Box 8213, University Station
Grand Forks, North Dakota 58202

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ABSTRACT

A laboratory study was done to establish the technical feasability of producing domestic cooking briquettes to be marketed in Haiti, from the Maissade lignite reserves of that country, which are high in both ash and sulfur and not yet mined. It was found that acceptable briquettes could be made from Maissade char, pyrolized and compacted with a molasses-lime binder and the addition of bagasse to improve strength and burning rate. Molasses, lime, and bagasse are all produced in Haiti. Sodium nitrate was added to enhance ignition, and borax as a wetting and release agent. Standard, "pillow-shaped" briquettes were successfully produced on a standard, double roll briquetting machine. The recommended process sequence and equipment selection are virtually identical to that used to produce standard U.S. barbecue briquettes from North Dakota lignite. The heating value of the Maissade briquettes is lower due to their high ash level, which may be acceptable if they can be produced at a cost per heating value comparable to wood charcoal, currently used in Haiti. The high sulfur content, mostly in organic form, presents no problem, since it is tied up after combustion as $CaSO_4$ by the unusually high calcium content of this lignite. Detailed analyses of Maissade lignite and its mineral components are included, as well as a preliminary plant design and capital cost estimate, for capacities of 10,000 and 50,000 metric tons per year, and for a smaller pilot plant.

1.0 INTRODUCTION

The Maissade lignite deposit is located in the central plateau region of Haiti, as shown in Figure 1.1, under a relatively thin overburden. Estimated reserves are 6.2 million metric tons. It is a relatively poor lignite, of high ash and sulfur content, which has never been mined. At present, wood charcoal accounts for the great majority of fuel used for domestic cooking and light industry in Haiti, which has no proven, significant natural gas or petroleum resources. In addition to massive balance-of-payment deficits already imposed by importation of petroleum-derived fuels, deforestation in Haiti is advancing at a potentially catastrophic rate. In the absence of other alternatives, it appears that commercial development of Haiti's lignite reserves should receive a high economic and political priority, even in the face of technical and economical constraints that would not justify such an effort in the United States nor in most other countries. This is the final report of experimental efforts to quantify the feasibility of such an effort.

The research reported here was done at the University of North Dakota Energy Research Center (UNDERC), supported by the U.S. Agency for International Development (AID), Bureau for Science and Technology, Office of Energy, with the cooperation of the Haitian Ministry of Mines and Energy Resources (MMER). Parallel efforts, also supported by AID are being made at Oak Ridge National Laboratory (ORNL), covering the economic and marketing aspects of lignite briquetting industry in Haiti, and at the East-West Center of the University of Hawaii (EWCUH), covering the environmental aspects of using such briquettes, based on experimental examples produced at UNDERC.

An earlier report* covered analytical work at UNDERC to define and characterize Maissade lignite in terms of its chemical and minerological properties. This report concluded that acceptable briquettes could be made from this lignite, using known processing steps and additives. Most of the content of the report is repeated here for convenience in Section 3, which also covers subsequent laboratory work to demonstrate a near-optimum sequence of processing steps, operating parameters and formulation to produce briquettes with acceptable handling and combustion properties.

Beyond the scope of this report is a preliminary evaluation of another Haitian lignite, the L'Azile deposit, located on the southern penninsula of Haiti. Analyses of this lignite, done at UNDERC, will be presented in a separate report by Mr. Betonus Pierre of MMER. The extent of the L'Azile reserves are at present still unknown.

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* Hauserman, Brown, Kleesattel, Johnson, White (all of UNDERC), Pierre and Louis-Jacques (of MMER), "Technical Evaluation of the Briquetting Properties of Maissade (Haiti) Lignite: Interim Report." UNDERC to AID. (This is the sole reference to be cited in the present report.)

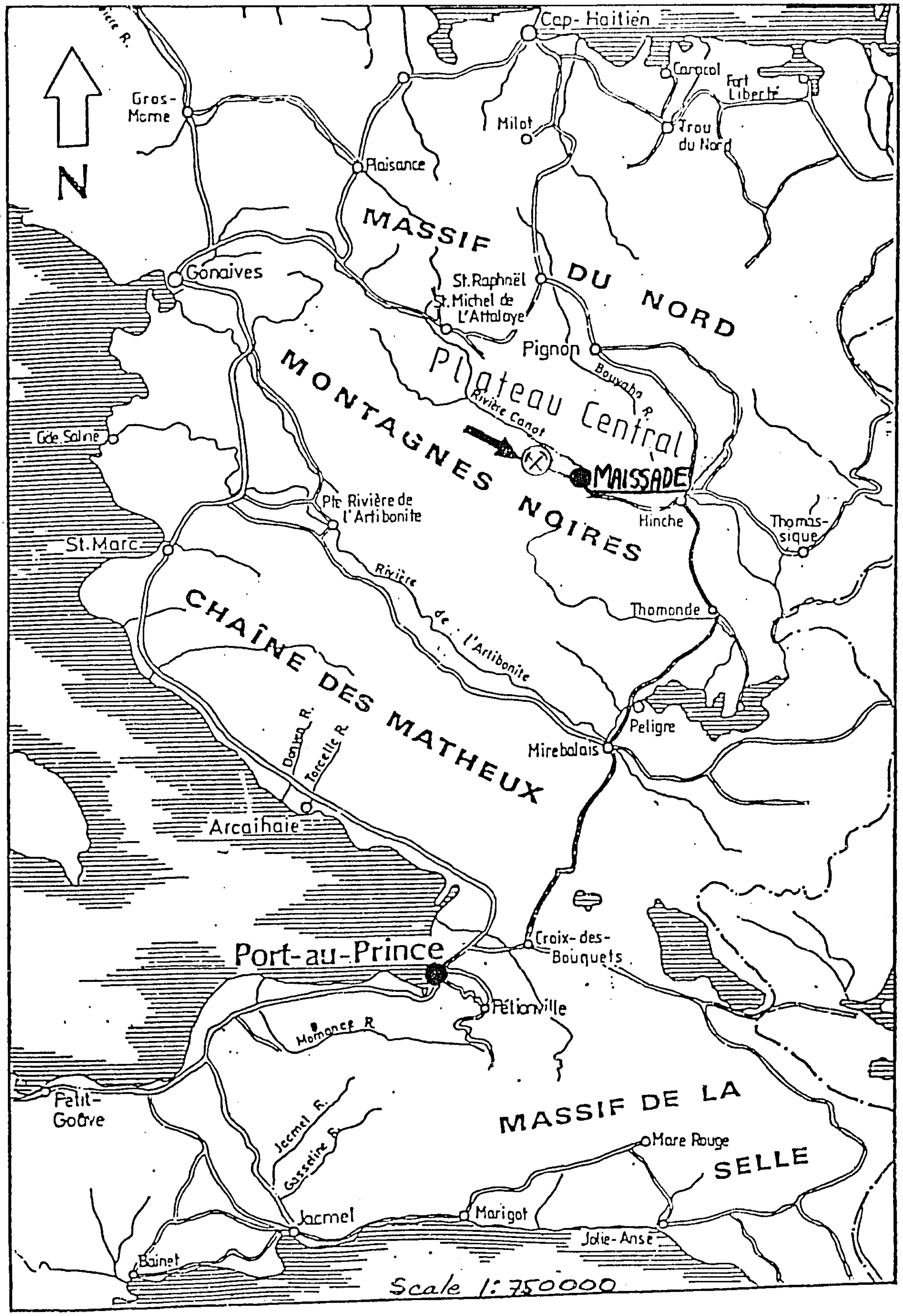


FIGURE 1.1 Location of Maissade Lignite Deposit.

2.0 OBJECTIVES

2.1 FABRICATION AND COMBUSTION OF TEST BRIQUETTES

The overall objectives of the work reported here were to make briquettes from a sample of Maissade lignite, varying the amounts of additives, to arrive at a near-optimum formulation, and then to demonstrate that such briquettes will be at least minimally acceptable with respect to durability when handled; ignitability; burning rate; peak temperatures while burning, without excessive smoke or unpleasant odors; and will not mold or degrade during reasonable storage. These objectives were achieved entirely at UNDERC's laboratories, forming briquettes one at a time with a hydraulic press and conducting burning tests in a chamber where temperatures and weight loss could be monitored under controlled air access, as well as in typical Haitian charcoal stoves, supplied by MMER.

2.2 PILOT SCALE DEMONSTRATION OF BRIQUETTE PRODUCTION

To demonstrate continuous production of briquettes comparable to those produced in UNDERC's laboratory, samples of Maissade lignite char and selected additives were provided by UNDERC to Minneapolis laboratories of Bepex Corporation, manufacturer of briquetting machines, to produce a small batch of briquettes, to be shipped to Haiti for demonstration by Betonus Pierre of MMER. A similar batch of test briquettes was shipped to Dr. Nazrul Islam of EWCUH for combustion testing with emission analyses.

2.3 PRELIMINARY PLANT DESIGN AND COST ESTIMATE

Using established technology in plants producing briquettes from lignite in the United States, preliminary plant designs for capacities of 10,000 and 50,000 metric tons per year are developed, with one or more recommendations for major equipment items and estimated, installed capital costs. Estimated operating costs and minimum selling price of product briquettes are beyond the scope of this study, due to uncertainties as to various operating costs, regulatory policies and options for financing that would apply to such a plant built in Haiti.

3.0 EXPERIMENTAL PROCEDURES AND RESULTS

The different unit operations and aspects of formulation to be optimized are explored separately. The end result is the near-optimum formula used as a basis for the plant design of Section 4.

While the objectives defined the scope of work to be done, the end result justifying the effort must be a set of realistic product specifications for marketable briquettes made from Maissade lignite. Therefore, definition of acceptability criteria must be estimated, as a project objective. These criteria are as follows:

Durability: The consumer must receive briquettes that are whole and relatively dust-free. A green briquette, just off the press and not yet cured, must be strong enough to handle the short fall from the press plus a minimum of handling until it can be cured to full strength. The finished briquette must be able to survive shock impacts and rubbing during transport.

Combustion Properties: The time required to reach peak temperature is critical when the briquettes are used for everyday cooking. They must be ready for cooking in about 15 to 20 minutes after being lit. Also, the peak temperature must be at least 300°C (570°F) long enough for cooking. Finally, the briquettes must remain essentially intact while burning so that complete combustion of the briquette can be realized.

Odors and Gaseous Emissions: The briquettes must not give off unpleasant odors nor impart an unpleasant taste to the food being cooked. If a majority of people in a large city are going to use these briquettes everyday, the emissions of such pollutants as SO_2 must be kept to a minimum.

Shelf Life: Both raw lignite and carbohydrate binders, such as molasses or cornstarch, are subject to biological action. To be aesthetically acceptable to the buyer's sight and smell, the product briquette must not undergo massive mold growth or fermentation during storage. Furthermore, it should not become excessively brittle or disintigrate through drying and aging.

National Economic Indepenaence: Since a major objective of developing Haitian lignite uses is to avoid importation of other cooking fuels, such as kerosine, no acceptable briquette formulation may require significant amounts of any imported material for the binder or other additives.

Marketability: To produce a briquette in Haiti which would be marketable, there are several potential obstacles to overcome. The traditional cooking fuel used presently is very high quality charcoal made from pyrolyzed wood, which has all of the above qualities, plus being very reasonable priced. Any change in appearance, ignitability, heating value, or cost could significantly affect the acceptability of alternative cooking fuels by the consumer.

3.1 PROPERTIES OF MAISSADE LIGNITE

The data reported here is based on a 300 kg sample taken from an outcrop of Maissade B seam during May 1985 by MMER and the U.S. Geological Survey. Complete analyses of the Maissade sample are shown in Table 3.1. The location of this seam in the vertical stratigraphic profile is shown in Figure 3.1. Compared with typical U.S. lignites, it is exceptionally high in ash and sulfur, and low in heating value. This lignite is of littoral origins, like most Caribbean coals, formed in a Miocene coastal bog, probably dominated by mangroves and salt grass with silt and marine plankton contributing to its high ash, calcium, and sulfur levels. The majority of the sulfur (approximately 80%) is organic. Also of interest is the large amounts of silica and calcium which, according to XRD (X-ray diffraction) analysis are

TABLE 3.1

ANALYSES OF MAÏSSADE LIGNITE

Proximate Analysis	
wt%, as received:	
Moisture	28.8
Volatiles	27.9
Fixed Carbon	18.6
Ash	24.6
Ulimate Analysis	
wt%, as received:	
Hydrogen	5.4
Carbon	28.9
Nitrogen	0.6
Sulfur	4.8
Oxygen	6.8
Ash	24.6
Sulfur Forms (2 samples)	
wt%, as received:	
Total Sulfur	5.40, 7.19
Sulfates	0.47, 0.63
Pyrites	0.49, 0.65
Organic	4.44, 5.91
Inorganic Analysis by X-ray Fluorescence	
(Oxides as % of total ash in coal):	
Silicon, as SiO_2	36.1
Aluminum, as Al_2O_3	17.0
Iron, as Fe_2O_3	10.8
Titanium, as TiO_2	0.8
Phosphorus, as P_2O_5	0.6
Calcium, as CaO	13.6
Magnesium, as MgO	3.2
Sodium, as Na_2O	0.5
Potassium, as K_2O	1.6
Sulfur (Inorganic), as SO_3	15.8
Mineralogical Analysis by X-ray Diffraction,	
following ASTM ashing at 750°C:	
Major Components: $CaSO_4$, SiO_2, Fe_2O_3 (Hematite)	
Minor Components: Fe_3O_4 (Magnetite)	
Trace Components: $NaALSi_3O_8$ - $CaAl_2Si_2O_8$ (Plagioclase)	
Heating value, Btu/lb:	
As received	5,207
Dry basis	7,309

present as quartz, calcium sulfate, and plagioclase. Because the sulfur is primarily organic, there is little hope of reduction by mechanical cleaning. However, it can be partially removed along with volatile matter during pyrolysis.

The low sulfate level in the coal suggests that calcium may also be present as $CaCO_3$. The XRD analysis of Table 3.1 showing $CaSO_4$ as a major mineral component appears somewhat inconsistent with the coal's initial high ash level and low sulfate level. Since the standard procedure for the XRD analyses includes ASTM ashing at 750°C (1380°F), most initial $CaCO_3$ would be calcined to CaO, which in turn would combine with SO_3 from the combustion of organic sulfur during ashing. Thus the XRD data do not provide a true indication of original calcium or sulfur forms.

Table 3.2 shows the distribution of ash and sulfur by particle size fraction, suggesting that some mineral matter is concentrated along natural fracture planes. The recommended briquetting process will divert the -60 mesh fraction of raw feed to small-scale steam and power generation in the interest of improved briquette strength and porosity. In addition, this would allow for a small reduction in ash levels.

TABLE 3.2

ASH AND SULFUR DISTRIBUTION BY PARTICLE SIZE
OF MAISSADE LIGNITE

Particle Size Mesh: mm:	-3/4" + 0 19-0	-3/4" + 1/4" 6.4-19	-1/4" + 20 0.8-6.4	-20 + 60 0.23-0.8	-60 0-0.23
% Sulfur: (Dry Basis)	6.89	7.08	6.23	7.16	8.43
% Ash (Dry Basis)	30.6	27.5	33.9	42.4	50.9
Screen Analysis: (wt%)	100	64.9	27.3	5.6	2.3
Wt% of Total Sulfur in Char[1]	100	35.6	31.2	7.34	3.55
Wt% of Total Ash in Char[1]	100	47.6	24.7	6.33	4.82

[1] (% in size fraction) (size fraction) (% in total).

The addition of a cleaning step, such as some combination of jigs, screens, and hydrocyclones, might potentially reduce ash content, but will add to the plant cost. A minimal washability study was done using standard float-sink tests for several size fractions.

