DOE/PC/93/57--79

IMPROVEMENT OF STORAGE, HANDLING,
AND TRANSPORTABILITY OF FINE COAL

Contract No. DE-AC22-93PC93157

FINAL REPORT

RECEIVED
OCT 07 1996
OSTI

Prepared for:
U.S. Department of Energy
Pittsburgh Energy Technology Center
P. O. Box 10940
Pittsburgh, PA 15236-0940

Submitted by:
Energy International Corporation
135 William Pitt Way
Pittsburgh, PA 15238
Project Manager: Russell C. Maxwell, Jr.
Principal Investigator: Philip R. Jamison

RECEIVED
USDOE/PETC
36 SEP -5 AM 8:49
ACQUISITION & ASSISTANCE DIV.

March 5, 1996
Revised: August 28, 1996

MASTER

~~U.S./DOE Patent Clearance is not required~~
prior to publication of this document

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CLEARED BY
PATENT COUNSEL

29

TABLE OF CONTENTS

	Page No.
1.0 INTRODUCTION	1
2.0 HOST SITE DESCRIPTION	5
3.0 CHARACTERIZE PROJECT FEEDSTOCK	9
3.1 Filter Cake	11
3.2 Froth Concentrate	14
4.0 EVALUATE ALTERNATIVE FEED SOURCES	18
4.1 Filter Cake	18
4.2 Laboratory Testing	20
4.3 Flocculent	22
4.4 Centrifuge	24
5.0 EVALUATE THE APPLICATION OF THE MULLED COAL PROCESS	26
5.1 Flotation Performance Tests	28
5.2 Repeatability Tests	31
5.3 Parametric Testing	35
5.4 Pilot Plant Testing	42
5.5 Stability Tests	46
6.0 PROCESS DESIGN ENGINEERING	53
6.1 Site Survey	53
6.2 Interface Design	56
6.3 Pug Mill Design	58
6.4 Surge Feeder Design	59
6.5 Reagent Delivery System Design	61
6.6 Take-Off Design	70
6.7 Chute Design	73
6.8 Access Design	75
6.9 Circuit Control Design	77
6.10 Control Room Layout	82
6.11 Preliminary Sketches	86

TABLE OF CONTENTS **(Continued)**

	Page No.
7.0 DETAILED ENGINEERING	93
7.1 Major Equipment Components	93
7.2 Bills of Material	94
7.3 Detailed Engineering	94
7.4 Electrical Controls	103
8.0 PROCUREMENT	109
9.0 CIRCUIT INSTALLATION	110
9.1 Mechanical Subcontractor	110
9.2 Electrical Installation	110
10.0 SHAKEDOWN OPERATIONS	113
10.1 Dry Run Tests	114
10.2 Wet Run Testing	116
11.0 PRODUCTION OPERATIONS	134
11.1 Feed Rate	134
11.2 Daily Production	142
11.3 Manpower	144
11.4 Hauling Mulled Coal	146
11.5 Stockpile	146
11.6 Production & Delay Time	147
11.7 Quality Control	151
11.8 Reagent Consumption	152
11.9 Special Samples	154
12.0 DECOMMISSIONING OPERATIONS	163
13.0 SHIPMENT DEMONSTRATION	165
13.1 Background	165
13.2 Stockpile Coal Temperature	165
13.3 Stockpile Condition Prior to Shipment	165
13.4 Hauling Arrangements	165
13.5 Loading	166

TABLE OF CONTENTS
(Continued)

	Page No.
13.6 Dumping and Handling at the Gorgas Station	166
13.7 Conclusion	166
14.0 COMMERCIAL CONSIDERATIONS	168
14.1 Commercial Applications	168
14.2 Major Equipment	172
14.3 Capital Cost <i>removed</i>	175
14.4 Operating Cost <i>removed</i>	179

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LIST OF FIGURES

Figure No.	Title	Page No.
1	Chetopa Location Map	6
2	Chetopa General Arrangement	7
3	Simplified Schematic Circuit Diagram	8
4	Size Distribution Analysis	10
5	Commercial Testing Proximate Analysis	12
6	Characterization Tests - Filter Cake	13
7	Froth Cell Performance	15
8	Characterization Tests - Froth Concentrate	16
9	Alternative Feed Sources	19
10	Filter Cake Vs. Froth Concentrate	23
11	Available Area for Take-off	29
12	Denver Cells Vs. Wemco Cells	30
13	Denver Cells Performance	32
14	Denver Cells - Ash Distribution	33
15	Flotation Release Analysis	34
16	Repeatability of Uniformity Tests	36
17	Effect of Size Distribution on Mullability	38
18	Effect of Moisture on Mullability	39
19	Effect of Reagent Dose on Mullability	40
20	Effect of Temperature on Mullability	43
21	Mulled Coal Pilot Plant	44
22	Freeze Resistance Drop Shatter Test	48
23	Freeze Test - Uniformity Results	49
24	Propensity to Slide Tests	51
25	Chetopa Plant Column Lines	54
26	Trackside Elevations	55
27	Available Sites	57
28	Pug Mill	60
29	Projected Reagent Usage	63
30	Reagent Pump Curve	64
31	Reagent Delivery System	66
32	Reagent Spray Manifold	67
33	Pug Mill - Feed End Cover	68
34	Location of Reagent Drums	69
35	Slipstream Take-off Point	71
36	Chute Arrangement	74
37	Mulled Coal Chute	76
38	Personnel Entrance	78
39	Access Steps and Hoist Doors	79
40	Inside Access Steps	80