Results suggested that no practical degree of ash reduction could be achieved by available coal cleaning technology, which is therefore not included in the plant designs of Section 4. These tests were discussed with manufacturers of coal washing equipment, who generally concur, but with the observation that the tests were too minimal to be conclusive.

Petrographic analysis of Maissade lignite is given in Table 3.3. Macerals appear generally similar to those in Beulah-Zap (North Dakota) lignite. The dominant maceral group in Maissade lignite is huminite (62%), with ulminite being the most abundant maceral type (41%). Ulminite has been documented as having poor briquetting properties. The presence of a large percentage of this maceral group confirms the need for a binder during briquetting. Maissade lignite has slightly more liptinitic macerals (16%) than most Northern Great Plains lignites. For reference, this sample was from the "B" seam located in the deposit's stratigraphic sequence as shown in Figure 3.1.

An important maceral composition difference between the Maissade and North Dakota lignite is the abundance of detrital huminite macerals (attrinite and desinite). Maissade lignite is composed of 15% attrinite and desinite, where as Beulah-Zap lignite contains up to 25% of these macerals. The presence of detrital huminite macerals has been directly correlated with better briquetting properties of coals.

Thermogravimetric analysis (TGA) involves radiant heating of small samples of coal or char at a constant rate in an argon atmosphere, while recording the decreasing weight of the sample. Figure 3.2 compares TGA data for Maissade lignite and Indian Head (North Dakota) lignite. In both samples, the tall peaks at 100°C (212°F) are moisture. The significance of the several minor peaks on the TGA trace for Maissade lignite is not known.

Figure 3.3 shows a similar comparison between a commercial briquette, made from North Dakota lignite with a starch binder, and a near-optimum briquette made from Maissade lignite. The commercial briquette, courtesy of Husky Industries, was made from an Oligocene lignite mined near Dickinson, in southwestern North Dakota, rather than Indian Head or other Paleocene lignites typical of the central part of the state. The Maissade briquette contained 7.5% finely shredded bagasse as a filler and 11.5% molasses-lime binder, both based on dry weight of char, but including the water content of the molasses. The similarity of TGA spectra is not surprising, in view of the similarity of the raw lignite spectra. It suggests that the presence of different binders and additives do not result in significant differences in TGA spectra, in spite of having a major influence on burning characteristics, as discussed later.

Further tests pyrolyzed samples of Maissade lignite to various temperatures in a Cahn System 113 TGA unit. The Cahn unit uses samples of roughly 400 mg and provides a quick, neat, controllable alternative to the study of pyrolysis phenomena in the muffle furnace, where batches are of 1 to 2 kg with no assurance of uniform temperature. Analyses of sulfur in the remaining char at each temperature step are plotted in Figure 3.4. The absolute percent sulfur in the char increases beyond 500°C (930°F), as volatiles are released more easily than the remaining, tightly bound pyrites and sulfates. The normalized curve of Figure 3.4 expresses the char sulfur content as percent of the original, total weight of lignite.

TABLE 3.3

QUANTITATIVE MACERAL ANALYSIS

Sample I.D.: Maissade lignite, Haiti
Magnification: 400X
Points Counted: 100
Date: October 15, 1985

Huminite	%	Liptinite	%	Inertinite	%
Textinite	0.0	Sporinite	1.0	Fusinite	0.0
Ulminite	41.0	Cutinite	2.0	Semifusinite	6.0
Attrinite	3.0	Resinite	0.0	Macrinite	0.0
Desinite	12.0	Suberinite	0.0	Micrinite	0.0
Gelinite	0.0	Alginite	2.0	Sclerotinite	1.0
Corpohuminite	6.0	Exsudatinite	0.0	Inertodetrinite	4.0
		Bituminite	0.0		
		Fluorinite	0.0		
		Liptodetrinite	11.0		
TOT. VIT.	62.0	TOT. LIPT.	16.0	TOT. INERT.	11.0
Mineral Matter	11.0				

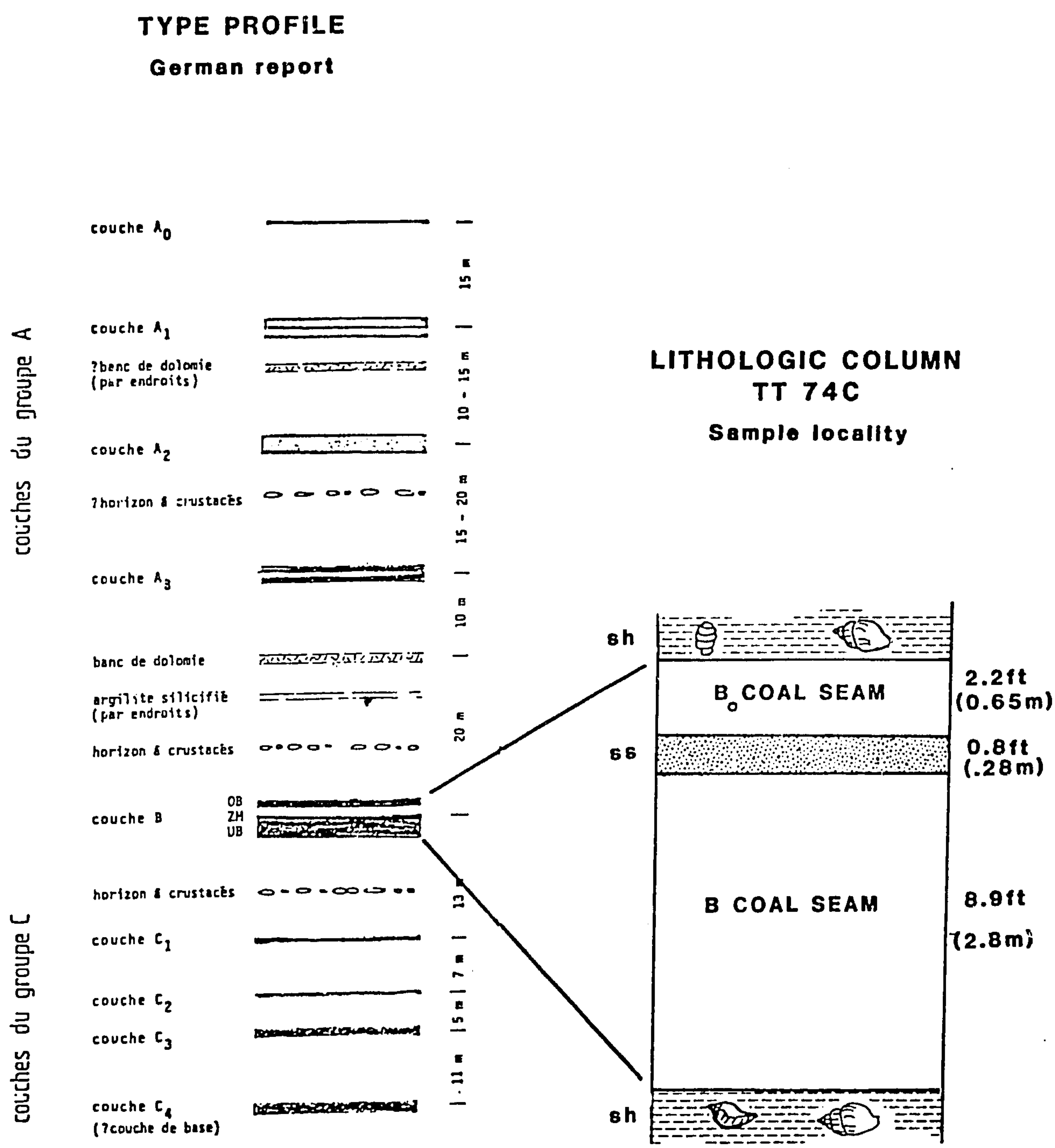
Comments:

1. The overall samples appear to be very weathered. Since the sample site was freshly exposed for this study, weathering suggests prolonged exposure to groundwater seepage. This can be seen by the overall low reflectance values and abundant desiccation features. The edges of many of the coal particles have a slightly higher reflectance indicating probable oxidation due to weathering.

2. The majority of the minerals present are pyrite, with lesser amounts of clays and quartz. The pyrite commonly occurs as framboids. These framboids are most often associated with the ultiminite maceral type. The dimensions of the pyrite framboids range between 10 and 50 microns, with the average at 20 microns. Discrete pyrite grains (<3 µm) not associated with framboids commonly occur in thin (<20 µm) layers.

3. Desinite often associated with clay layers.

4. Alginite is low fluorescing and is associated with the detriatal huminite group macerals.



TYPICAL STRATIGRAPHY OF MAISSADE COALFIELD

FIGURE 3.1 Typical stratigraphy of Maissade coal field.

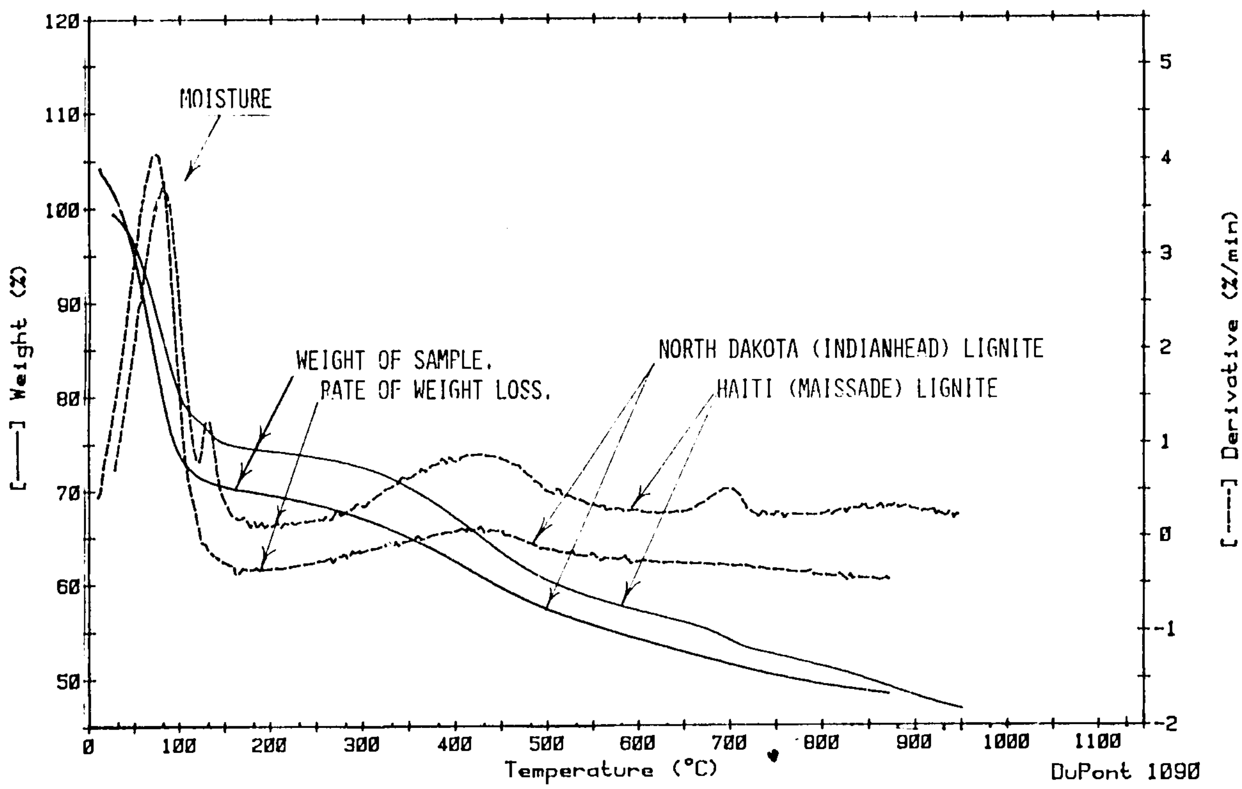


FIGURE 3.2 Thermogravimetric comparison of North Dakota and Haitian Lignite.

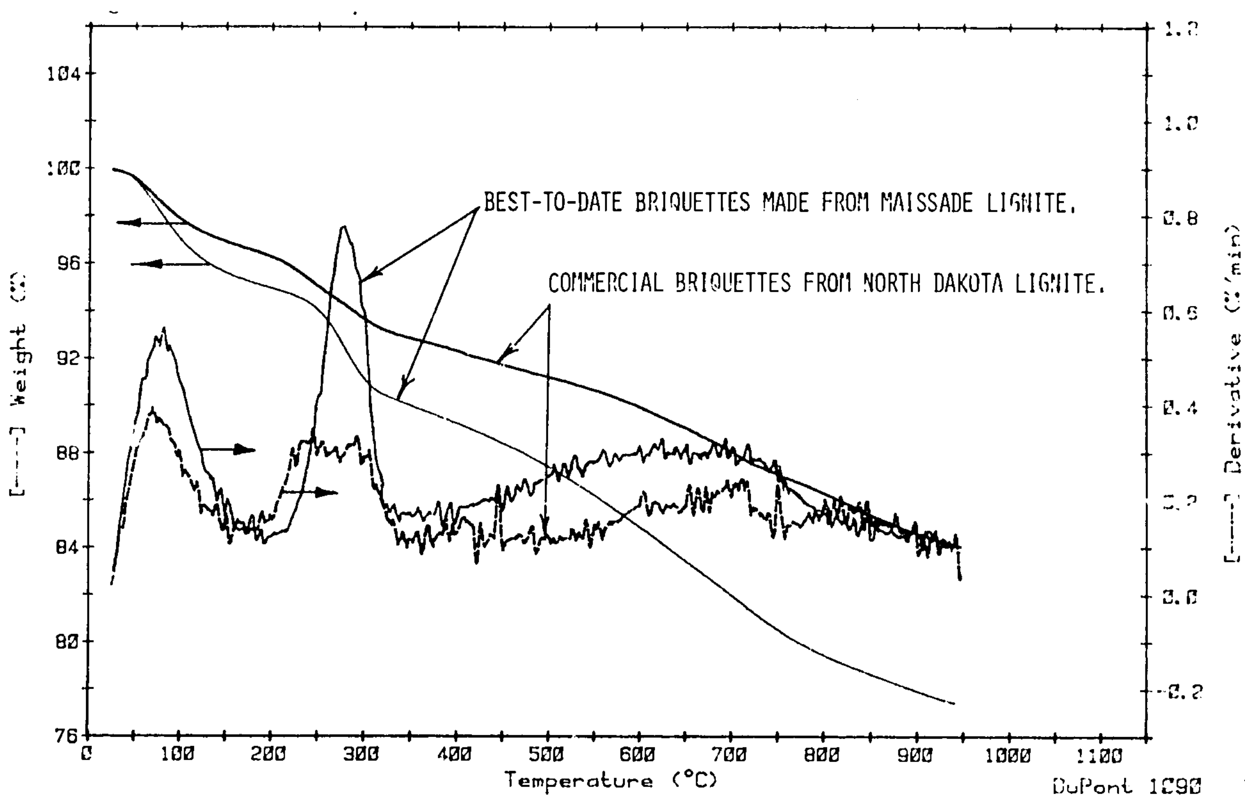


FIGURE 3.3 Thermogravimetric comparison of briquettes from Maissade and North Dakota Lignite.

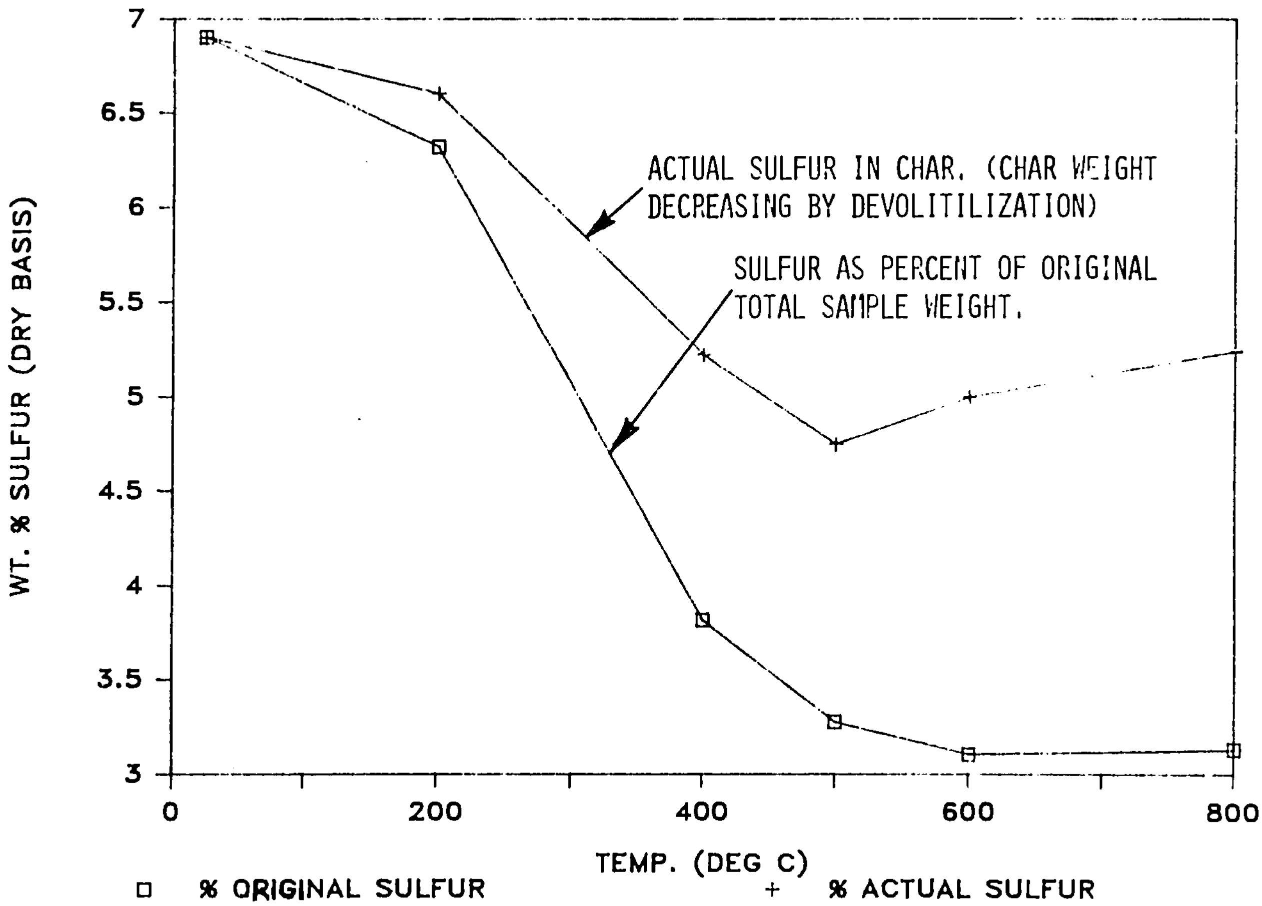


FIGURE 3.4 Residual sulfur in char vs. pyrolysis temperature, Maissade Lignite.

Test briquettes were made one-at-a-time, in briquetting dies fabricated at UNDERC, using a hydraulic press, applying variable pressure. To date, the "near optimum" formulation (all percentages are based on dry weight of char) is 10-25% bagasse, up to 15% of a mixture of two parts of molasses and one part $Ca(OH)_2$, 0.2% borax used as a wetting and mold release agent, and around 2% sodium nitrate to improve ignitability. Pyrolysis at 550°C (1020°F) leaves enough residual tar to cause a smoke/odor problem, which appears to be eliminated in char produced at temperatures approaching 800°C (1400°F).

An economic trade-off involved in pyrolysis temperature selection is that higher temperatures remove more volatiles, thus reducing the calorific recovery of the raw lignite in the briquettes. Sodium nitrate appears to accelerate ignition by reacting to form elemental oxygen upon heating according to the following reaction: $4NaNO_3 \rightarrow 2Na_2O + 4NO_2 + O_2$. the presence of the unpyrolyzed bagasse also improves ignitability, as well as the strength of briquettes. Other additives considered are rice hulls (as an available extender) and starch (from either corn or manioc) as an alternative to the molasses-lime binder.

Addition of bagasse not only improves briquette strength and ignitability but increases heating value. A briquette made entirely from North Dakota lignite having an ash content of 18.5% (versus 40-50% for Maissade char) showed a cooking temperature of 290° to 370°C (550-700°F), measured by a thermocouple placed two inches over the coals. A Maissade briquette, under the same conditions showed a cooking temperature of only 120°C (250°F) with 10% bagasse addition, but 400°C (750°F) with 25% bagasse addition. Burning rate and peak temperature are very sensitive to bagasse content and the surface/volume ratio of the briquette. It also appears that the collection of bagasse in the region around the mine and briquetting plant will be an important economic consideration in operation of a briquetting plant.

3.2 PYROLYSIS

Massaide lignite is high in volatiles, including tars that would impart an unpleasant odor and taste to food being cooked on briquettes made from raw lignite. This lignite can be pyrolyzed to produce a relatively smoke-free product with very little odor. Also, much of the organic sulfur can be removed by pyrolysis. The heating of the lignite also produces thermal fracturing which reduces the size of the lignite and makes the resulting char easier to crush. The tars and other volatiles given off during pyrolysis can be burned and the heat recovered used to generate steam.

The apparatus used to produce the char consisted of an electric muffle furnace and a sealed metal retort. The lignite was initially screened and the -6 mesh (3.4 mm) portion discarded. The remaining lignite, about 86 wt%, was then sealed into the retort and purged with a small stream of nitrogen while heated. The furnace was heated to the desired temperature and held there for at least one hour. The gases were flared over a bunsen burner. Finally, the cooled char was crushed to -8 mesh (2.4 mm) in a hammer mill.

Temperature was the only parameter varied during the pyrolysis experiments, at essentially atmospheric pressure in an inert atmosphere. The lowest temperature which can be used to produce the desired product is the most economical. However, higher temperatures produce a char with fewer undesirable volatiles and remove more organic sulfur. Finally, a small percentage of the volatiles should be left in the char so that the briquettes will ignite more easily.

Another factor influenced by pyrolysis temperature was the amount of smoke and foul odors given off by the briquettes. TGA data in Section 3.1 above indicated that at about 750°C (1380°F) only a small fraction of the volatiles remained. If more volatiles are left in the briquettes, smoke and noxious odors result. This was confirmed by producing and burning char at lower pyrolysis temperatures. The amount of smoke and the smell of this smoke was determined to be unpleasant enough to warrant using a higher pyrolysis temperature. All of the people working on this project were used to determine whether or not the odors were considered objectionable. Pyrolysis temperatures ranging from 150° to 1000°C (300° to 1800°F) were used and the resulting briquettes burned and compared. The results indicated that a pyrolysis temperature of about 750°C (1380°F) would be necessary to produce a clean burning briquette.

3.3 BINDERS

Binders are used in the agglomeration business to glue particles together whenever the coal or other major components cannot be made to agglomerate by themselves. A binder must be inexpensive and, in this case, locally available. Yet it must yield a strong briquette with very little smoke or odor. An overview of the available binders in Haiti showed molasses to be the most promising. Where molasses and lime are used together, the calcium in the lime will capture sulfur released during combustion. The molasses-lime binder is well known, having been used in a number of established briquetting operations. It was selected here, without experimental comparison with other potential binders, simply because molasses and lime are both readily available in Haiti, thus avoiding imported materials.

The binder solution has to be well mixed before it is added to the char and it also has to be well mixed with the char. Mixing the binder and char should be done immediately before briquetting, before the binder starts to set up and become hard. Finally, the binder must evenly coat all of the particles.

The only equipment used to mix the binder solution with the char was a household bread dough mixer. All ingredients were weighed and then added to the water. By adding the soluble materials to the water first, and then the molasses, a homogenous binder solution is assured.

The binder solution was then added to the char-bagasse mixture. A plastic cover was placed over the mixing bowl to contain dust. The mixture was stirred at high speed for about 5 to 10 minutes until all particles were evenly coated. The mix should have a smooth consistency and should stick loosely together when rolled into a ball.

Variations in the amount of lime and molasses were tried, to produce an acceptable briquette with minimum molasses. A high lime to molasses ratio was used for two reasons. First, the calcium in the lime acts both to bind the briquettes and to capture sulfur. Second, lime is the most inexpensive ingredient added. Results were evaluated quantitatively. Too low a lime-to-molasses ratio resulted in weak, slow-curing briquettes. Too high a ratio of molasses to char or to lime resulted in excessively damp, slow curing briquettes, while too little molasses resulted in weak, crumbly briquettes.

Near-optimum briquettes of minimum lime and molasses were analyzed for ash and sulfur. The briquettes had 3.8% sulfur. The ash had 9.8% sulfur. Since the briquettes were 38.9% ash, a mass balance indicates that almost all the sulfur released during combustion was captured in the ash.

Another additive to the binder is borax. Which acts as both a wetting agent and as a release agent to ease the briquettes out of the mold. The amount of borax needed was determined by trial and error. The binder solution needed very little borax to act as a good wetting agent. However, it was found that 0.2% by weight was needed to act as a releasing agent. With the addition of the proper amount of borax, the briquettes should fall out of the mold by the weight of gravity alone. The mold should be clean and ready to use again.

Finally, the proper moisture content of the binder has to be determined. The addition of too much water results in fluid being squeezed out of the mold during compression. Also, the pressure applied is partially wasted due to the hydrostatic back pressure. The addition of too little water results in poor wetting of the char surface and low cohesion between the particles.

3.4 FUEL AND OXIDIZING ADDITIVES

Because of the poor quality of the Haitian lignite, bagasse (sugar cane refuse) was added to improve the combustion characteristics of the briquettes. Bagasse also acts as a binder by joining planes of weakness in the briquette. In order to break the briquette in half, many strings of bagasse have to be pulled apart. The tensile strength of bagasse is relatively high. It should be noted, however, that the large pieces of bagasse are good for structural strength but are not good for frictional strength and appearance. The large strings of bagasse make the outside of the briquette flaky. The right blend of large strings of bagasse and bagasse fines produces a briquette which is both strong and resistant to friction between the briquettes.

The sugar cane stalks were initially chopped with a hand axe to a size that would not plug a hammer mill with a half-inch screen. This reduced it to a size that would make it suitable as a feed to a hammer mill with an 8 mesh screen. This bagasse was then either used directly or sent through a third hammer mill with a sixty mesh screen. In commercial practice, this would all be accomplished in a single, large mill. Experiments were then conducted to investigate the optimum size distribution of the bagasse

Rice hulls were tried as an additive. The resulting briquettes were extremely weak, because the rice hulls had been ground very fine before being shipped to UNDERC. It may be feasible to produce a briquette made with whole rice hulls or a combination of rice hulls and bagasse. However, the decision was made to concentrate the rest of the project on making a good lignite-bagasse briquette.

Another additive is sodium nitrate. A strong oxidizing agent, it helps achieve both faster ignition times and higher peak temperatures.

3.5 COMBUSTION TESTS

Experiments were devised to evaluate the effect that the different fuel and oxidizing additives have on combustion. These tests were done in an enclosed metal box with a glass door. Air was introduced through holes in the four corners of the box about halfway between the bottom and the top. The flow rate of air was closely controlled. The temperature of the briquettes was monitored by a thermocouple placed 2 inches over the top of the briquettes. Approximately 2 pounds of briquettes were placed in a pyramid on a flat plate, sprinkled with forty milliliters of kerosine. Kerosine, as used for charcoal starter in some Haitian households, was selected for these tests in the interest of repeatability. Similar results were obtained using small sticks and slivers of dry pine wood, which is reported typical practice in most Haitian households. For experimental procedures, however, use of pine sticks would introduce excessive variability in geometry and heat output. The pile was lit and the temperature monitored during burning. Initially, temperature readings went above 540°C (1000°F) because of the intense heat given off by the kerosine. Temperatures then dropped to under 300°C (570°F) and slowly began increasing again. The next maximum temperature reached and the time required to reach this second peak were observed, as the principle measure of performance.

Bagasse has roughly the same heating value, 7800 BTU/lb (4340 Kcal/Kgram) as the char, at 7700 BTU/lb (4280 Kcal/Kgram). The briquettes have 7600 BTU/lb (4230 Kcal/Kgram). However, the bagasse has a much higher percentage of volatiles than the char, 82% compared to 16%. Apparently the volatile matter in the bagasse imparts very little obnoxious taste or odor to the briquette, unlike the volatile matter in the lignite. Since the volatiles in the bagasse do not make a smokey briquette, bagasse can be used to upgrade ignitability.

The ash content of Maissade char is about 45%. The ash content of the bagasse is about 3%. By adding 15% bagasse, ash content of the briquette can be lowered to a more tolerable 38.9% ash. As a practical plant operating proceedure, the ratio of bagasse to char could be varied over a considerable range with day-to-day variations in the relative supplies and delivered costs of the two components. For the purpose of this project, however, it was desired to determine the minimum amount of bagasse required to make an acceptable briquete.

Figure 3.5 shows the strong effect that the level of bagasse in the briquette has on peak temperature. With no bagasse added, the briquettes would not even sustain combustion. At high bagasse concentrations, peak temperatures reached were similar to the peak temperatures of commercial U.S. lignite briquettes.

The plot of sodium nitrate versus peak temperature as seen in Figure 3.6 indicates that some addition of sodium nitrate is warranted. Figure 3.7 is a plot of the wt% of sodium nitrate versus the time required to reach maximum temperature. Since sodium nitrate is a relatively expensive ingredient, some trade-off between product quality and product price will have to be reached. Sodim nitrate from Chile and borax from the U.S. Southwest are the only essential ingredients that are not native to Haiti. Fortunately, they are the ones used in the smallest amounts and should not impose any major constraint on the overall economic feasibility.

3.6 LABORATORY BRIQUETTING

The press used at UNDERC was an air-operated hydraulic press capable of 30 tons. Molds were filled with a mixture of char, bagasse and binder, and then compressed to some desired pressure. Several different molds were tried. The briquettes made from these molds are shown in Figure 3.8. The first mold was the "flying saucer" type. After input from the Haitian scientists that a log shape would be more marketable, the two log shaped briquette molds were built. A briquette mold shaped like the U.S. pillow briquette molds was finally made.