LIST OF FIGURES (Continued)

Figure No.	Title	Page No.
41	Projected Reagent Flow Rates	83
42	Control Room Layout	84
43	Main Project Bay	85
44	Schematic Flow Diagram	87
45	Machinery Plan at Elevation 476'	88
46	Machinery Plan at Elevation 467'	90
47	Machinery Plan at Elevation 458'	91
48	Machinery Elevations Between Columns	92
49	Bill of Materials - Pipe Supplies	95
50	Bill of Materials - Pipe Supplies	96
51	Bill of Materials - Fabricated Parts	97
52	Bill of Materials - Fabricated Parts	98
53	Bill of Materials - Structural Steel	99
54	Bill of Materials - Electrical Equipment	100
55	Bill of Materials - Electrical Equipment	101
56	Bill of Materials - Miscellaneous Equipment	102
57	Electrical Circuit Diagram	105
58	Electrical Circuit Diagram	106
59	Electrical Circuit Diagram	107
60	Electrical Circuit Diagram	108
61	Indicated Feed Rate	120
62	Centrifuge Dam Position	123
63	Moisture Analyzer Installation	129
64	Moisture Analyzer - General Arrangement	130
65	Feeder Discharge - Tube Extension	131
66	April Production Summary	135
67	May Production Summary	136
68	June Production Summary	137
69	Three Month Production Summary	138
70	Chetopa Plant Delays	139
71	Take-Off Delays	140
72	Mulled Coal Circuit Delays	141
73	Daily Production Record	143
74	Moving Average Daily Production	145
75	Quality Control Test Results	153
76	Reagent Usage	155
77	Product Reconstruction Test	157
78	Screen Bowl Centrifuge Product Analyses	158

LIST OF FIGURES
(Continued)

Figure No.	Title	Page No.
79	Particle Size Stratification	160
80	Air Drying Effect	162
81	Power Station Coal Receiving Setup	167
82	Pug Mill Specifications	173
83	Surge Feeder Specifications	174
84	Reagent Cost Per Mulled Ton	184
85	Reagent Cost Per Clean Ton	186
86	Operating Cost Summary	187

ACKNOWLEDGEMENTS

This report describes a complex demonstration project carried out in an industrial setting under contract to the U.S. Department of Energy. We would like to acknowledge a number of the direct and indirect contributions that have had a bearing on the success of this project.

- The U.S. Department of Energy for their sponsorship of this project, and Mr. William P. Barnett (Contracting Officer's Representative) who facilitated the DOE's response to various technical issues over the course of the contract.
- Energy International Corporation who contributed a number of personnel including: Russell Maxwell (Project Manager); Ron Magalich (Lab Technician); George Allison (Lab Technician & Alabama Operations); Alan Singleton (Executive Responsibility); Burl Davis (Senior Consultant); Ed Albaugh (Consultant); Jean DeCroo and Carla Lunden (Report Preparation).
- Beard Technologies, Inc. who provided a portion of the private cost share and who supplied one of the key technical contributors, Phil Jamison (Principal Investigator).
- The Drummond Company who contributed both the host site for the project and a thoughtful and helping hand at every step along the way. We would especially like to acknowledge John McClellan who was the senior Drummond official responsible for our project. His guidance, helpful suggestions and encouragement throughout the planning, construction and production phases of the project were instrumental to our success. We would also like to thank Lawrence Bice, plant superintendent, and all of the other employees at the Chetopa preparation plant. They were always there to help when we needed them -- which was often.
- Decanter Machine, Inc. who generously contributed the use of an 18"x42" screen bowl centrifuge for the life of the project. The use of the centrifuge greatly reduced the complexity and cost of the task of taking out a 3 TPH slipstream from the Chetopa fine coal circuit. A special thanks to Ken Robinette who made all of this possible, and who saw to it that we had a Decanter Machine service man at our door-step within a few hours if we were having any problems with the operation of the machine.