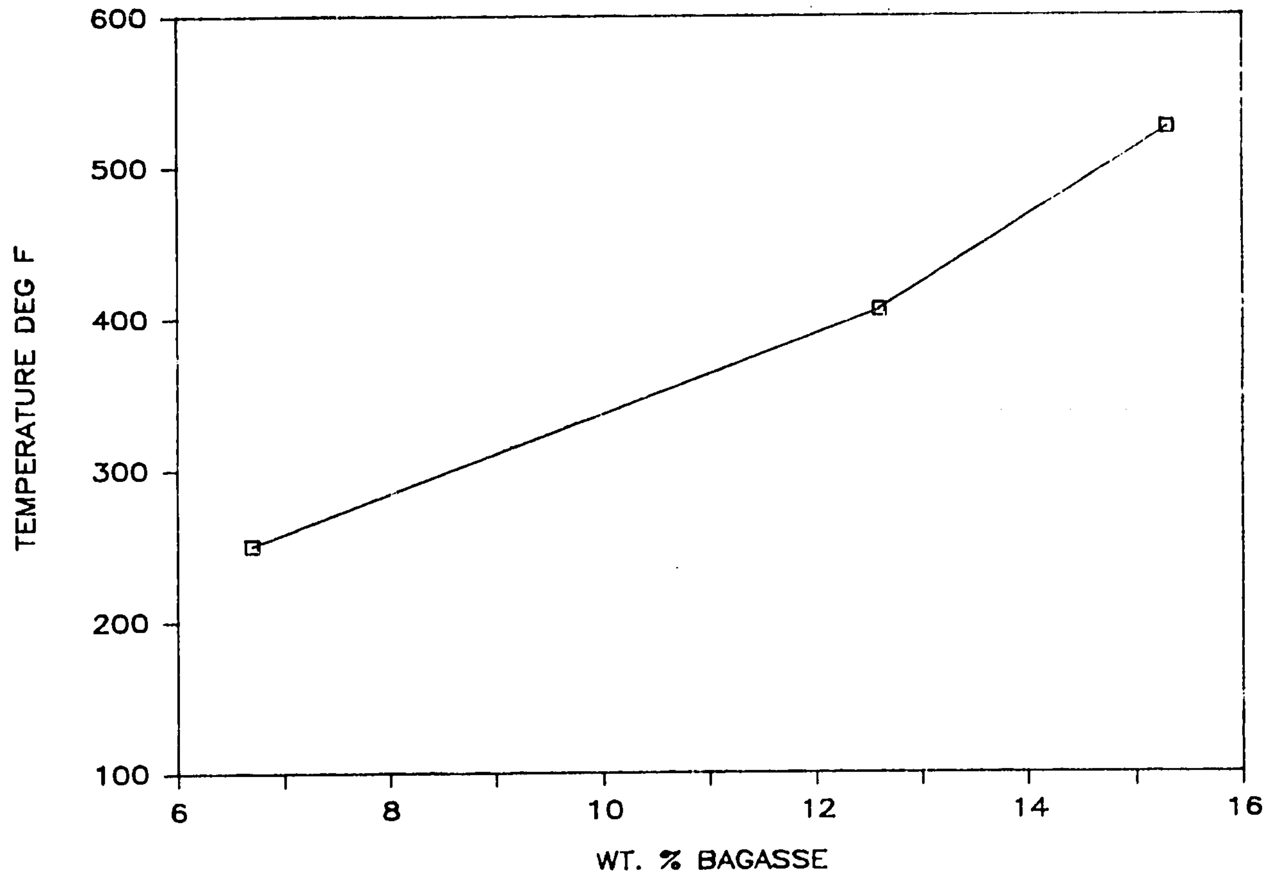


FIGURE 3.5 Effect of Bagasse on combustion.

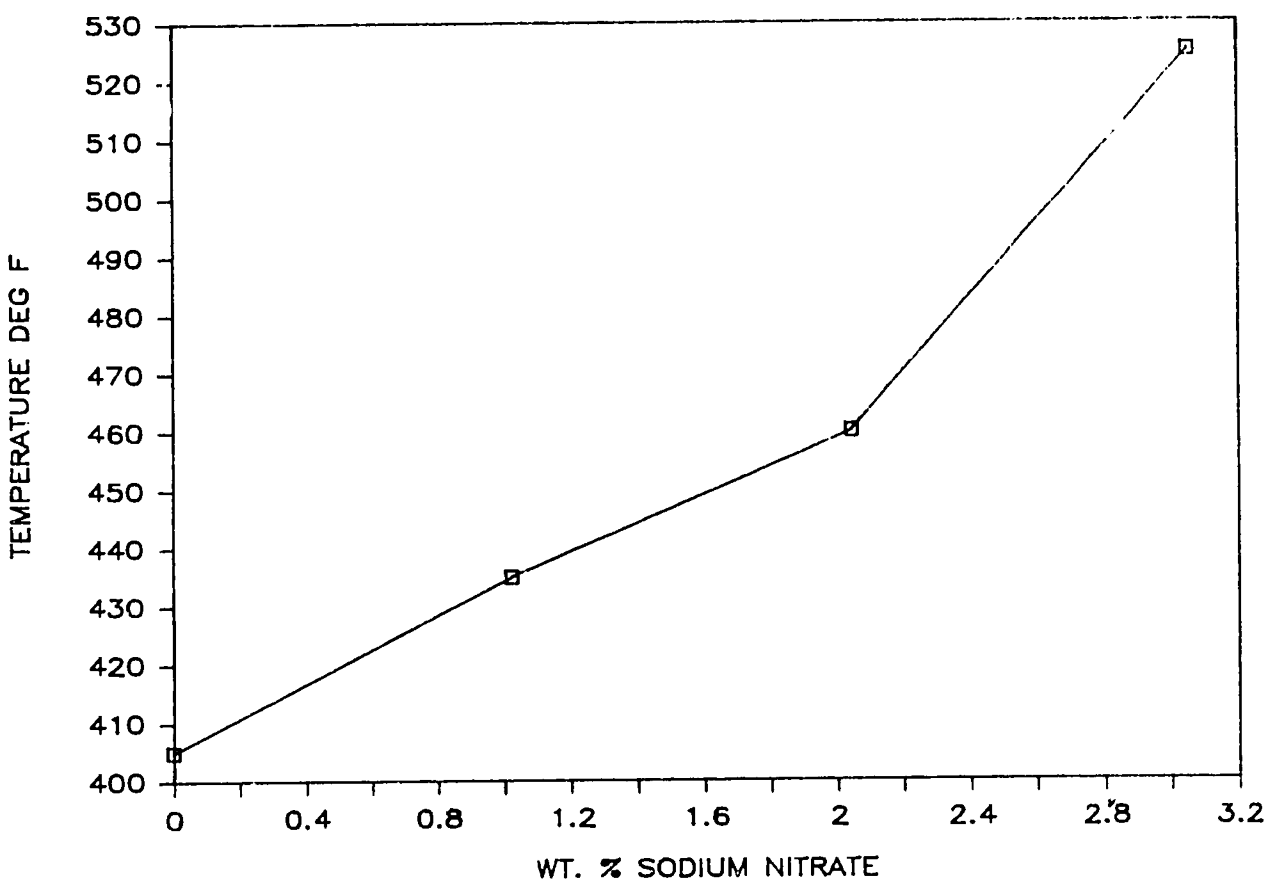


FIGURE 3.6 $NaNO_3$ concentration vs. temperature.

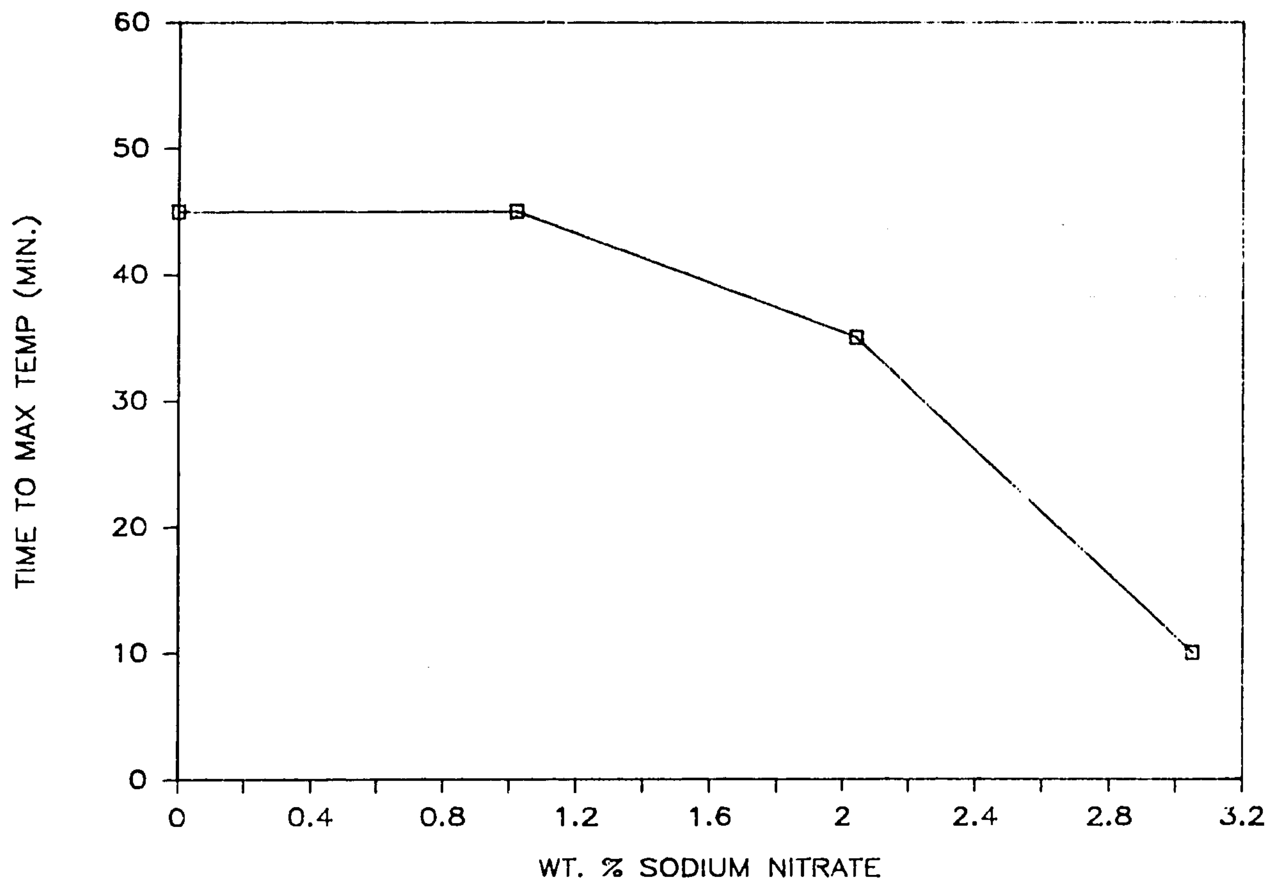


FIGURE 3.7 Sodium Nitrate concentration vs. time.

The flying saucer briquettes were quite durable but burned very poorly, apparently due to their lower suface-to-volume ratio. The first log shaped briquette mold produced was the larger of the two shown. These briquettes were also quite hard and durable but combustion continued to be a problem. The top half of the mold was flipped around so that a briquette was produced which was only 1.9 cm wide compared to the original 3.8 cm wide briquettes. These were very fragile but burned extremely well. This confirmed the hypothesis that a high surface to volume ratio for a briquette was more desirable. The smaller log shaped mold was then built. The briquettes made from this mold were quite sturdy and also burned much better than the larger briquettes.

The last briquette mold was made to achieve a higher surface to volume ratio and to resemble commercial briquettes for comparison. These burned even better than the small log shaped briquettes and were also quite sturdy. The only conclusion drawn from comparison of shapes is that the shape, per se, is not important, as long as the highest convenient surface-to-volume ratio is provided. This is an argument in favor of generally smaller briquettes.

Using the near-optimum formulation, several briquettes were made at increasing pressures and tested by manually twisting immediately as they were removed from the molds. Using a pressure of 4 Tsi (Tons per square inch), as applied to the material in the molds, the briquettes could be crushed by

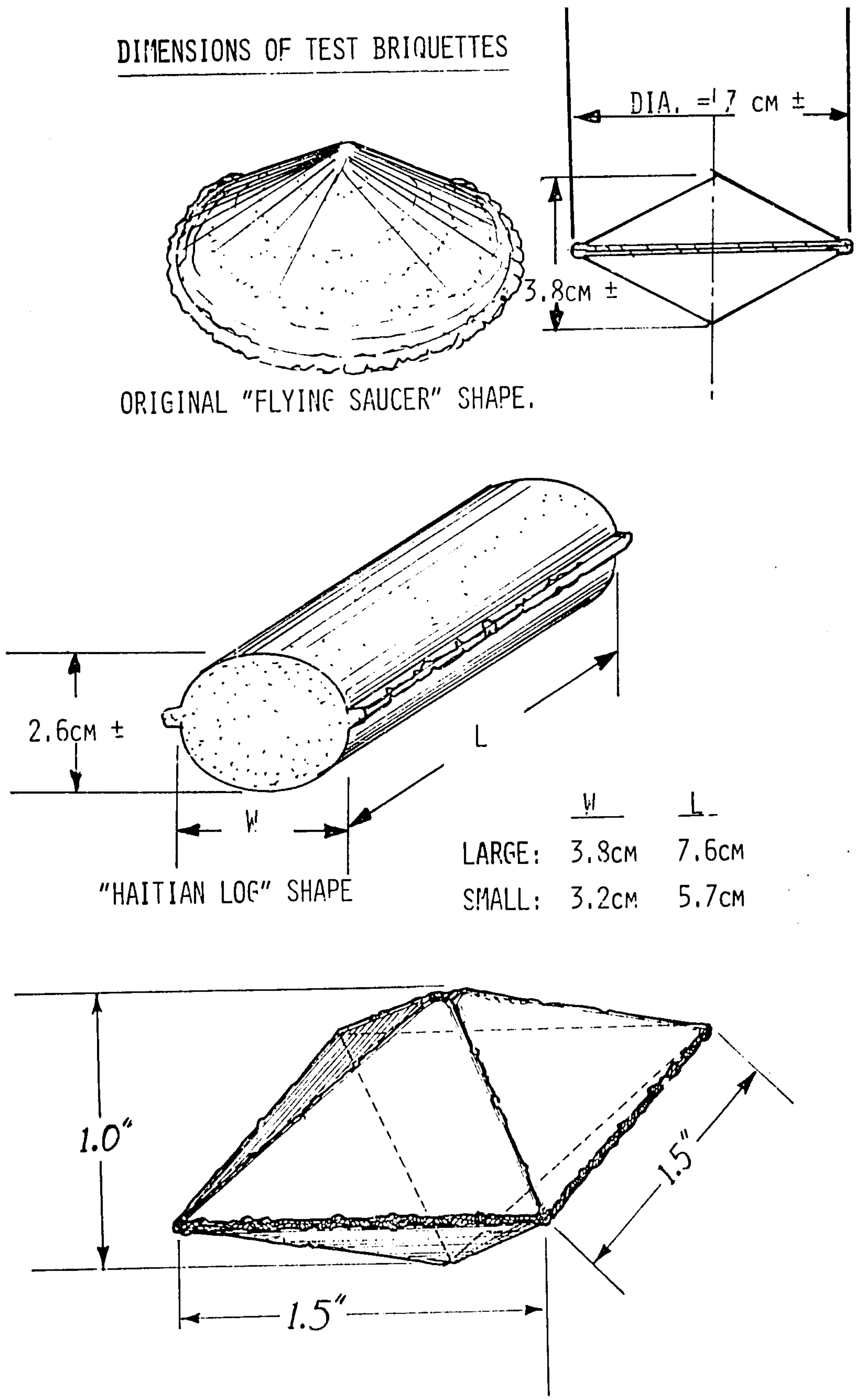


FIGURE 3.8 Dimensions of test briquettes.

hand. At 5 to 6 Tsi, they could be broken with some difficulty, while at 7 Tsi they couldn't be broken by hand and even survived dropping from several feet high onto a concrete floor.

3.7 PILOT SCALE DEMONSTRATION OF BRIQUETTE PRODUCTION

The last part of the program was to test the near optimum formula in a small production model briquetter, located in the Minneapolis laboratory of Bepex Corporation. Pyrolized Maisade char and all additives were supplied by UNDERC, with mixing and briquetting done by Bepex. In the first attempt the feed was poured directly onto and between the twin rollers, as Bepex reports to be normal practice for briquetting coals and chars. This test produced briquettes which were too soft for any extensive handling.

It was then noted, with all the wisdom of hindsight, that the addition of 10% to 15% by weight of fluffy, low-density bagasse roughly doubles the volume of the mixture, reducing the weight of material that can be caught between the rolls by gravity feed alone. Low density materials require a greater volume reduction during compression to achieve the maximum compression for which the machine is designed. In this case, 7 Tsi was required for the briquettes to stick together.

The roll briquetter can only accomplish a 2:1 volume change. Later tests at UNDERC showed that a compression ratio of 2.5 to 1 would be required for the briquettes to be compressed properly. A screw feeder can be used to initially compress the material so that most of the volume change is accomplished before the material is gripped firmly by the converging rollers, to apply the full pressure for which they are set hydraulically.

A second batch of material was taken to Bepex, using the same, near-optimum formulation but with the addition of a screw feeder to the briquetting machine. In addition, a different set of rollers was used, with smaller pockets, to form briquettes very similar to the 4x4 cm briquettes last formed at UNDERC, but with rounded centers, like standard U.S. commercial briquettes. Results were considerably better than the earlier tests, producing briquettes that could be handled and transported.

According to Bepex applications engineers, the problem of mixtures of char with any low density biomass, such as bagasse or sawdust, is that the cellulosic fibers are springy and tend to expand after the fraction of a second that they are compressed between the rollers. When made one at a time at UNDERC, pressure is applied slowly and for many seconds in a hydraulic press, allowing internal relaxation of the elastic stresses in the bagasse fibers. In the last Bepex tests, a small sample of superior briquettes was produced by screening off and recycling the uncompacted residues and fragments of failed briquettes, following the first pass through the machine with the raw feed. The multiple compaction appears to have worked the bagasse fibers into a less resiliant state.

This second batch of briquettes has been sent to the Haiti MMR, to the attention of Mr. Betonus Pierre, to be used for demonstration purposes. It must be kept in mind, however, that any deficiencies of these briquettes are not conclusive and futher optimizatin studies are needed, using a continuous roll briquetter with larger quantities of char.

During this last briquetting test, it was the opinion of a Bepex engineer that the feed simply did not look or feel damp or sticky enough. He felt that there was probably not enough binder to completely coat the particle surfaces to insure that they can bond together during the very brief time under full pressure. A typical symptom of the elastic "bounce back" behavior is an expanded plane of weakness along the briquette's plane of symmetry. In view of Bepex experience in similar applications, an increase in molasses and/or moisture levels, or a decrease in the bagasse content, or an increase in particle size of both char and bagasse would all be beneficial. The latter observation is consistant with UNDERC observations that coarse, long fiber bagasse imparts superior structural properties, though it may not be desirable on aesthetic grounds.

In a similar application, Bepex has just completed the installation and testing of a briquetting machine in Colombia, to make briquettes of raw, subbituminous coal, crushed to -1/8", with 25% sawdust and/or coffee hulls and 10% molasses, with an equivalent of lime.* Attempts to increase the sawdust content to 30% resulted in an unacceptably fragile briquette. It is of interest that the ratio of sawdust to molasses in this case was 2.5, which is identical to the ratio of bagasse to molasses used in UNDERC's near-optimum formula.

It is also of interest that the Colombian raw coal briquettes are to be used in closed stoves where cooking pots sit on an iron top and all the smoke goes up a chimney. This precludes the need for pyrolysis, since none of the noxious volitiles are released inside a residence or in direct contact with the food. Although beyond the scope of this project, this suggests that IF such stoves could be promoted in Haiti, they would enable the consumer to use briquettes of raw lignite, merely dried in a simple rotary kiln, which could eliminate the capital cost of the pyrolizer, the most costly part of the proposed plant. It would also eliminate the primary crushing and screening steps, reduce the amount of dust to be removed, and retain the organic volatiles to enhance ignitability. Overall, this could greatly increase the yield of briquettes per ton of coal mined and reduce the cost per kcal to the consumer, which in turn could offset the greater cost of the closed stove. Such an alternative scheme should be considered.

3.8 BIOLOGICAL DURABILITY

Low density briquettes formed by the first, unsuccessful briquetter test described above were set aside for roughly five weeks. These include a small batch made with raw Maissade lignite, the rest being made of the pyrolized char. At the end of this time, the unpyrolized briquettes were covered with a conspicuous growth of mold, while those made with pyrolized char were not. This would indicate that the major components sustaining mold growth are those

*Further details of this project can be obtained from Mr. Mike White, Bepex Corporation, 333 N. Taft St., Minneapolis, MN, 55413, (612) 331-4370.

removed from the lignite by pyrolysis. Earlier it was observed that a mixture of char and molasses without the addition of lime also grew mold profusely. It is therefore tentatively concluded that the sucrose in the molasses becomes biologically inert when combined as calcium sucrate.

The chemistry of molasses was generally beyond the scope of this project. Upon running out of crude Haitian molasses, some retail grade U.S. molasses was used with surprising results. Though it smelled and tasted virtually idential, the U.S. molasses proved conspicuously ineffective as a binder. Further development of a briquetting industry in Haiti should include a better understanding of the variation in the molasses used as a binder.

4.0 PLANT DESIGN AND COST ESTIMATE

4.1 DESIGN ASSUMPTIONS

The following is a preliminary design for a plant to produce cooking briquettes from Maissade lignite, provide the minimum information needed by vendors for rough cost estimation and by an engineering/construction firm to work up a complete set of specifications and cost estimates for bidding purposes. There are two designs, for capacities of 10,000 and 50,000 metric tons per year, to establish the economy of scale for this process. Design suggestions and a rough cost estimate for a smaller scale pilot plant for field demonstration of the process concept are presented in a separate section.

One or more vendors of all major equipment items were contacted to recommend equipment sizes and models and to provide approximate costs. It must be kept in mind that vendors do not see a high probability of sales in a request for preliminary cost estimates and are understandably reluctant to expend much time on their responses. This is, unfortunately, especially true with the more costly items such as furnaces and boilers, that are essentially designed for each application.

A generalized process flow sheet, giving a material and partial energy balance is shown in Figure 4.1 Two alternative versions are presented, with all quantities in English and metric units. Each version gives all quantities for annual throughputs of (A) 10,000 and (B) 50,000 metric tons per year. Included are the same processing steps that are present in the plant of Husky Industries, producing cooking briquettes from North Dakota lignite at Dickinson, North Dakota.

The high ash levels in Maissade lignite may impose a liability on its acceptance by the average Haitian consumer. It is assumed here, however, that they will be minimally acceptable without processing steps to reduce the ash level. This assumption is made in the interest of establishing the bare minimum costs for such a plant, and also because preliminary washability data does not suggest that prewashing the raw lignite would achieve a significant ash reduction. The result is a process sequence that closely duplicates the Husky plant, which is quite old, probably as simple as possible, of proven efficiency and reliability and generally defines the state of the art in making cooking briquettes from lignite.

PROCESS FLOW SHEET: COOKING BRIQUETTES FROM MAISSADE LIGNITE (ENGLISH UNITS)

Figure 4.1A

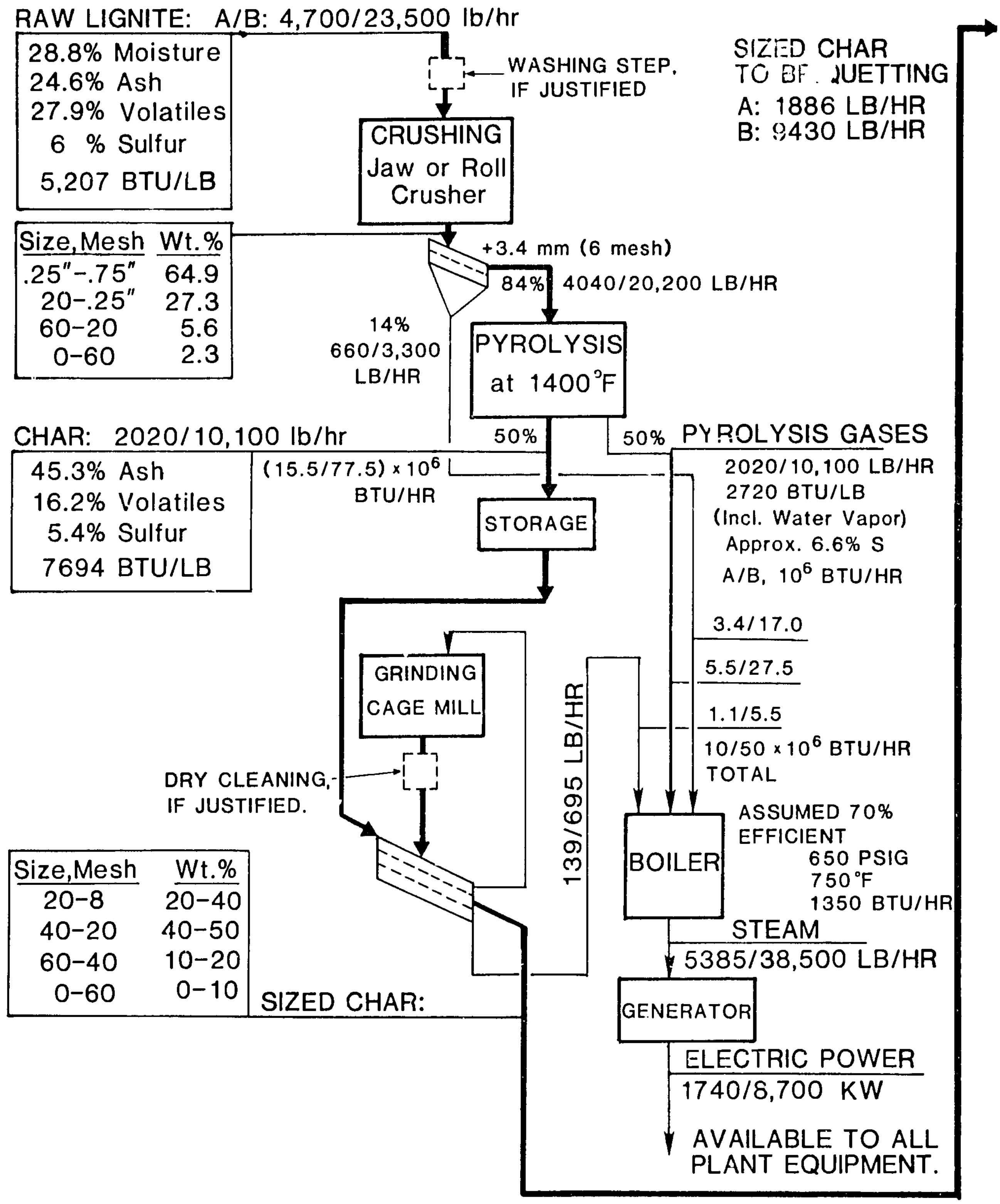


FIGURE 4.1A Process flow sheet: Cooking briquettes from Maissade Lignite (English Units).

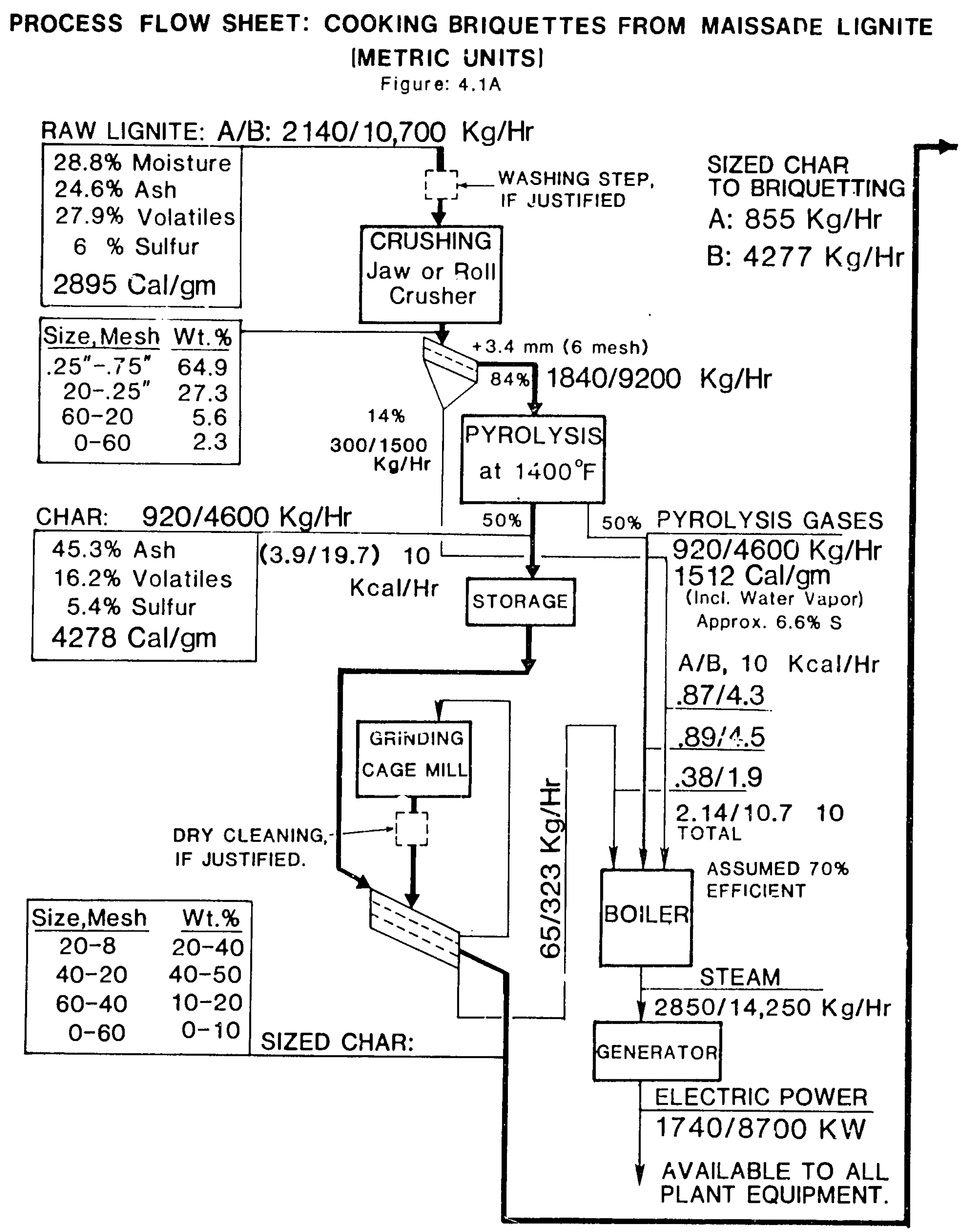


FIGURE 4.1A Process flow sheet: Cooking briquettes from Maissade Lignite (Metric Units).

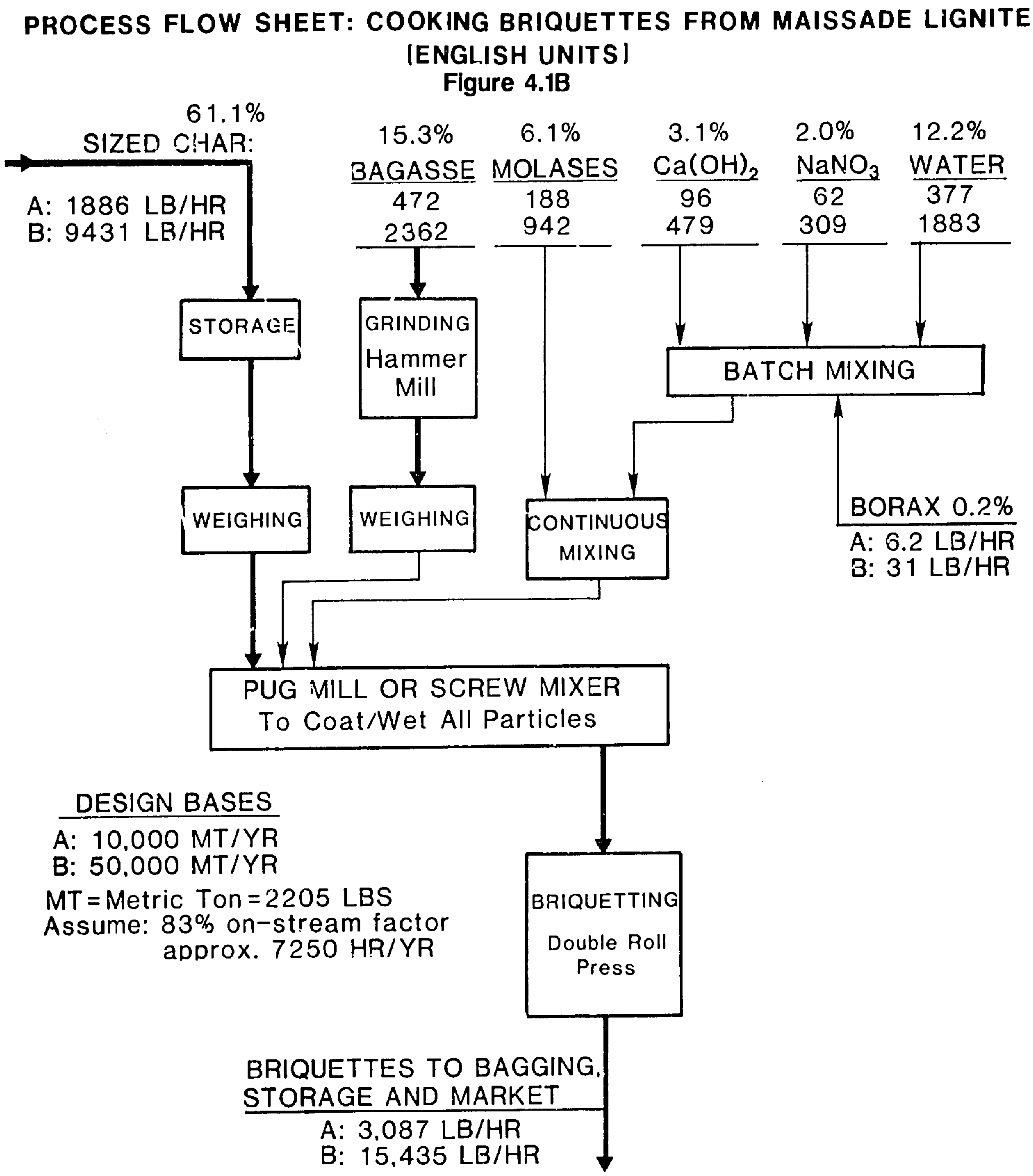


FIGURE 4.1B Process flow sheet: Cooking briquettes from Maissade Lignite (English Units).

PROCESS FLOW SHEET: COOKING BRIQUETTES FROM MAISSADE LIGNITE (METRIC UNITS)

Figure 4.1B

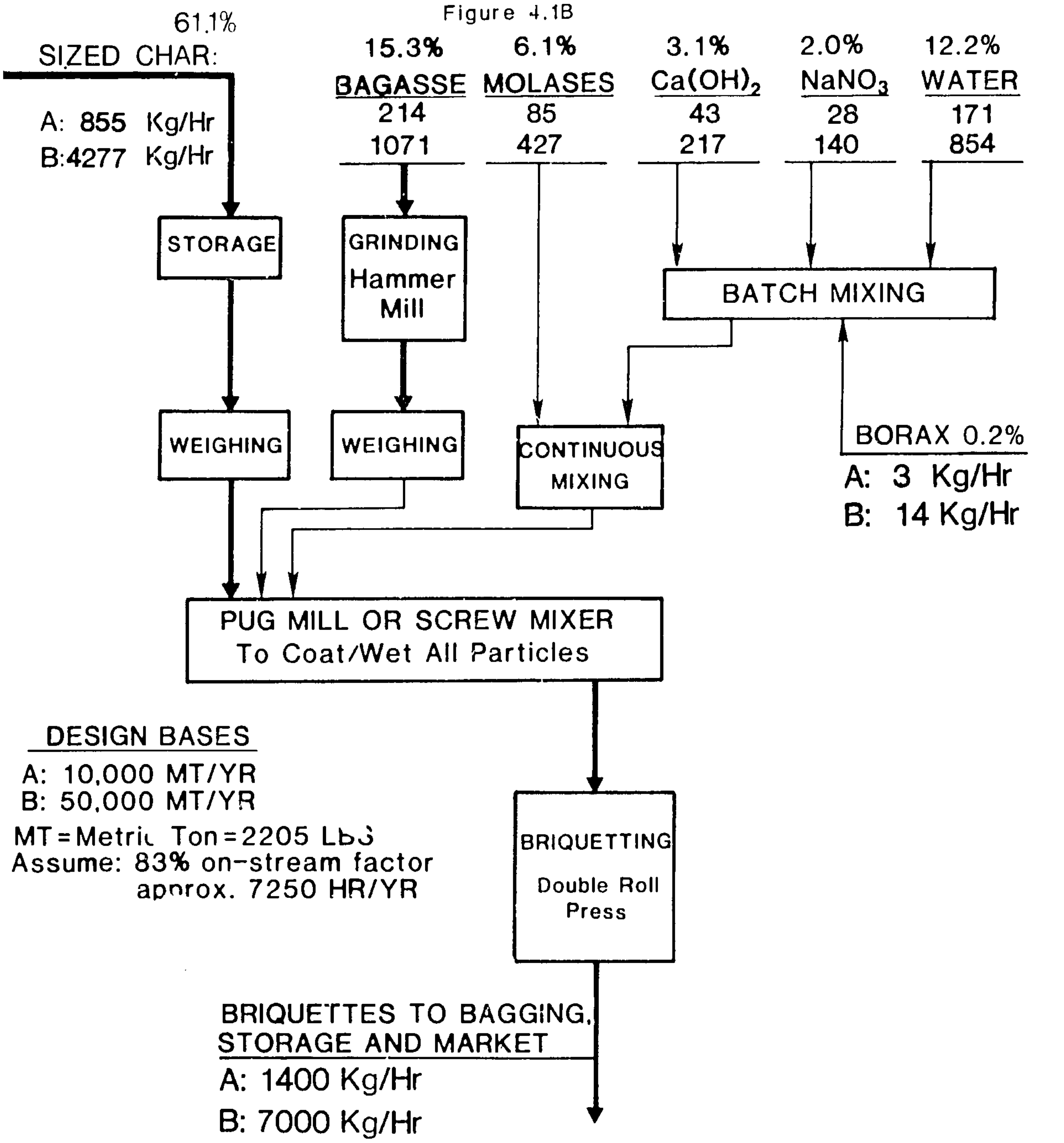


FIGURE 4.1B Process flow sheet: cooking briquettes from Maissade Lignite (Metric Units).

By far the greatest single cost in the proposed plant designs at either capacity level will be the pyrolyzer. This study asumes two alternatives for the pyrolyzer design. One is a multi-hearth furnace, as used in the Husky plant. The other is a traveling grate carbonizer offered by Mansfield Carbon Products of Nashville, Tennessee. A Mansfield unit is also in operation, producing coke from coal, which has been formed into briquettes.

By comparison, selection of most other equipment items is a simple matter. Screens, conveyor belts and mixers are available from a variety of manufactures. Any jaw or roll crusher should be adequate for the initial crushing of the coal. For final sizing of the pyrolyzed char, a cage impactor, offered only by Gundlach, has been found to give satisfactory results at the Husky plant. In no case should hammer mills be considered for raw lignite or char, as they will produce excessive fines which must be removed from the final briquetter feed, representing a reduced yield in terms of tons of briquettes produced per ton of raw coal.

Figure 4.2 shows on four sheets all the major equipment items required. For the pyrolysis unit it shows the multi-hearth furnace (per estimate from Chevond-Barry Engineering Co.) and, on an alternate Sheet 2, the proposed Mansfield Carbon system.

The particle size data given for the raw coal is an indication of Maissade lignite's mechanical and thermal friability, to predict the amount of lignite dust available to the plant's auxiliary boiler. It is based on UNDERC's data for raw lignite after passing through a jaw crusher set to a 3/4 inch nip. The Mansfield carbonizer assumes that the feed will not need to be pre-screened and all of it will go to the carbonizer, with more fines being removed at the screening step following pyrolysis. In the Husky plant the portion of the raw coal too fine for desirable briquetting is removed before pyrolysis, thus reducing the required capacity of the pyrolyzer. In the case of Maissade lignite, where ash levels are significantly higher in the finer size fractions, this pre-screening step will reduce somewhat the amount of ash carried through to the product briquettes. In an actual plant the sized char specification is that found suitable to make an acceptable briquette and defines the performance required of the cage mill.

In selecting equipment capacities, an on-stream factor of 10/12 was assumed. That is, the pyrolyzer will operate around the clock for a few long runs, adding up to ten months each year. If all goes smoothly, it may conceivably operate continuously for 10 months. With the objective of making the process as labor-intensive as possible and avoiding capital investment in over-capacity, it is assumed that all processing steps will also operate around the clock during pyrolizer runs. If everything can be kept running and coordinated for more than 10/12 of the year, then the plant's capacity can be increased accordingly, for the same capital investment. The proposed Mansfield system claims an on-stream time of around 95%, based on the performance of an existing plant. This, however, may be a bit optimistic for a new installation with newly-trained operators at a remote location in Haiti.

From the energy data of Figure 4.1 we can determine the available electric power. It is assumed, based on performance of the Husky plant, that the total power generated, from the fine coal and char and the pyrolysis gases, per Figure 4.1, is well above that needed by all motors in the plant.

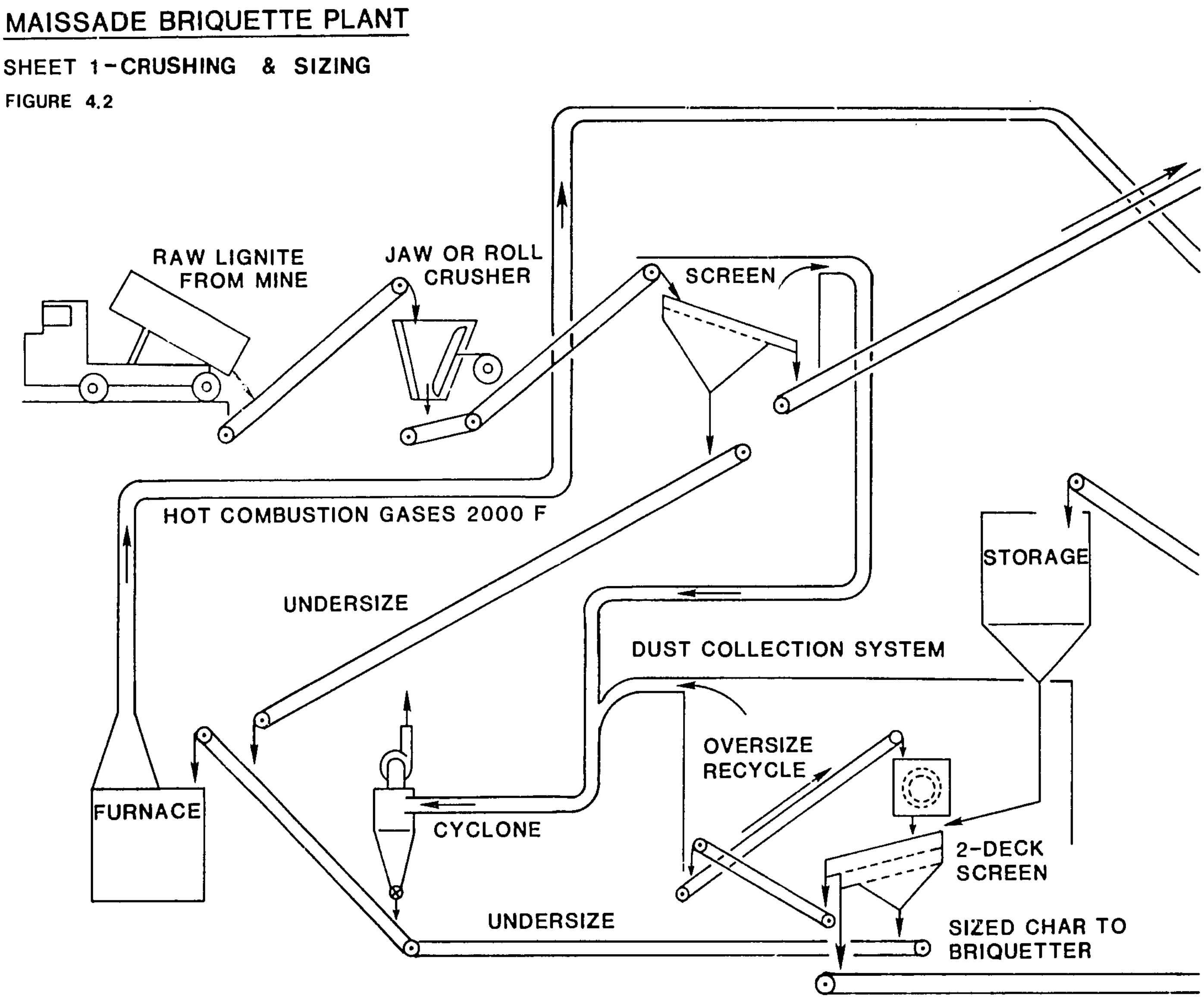


FIGURE 4.2 Maissade Briquette Plant - crushing and sizing.

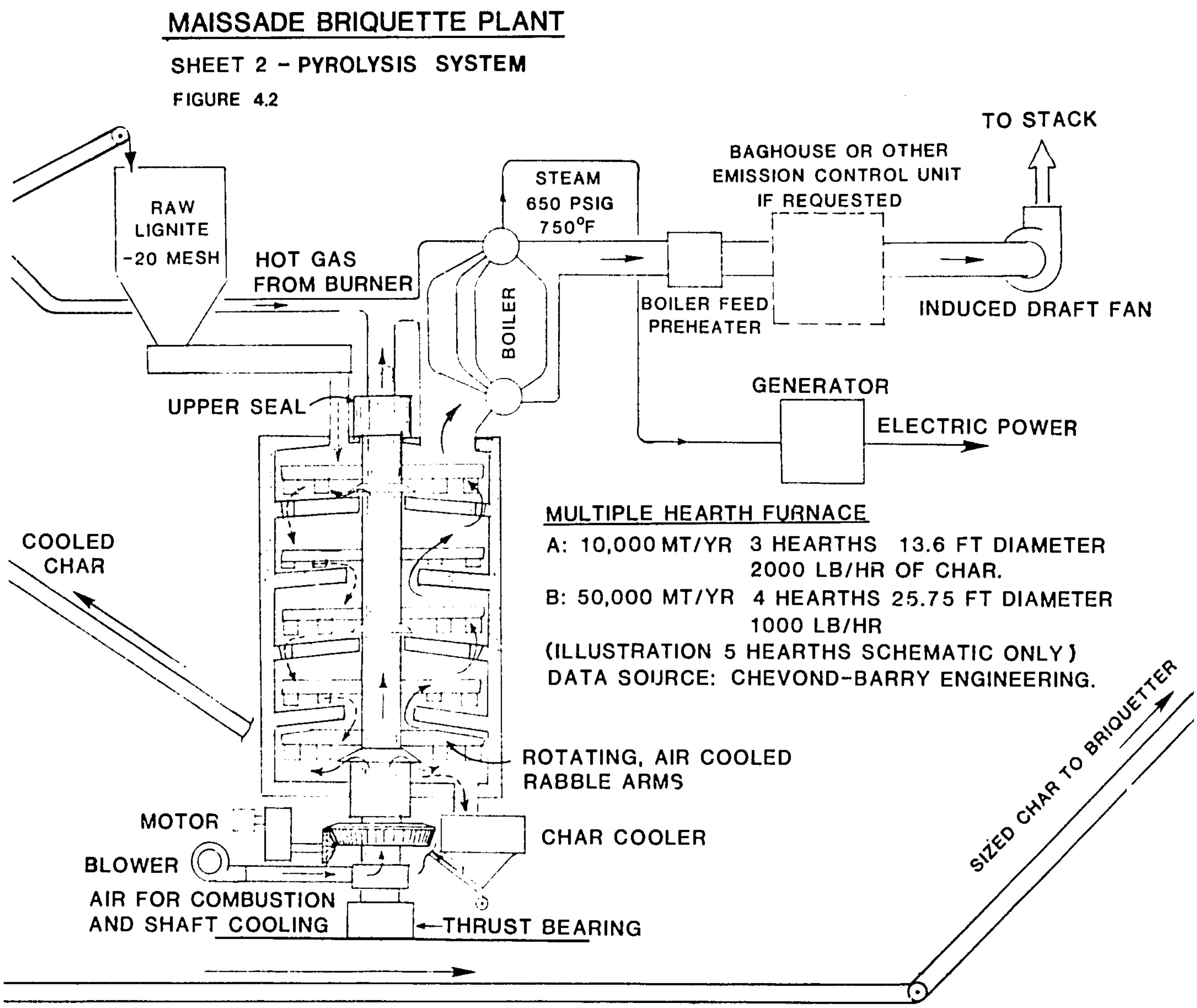


FIGURE 4.2 Maissade Briquette Plant - pyrolysis system.

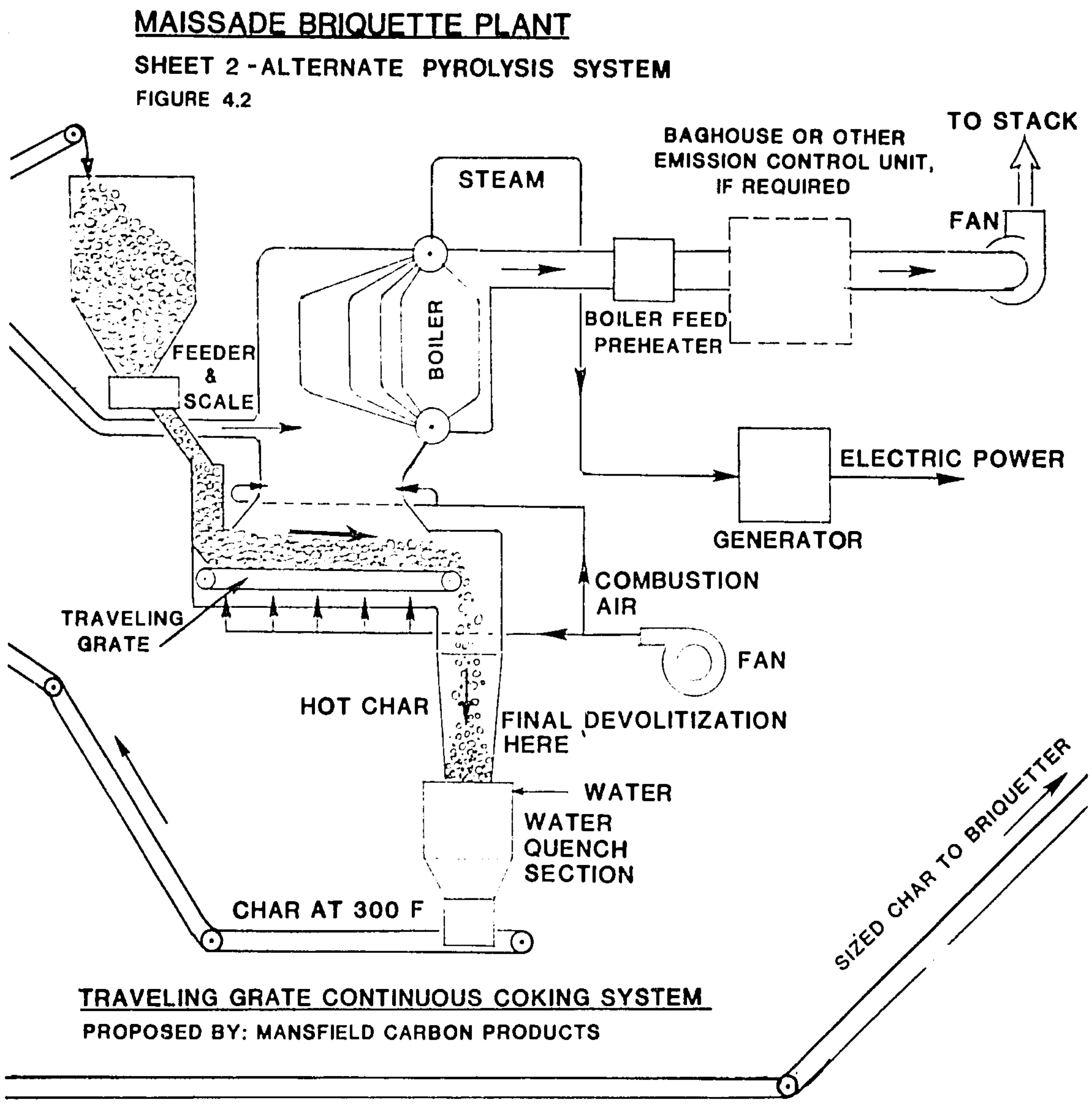


FIGURE 4.2 Maissade Briquette Plant - alternate pyrolysis system.

MAISSADE BRIQUETTE PLANT

SHEET 3 - BRIQUETTING

FIGURE 4.2

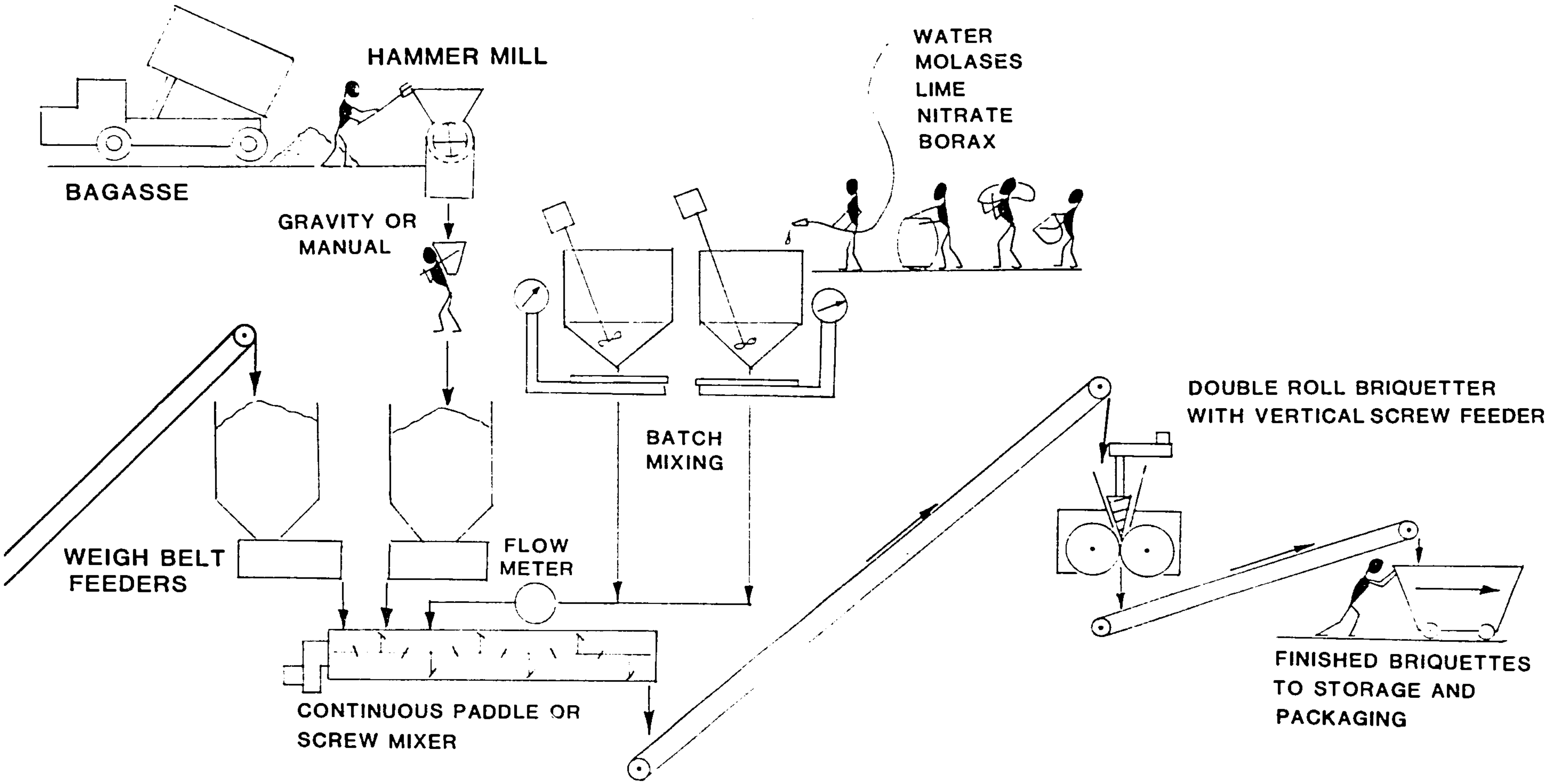


FIGURE 4.2 Maissade Briquette Plant - Briquetting.

A further reason for round-the-clock operation of the entire plant is the complexity of designing the boiler-generator system to operate at a greatly reduced level when waste heat from the combustion of the pyrolysis gases is not available. It should be pointed out that the boiler in Figure 4.1 includes the waste coal/char furnace of Figure 4.2.

One of the assumptions of Figures 4.1 and 4.2 was that the ratio of total feed to char produced is 2.5 to 3.0, as reported by Husky. Laboratory tests showed a 50% yield of char through the pyrolyzer, which it was assumed will apply roughly to the proposed plants, the remaining loss being as fines. The assumption of 14% of the raw coal being rejected as -6 mesh (3.4 mm) waste is based on UNDERC's jaw crusher performance. By difference, the remaining loss is assigned to the undersized char. In an actual plant, the 2.5 to 3.0 ratio of feed to char is submitted as a reliable performance criterion, while the actual distribution of losses, as coal fines, char fines and pyrolysis gases, will vary considerably with the relative dryness of feed and with minor variations in the operation of the crushing, grinding, screening and pyrolysis steps.

An overall design objective of the project is to minimize capital cost and make maximum use of the cheap labor available in Haiti. Thus a number of conveyors and automatic weighing steps can be avoided for some of the smaller process streams, such as the additives and binder components. Several laborers with baskets or shovels can serve the same purpose more economically. These are indicated on Figure 4.2. Many such decisions regarding manual or machine functions will probably not be possible until the plant is in final stages of design or even under construction.

While this report provides estimates of capital equipment costs, operating costs are not possible with standard assumptions used by typical engineering economic studies for plants to be built in the United States. Labor in Haiti is far cheaper and a mandate of the project will be to use as many people as possible, reduce the capital cost of instrumentation, control and materials handling components and to keep all equipment as simple as possible. The actual cost of labor, utilities, local raw materials as delivered at the plant site and amortiztion at available, subsidized interest rates must remain beyond the scope of this work.

All equipment costs given in this study are based on prices of new equipment, covered by manufacturers' warrantees, backed by the expertise and experince of those who design and install the equipment. Traditionally, this factor is a necessity to engineering-construction firms aspiring to bid on a diversity of projects. An alternative, suggested by an executive of Husky Industries, it that there may be enough reusable, surplus equipment present at several of Husky's plants or at other plants to supply most of the capital equipment required for a commercial scale plant, at a fraction of the cost of all-new equipment. To take advantage of this saving, however, would require finding and assembling an engineering, construction and start-up staff thoroughly familiar with plants of this type.

Mining operations, which are beyond the scope of this report, would only be active during the dry season of the year, so that lignite supplied to the plant will be from storage for roughly half the year. The stored lignite should be covered during the rainy season.

The length of conveyor belts cannot be estimated without preliminary plant layout and elevation drawings. For the purposes of this study, it is assumed that 12 coveyor belts will be needed and that all of them are 50 feet long by 18 inches wide. In the final design, some belts will be longer or shorter, while others may actually consist of two or more belts, while at least one, carrying feed to the top of the pyrolyzer, might be replaced by a bucket elevator.

4.2 PLANT COST SUMMARY: 10,000 AND 50,000 MT/YR.

The costs of all major equipment items of Figure 4.2 are given in Table 4.1. A completely responsible estimate, such as will be prepared by an engineerng-construction firm, will require several engineering man-months and involve careful comparison of competitive estimates by multiple vendors. It will also require attention to relatively minor items, which are not covered here. These would include, for example, boiler duct work, batch scales, minimal instrumentation, dust collection system, boiler feed water system, miscellaneous fans and pumps, and specific structures, such as storage bins. For the scope of this study, such items are assumed included in the installation cost factor, along with minimum structures, foundations and utilities.

The installation cost factor is difficult to predict for grass-roots construction in remote, overseas locations. For the envisioned, no-frills project, it would be kept minimal. In Table 4.1, this factor is assumed at both 1.3 and 1.6, on the advice of Chevond-Barry Engineerng who are experienced in the design and construction of multi-hearth furnaces and associated materials handling systems.

4.3 ONE-TON-PER-HOUR PILOT PLANT

To demonstrate acceptability of lignite briquettes on the Haitian market, it is proposed to build a pilot plant, of roughly one-ton-per-hour feed capacity, to produce test batches of briquettes, while experimenting with different formulations. As a pilot plant is not expected to be economically efficient, various simplifications are possible to reduce capital cost and increase versatility.

It is assumed that the plant will not be operating as continuously as a full-scale production facility would, so that capacities of the different equipment components need not be synchronized. For instance, a minimum size pyrolyzer, of say 1000 Lb/Hr capacity, could be operated continuously for a month, with the other components of higher capacities operating at the ton per hour level or higher for shorter periods. Because of the smaller throughput, even greater use can be made of manual labor, particularly in the various feeding and transfer operations, with more workers working harder but for shorter periods.

TABLE 4.1

EQUIPMENT COST SUMMARY

Equipment Item	Estimated Cost, $ 10,000 MT/Yr	50,000 MT/Yr	Source
PYROLYSIS UNIT PLUS BOILER			
1-A Moving Bed Type Pyrolizer, incl: feeder, boiler, bunker stack, fans and hot char conveyor.	2,590,000 (Installed*)	4,580,000	Mansfield Carbon Products
1-B Alternative: Pyrolizer, multi-hearth type, incl. only furnace and inlet blower.	550,000 (Installed*)	1,000,000	Chevond-Barry Engineering
(Following "-B" items are accessoreis for 1-B, required to make alternative package B equivalent to package A.)			
2-B Coal feeder for pyrolizer.	20,000	50,000	Rexnord
3-B Boiler (Incl. superheater, economizer, deaerator, soot blowers, valves, piping, instruments)	350,000	450,000	Deltak
4-B Hot char screw conveyor with water quench	10,000	20,000	(Physically similar to Item 12)
Total of Items 2-B through 4-B, X installaion factors of 1.3 (low) and 1.6 (high)	494,000 608,000	676,000 832,000	
Total for package B, = above costs, + Item 1-B (For comparison with 1-A) (low) (high)	1,044,000 1,158,000	1,676,000 1,832,000	

TABLE 4.1 (Continued)

ENERGY RECOVERY SYSTEM, OTHER THAN BOILER

5 Fine rejects furnace (fluidized bed)	200,000	300,000	EPI (Energy Products of Idaho)
7 Generator	150,000	---	Skinner (2000 KW)
" "	---	600,000	Asume above X4, for 8,000 - 9,000 KW
Subtotal of Items 5 through 7, X installation factors of 1.3 (low)	455,000	1,170,000	
and 1.6 (high)	560,000	1,440,000	
ALL COMPONENTS OTHER THAN PYROLIZER THAT CONTACT PRODUCT DIRECTLY			
8 Primary roll crusher (Same for both capacities)	46,000		Rexnord
9 Feed screen (4 req'd for higher capacity)	15,000	60,000	Rexnord
10 Product screen	15,000	60,000	Rexnord
11 Char grinder (gage mill)	25,800		Rexnord/Gundlach
12 12 Conveyor Belts all 50' X 18"	180,000		Rexnord
13 Continuous solids mixer	8,000	11,000	Marion Mixers
14 Hammer mill for bagasse	25,000		(Assumed same as Item 14)
15 Belt feeders for char and bagasse (2 req'd)	22,000	50,000	Rexnord (Assume similar to 2-B smaller,simpler)
16 Double roll briquetter	65,000	135,000	Bepex
Total purchased equipment costs of 9 through 16	402,300	593,300	
Approx. installed cost of above sub-totals, assuming 1.3 factor (low)	522,990	771,290	
1.6 factor (high)	643,680	949,280	

TABLE 4.1 (Continued)

TOTAL PLANT COST, INSTALLED:

Sums of above installed costs, rounded off to 2 significant digits.

	10,000 MT/Yr	50,000 MT/Yr
With Package A (Moving Bed Pyrolizer)		
Low	$3,600,000	$6,300,000
High	3,800,000	7,000,000
With Package B (Multi-hearth Pyrolizer)		
Low	2,000,000	3,600,000
High	2,400,000	4,200,000

For some components, such as the crusher, cage mill and conveyor belts, the minimum sizes offered for the larger of the plants described above amount to a great excess capacity for a ton-per-hour pilot plant or even for the 10,000 MT/Yr plant, which receives raw lignite feed at only about 2.5 tons per hour. Construction and operations of the pilot plant is based on the assumption that pilot project conclusions will probably justify later expansion to full-scale production. It is therefore recommended that the inherrently excess capacity items be selected as the same sizes and models cited for the two levels of full-scale production described above. At the conclusion of the pilot scale effort, they will be available as components of the commercial production plant. By careful shopping around, smaller and/or used crushers, grinders, screens and mixers might be found at substantial savings. The costs of all major components for this pilot plant are given in Table 4.2.

A large part of the complexity of the full-scale plant design is in the heat recovery and electric generation factilities. These will be eliminated from the pilot plant design. Pyrolysis gases will simply be flared as waste and the undersized lignite and char discarded, or sold on the local market if one exists. Electric power for the pilot plant will be provided by a standard diesel generator set, which should be easily sold later for capital recovery. The Husky plant generates all of its own electric power and could generate an excess for sale by the addition of more efficient boiler accessories. Thus it is assumed here that the pilot plant will require, as a maximum, the amount of electric power that could be generated if all waste combustibles were recovered. The 1000 KW specified appears adequate to power the plant and provide lighting for the immediate vecinity.

TABLE 4.2

CAPACITY: APPROXIMATELY 2000 LB/HR OF RAW LIGNITE FEED

Capacity: Approximately 2000 Lb/Hr of raw lignite feed

Equipment Item	Estimated Cost,$	Source
1 Milti-hearth furnace 3 hearths, 8.4 ft ID (Installed)	420,000	Chevond-Barry Engineering
(Alterntive, if reduced capacity considered 4 hearths, 4.5 ft ID)	<350,000>	" " "
2 Primary crusher *	46,000	Rexnord
3 Feed screen	15,000	Rexnord
4 Product screen *	15,000	Rexnord
5 Continuous solids mixer *	8,000	Marion
6 Hammer mill for bagasse *	25,000	Rexnord
7 Belt feeder for raw lignite *	20,000	Rexnord
8 Weighing and feeding of char and bagesse to mixer	negligible	Assumed batch and manual
9 Double roll briquetter with feed screw	50,000	Bepex
10 6 conveyor belts 20 ft x 18 inches wide 5000 each	30,000	Rexnord (*, but cost proportional to length)
Sub-total of items 2 through 10 X 1.3 as minimal installation factor	727,350	
Add Item 1 for installed cost of all direct product handling equipment	1,147,350	
11 Diesel generator set 1000 kw continuous	150,000	Diesel Power Systems, and Caterpillar
TOTAL COST OF PILOT PLANT	$1,297,350	

* Capacity and cost of equipment item assumed same as for smallest of full scale plants, representing smallest units offered by same manufacturers.

Within the objective of estimating a minimal plant cost, some major components have been omitted, that would be standard items in a U.S. location. One of these is a baghouse or other means of stack emmisions control, which should be included in later, more detailed cost studies, if required by Haitian environmental authorities. It is also assumed that the packaging/shipping facilities will be very simple and labor intensive, such as a large shed where workers pour briquettes into cheap sacks and load them onto vehicles, consistant with current Haitian practice in the distribution of wood charcoal.

5.0 CONCLUSIONS AND RECOMMENDATIONS

It is possible to produce durable cooking briquettes from Maissade lignite, using a molasses-lime binder. While the high ash level detracts from the briquettes' heating value, this can be compensated by the addition of shredded bagasse, which also enhances ignitability.

A near-optimum formulation, determined by the laboratory work reported here, is roughly 60% to 65% Maissade lignite char, pyrolized at roughly 760°C (1400°F), 15% bagasse, 6% molasses, 3% $Ca(OH)_2$, 0.2% borax and the remainder water. The briquettes must be formed at a pressure of 7 tons per square inch (about 1000 kg/cm^2), with a screw feeder to pre-compress the feed between the rolls of a double roll briquetting machine.

Slightly different proportions will probably be indicated by pilot scale testing, using a continuous pyrolysis furnace, though the above formulation is suitable for the material balance and capital cost estimate presented here. Minor variations in coal composition within the seam, in size distribution of bagasse, in composition of molasses and in the pyrolyzer and briquetter operating parameters may alter optimum composition. It is RECOMMENDED that a pilot plant be built to study these variations under operating conditions, as well as to produce test market batches of briquettes and to train operating personnel.

Using the above, near-optimum formulation, the product briquettes will have a heating value of around 4,230 cal/gm (7,600 Btu/Lb), as compared with 6,100 cal/gm (11,000 Btu/Lb) for typical U.S. barbecue briquettes made from North Dakota lignite. Maissade briquettes will have about twice the ash content as the North Dakota lignite briquettes, and far higher than the ash content of wood charcoal as currently used in Haiti. Their market acceptability will have to rest on their relative selling price, in $/Btu or equivalent, which is beyond the scope of this report.

The high sulfur content of Maissade lignite presents little or no problem as most of it is organic sulfur and removed during pyrolysis. The remainder is tightly bound as $CaSO_4$ by the unusually high calcium content of this lignite, so that no significant bad odors or polutants are given off during combustion. The 750°C (1380°F) pyrolysis temperature is required to drive off noxious, volatile tars, as well as organic sulfur.

The effectiveness of the 2:1 molasses-lime binder is not unique for briquetting coal. Its effectiveness is fairly sensative to minor variation in molasses composition. It was found that highly sanitized U.S. commercial molasses was notably less effective as a binder than the bulk Haitian molasses used. While mold grows profusely on the raw lignite, pyrolysis destroys the biodegradable components. Molasses apparently becomes biologically inert when the sucrose is bound as calcium sucrate binder.

Relatively long, coarse bagasse fibers improve the durability of these briquettes, though they may detract from their aesthetics. Excessively fine bagasse or char both increase the amount of binder needed to coat all particles adequately. The total amount of bagasse can be increased to any level, even exceeding that of the lignite char, without adverse effect on burning properties or fuel value. In a production plant the ratio of char to molasses can be varied over a broad range to best accomodate daily logistics of availability and delivery cost of each.

Sodium nitrate, $NaNO_3$, is added to enhance ignitability of the briquettes, as is standard practice in production of U.S. barbecue briquettes from North Dakota lignite. The borax is added as a wetting agent and as a mold release agent. The nearest commercial source of nitrate to Haiti is in Chile, and the nearest sources of borax are probably in the Mojave desert of California. All other ingredients are native to Haiti. The cost of imported borax is neglegible. The level of nitrate and the cost might be reduced by increasing the bagasse level and by further optimization of particle sizing of the char, both by amounts that could be determined through continuous pilot scale operations.

The size and shape of the briquetes is unimportant, except that for good combustion they must have a surface-to-volume ratio at least as great as the standard U.S. pillow shape. All the experience of this project indicates that a pillow, or similar near-square shape, of 2 to 5 centimeters on a side, will give good results.

The ratio of raw lignite feed to pyrolyzed char is roughly 2.5 to 1.0, from the laboratory data of this study and from operating data at a plant producing briquettes from North Dakota lignite. The amount of loss during pyrolysis is slightly greater than the final, remaining char. The remaining losses are the dust rejected from the primary and secondary grinding an screening. The combined dust and volatiles can be burned in a boiler to produce the entire supply needed by the plant, which will be independent of any local power source.

For a capacity of 10,000 metric tones/year (MT/YR), the installed capital cost of complete briquette plant is estimated to range from $2,000,000 to $3,800,000 (U.S.), depending on variation in choice of equipment and assumptions as to installation costs. For a capacity of 50,000 MT/YR, approximating the total potential market in Port au Prince, the capital cost is estimated to range between $4,200,000 and $7,000,000 (U.S.). These figures assume coal delivered from the mine and the briquettes stored in a pile, ready for manual packaging.

A pilot plant, to produce briquettes from roughly a ton-per-hour of raw lignite, is estimated to cost around $1,300,000 complete with its own diesel power plant.

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APPENDIX

EQUIPMENT VENDORS

The following is a list of equipment manufacturers, vendors and contractors, whose products and areas of expertise appear unique to the requirements of the plant design described herein, or who have been particularly helpful in providing estimates to this study.

* Chavond-Barry Engineering Corp.
P.O. box 157, Glen Gardner, New Jersey 08826
201-537-6565 Contact: Mr. Lou Barry, VP

Designer and builder of multi-hearth furnaces in all sizes. Offers complete engineering and construction services for most sections of complete lignite-to-briquettes plant.

* Mansfield Carbon Products
814 Chruch St., Nashville, Tennessee 37203
615-252-3652 Contact: Mr. Vaugn Mansfield, Press.

Designer and builder of alternative, moving grate pyrolizer furnace. Offers complete engineering and construction services for most sections of complete plant.

* T.J. Gundlach Machine Division of Rexnord Corp.
P.O. Box 385, Bellville, Illinois
618-233-7208 Contact: Mr. Dan Miller

Rexnord Divisions, including Gundlach, offer "one stop shopping" for roll crushers, cage mills, conveyor belts, screens and weigh-belt feeders. Estimates for most of these items were obtained from Mr. Miller at Gundlach.

* Bepex Corporation
333 NE Taft St., Minneapolis, Minnesota 55413
612-331-4370 Contact: Mr. Mike White

Manufacturer of double roll briquetting machines. Experience in applications involving coal with molasses-lime binder. Also familiar with this project, another division of the company makes continuous paddle mixers.

* EPI (Energy Products of Idaho)
4006 Industrial Ave., Coeur d'Alene, Idaho 83814
208-765-1611 Contact: Michael W. Oswald, VP, Sales.

Manufactures a fluid bed combustor, from which hot gases can be ducted to the boiler mounted on the pyrolyzer furnace. This is an unusual item, for which alternative/competition may be difficult to find.

* Husky Industries
Drawer 1, Dickinson, ND 58601
701-225-6023 Contact: Kent Hudson, Plant Manager

Though a producer of charcoal briquettes and not in the equipment business, Husky has an assortment of recoverable, used equipment spread through several plants, that could be purchased at considerable savings.

The above companies are recommended for future, detailed plant design efforts, as a result of considerable technical discusion and assistance in the course of this project. The following companies represent the first that could be found through telephone inqueries, whose products appeared acceptable for estimating purposes, but not necessarily unique or optimum. For complex though semi-standard items, such as boilers or generators, it is assumed that appropriately skilled designers within an engineering-construction firm will locate and review a wider range of vendors in far more detail.

* Rapids Machinery Company
  P.O. Box 286, Marion, Iowa 52302
  319-377-6371 Contact: John Winistorfer, Sales Mgr.

Manufactures Marion Mixers, Inc. continuous paddle mixers.

* Deltak
  Minneapolis, Minn.
  612-544-3371 Contact: Ms. Sandra Broekema

Offers boilers, mountable on multi-hearth pyrolysis furnaces, capacities covering range of 6000 to 40,000 Lb/Hr of motive steam at 650 psig/750°F. Fans, soot blowers and ecoonomizers included.

* Skinner Turbine Co.
  Erie, Penn.
  814-454-7103

Manufacturers a 2000 KW steam turbine-generator.

* Western Engine Co., Power Systems Div.
  750 Route 53, Itasca, Illinois
  312-773-5700 Contact: Mike Rutter

Offers 1000 KW, continuous diesel generator set.

* Caterpillar Diesel
  Any sales outlet.

Offers units comparable to above, at similar cost/KW.

* K.R. Komarek, Inc.
  1825 Estes Ave., Elk Gove, Ill. 60007
  312-956-0060 Contact: Richard K. Komarek

Offers briquetting machines, similar to those of Bepex, above.

* Dresser Industries, Inc.
  Jeffrey Div., Processing Equipment
  P.O. Box 387, Woodruff, S. Carolina 29388
  803-476-7523 Contact: Mr. Chuck Wolfe

Offers a flex-tooth, single roll crusher, comparable in performance to a double roll or jaw crusher. (Plant design engineers will have individual preferences between these kinds of primary crushers. In most cases, performance differences will not be significant.)

For screw conveyors, with spray cooling added for hot char quench, or small additional units, not specifically identified here, a great variety of manufacturers are available, with no significant differences in simple designs that might be needed for this project. Check yellow pages or Thomas Register.

Though coal washing was not found to be a necessary addition to the process, within the scope of this study, reduction of ash levels in Maissade by mechanical cleaning MIGHT be considered in the future IF the present plant design allows any margin for additional processing steps and IF future studies reveal anything to be gained by a washing step. The following manufacturers are aware of this study and offer a wide range of coal cleaning equipment for future reference.

* Dresser Industries, Jeffrey Manufacturing Division
  P.O. Box 3080, Greenville, S. Carolina
  803-288-7324 Contact: Richarch J. Adams, General Product Mgr.

* Roberts and Schaefer Company
  120 South Riverside Plaza, Chicago, Illinois 60606
  312-236-7292 Contact: Mr. Phillip C. Reeves, Sr. VP

Offers range of coal cleaning equipment and has experience with emerging lignite industries in developing nations.

* McNally Pittsburg International, Inc.
  (includes Kennedy Van Saun Corp.)
  Danville, Pennsylvania 17821-0500
  717-275-3050
  Contact: Mr. John J. Glista, Senior Project Engineer