1.0 INTRODUCTION

Since mechanization was introduced to the coal industry, underground mines have always produced a certain amount of 28M x 0 coal which is difficult to clean and difficult to market. Substantial productivity gains in underground mining have been achieved over the past four decades through the introduction of faster cutting continuous miners and shearing machines, however these gains have come at the expense of substantial increases in fine coal production. Faster cutting and more horsepower at the point of attack results in higher percentages of fine coal in the run of mine product. Not only is fine coal production on the rise, the fines produced are higher in ash. The shear size, weight and power of modern coal cutting equipment makes it very difficult to avoid cutting out of the coal seam into clay bottoms and various top rocks. The majority of this out of seam contamination ends up in the finest size fractions -- especially when it gets wet.

While the percentage of 28M x 0 coal has been increasing, market resistance remains steadfast. A portion of that resistance stems from the fact that the 28M x 0 size fraction is generally higher in impurities and lower in heat value than the coarser size fractions, but the primary objection has always been that fine coal causes handling problems. When it is too dry it causes airborne dust problems, and when it is too wet (as is normally the case), it can cause plugging, fouling, bridging, carry back and freezing problems in conventional coal storage, transportation and conveying systems.

It is very difficult to prepare the 28M x 0 size fraction in such a way that it satisfies market requirements for both heat value and handling characteristics. There are a number of existing and emerging washing processes which can be used efficiently to prepare 28M x 0 coal so that it meets or exceeds market requirements for ash content and heat value, but they are all wet processes, and clean coal comes off the washing equipment as a high moisture slurry. The problem is that, with the use of conventional equipment and wisdom, it is always difficult, and sometimes very expensive (and sometimes even impossible) to dewater 28M x 0 clean coal slurries down to that narrow moisture range where the product is neither too dry nor too wet to be accepted in the market.

To put the problem in some perspective, it should be noted that there is in excess of 100 million tons of recoverable fine coal (28M x 0) deposited in slurry impoundments throughout the U.S. coal fields. Most of this fine coal was originally directed to slurry impoundments from the cleaning plants of deep mine operators which were either unable to include 28M x 0 in clean coal because of market reasons, or they were operating overloaded or inefficient fine coal circuits. Recoverable coal in slurry impoundments represents a very significant potential source for low cost fuel, and the inventory figure is growing every day.

There are currently over 100 coal preparation plants in the U.S. which employ completely wet washing circuits, but which, for one reason or another, are not equipped with fine coal washing or recovery circuits. Collectively these plants have an installed washing capacity of about 50,000 tons per hour, and they process about 190 million tons per year of run of mine coal.

It is estimated that these plants bleed off between 10 and 20 million tons per year of potentially recoverable fine coal. Not all of this coal ends up in accessible slurry ponds, and not all

coal which ends up in ponds is worth recovering. However it is safe to assume that we are putting coal into ponds at a much faster rate than we are removing it or reclaiming the ponds.

The Mulled Coal technology could play a key enabling role in projects designed to recover marketable coal from slurry impoundments. It could also be used in existing and future preparation plants (along with fine coal separation and dewatering equipment) to redirect the finest size fraction from plant bleed to the regular clean coal product. There are, of course, many coal preparation plants which are equipped with fine coal separation and dewatering equipment, and the finest size fractions are routinely included in the clean coal product. Generally, the plants which are washing to 0" either thermally dry the clean coal product, ship to markets with lenient moisture restrictions, or the 28M x 0 size fraction is an insignificant percentage of the total clean coal product. This project is directed at the many cleaning plants which do not fit into one of the above categories.

The Mulled Coal process is a technology which has evolved from a line of investigations which began in the 1970's. There was a major breakthrough in 1990, and since then, with significant support from DOE-PETC, the technology has progressed from the conceptual stage to a proven laboratory process. It is a simple process which involves the addition of a low cost specifically formulated reagent to wet fine coal by mixing the two in a pug mill. Although the converted material (Mulled Coal) retains some of its original surface moisture, it handles, transports, and stores like dry coal. But, unlike thermally dried fine coal, Mulled Coal is not dusty, it will not rewet, and it causes no fugitive dust problems.

The process was originally developed as a means of converting Coal Water Fuel into a granular, free flowing intermediate fuel form so that it could be inexpensively stabilized for storage and shipment. The process works extremely well in this application, but the use of Coal Water Fuel has not gained widespread acceptance in the U.S., and it does not appear that there will be many near-term commercial opportunities to apply the process in this manner.

The primary objective of this project was to evaluate the commercial application of the Mulled Coal technology to the types of every day wet fine coal problems which have plagued the coal preparation industry ever since the introduction of wet processes for washing fine coal.

In 1991 Energy International began looking at ways to adapt the process to wet fine coal problems in existing preparation plants; where the fine coal products are generally higher in ash, lower in moisture, and have larger particle sizes than Coal Water Fuels products. In the next two years laboratory scale screening tests were run on a wide range of fine coal products being produced at preparation plants throughout the U.S. It was found that the process worked well on anthracite, low volatile, mid volatile and high volatile A and B coals with an ash content of up to 25%, a moisture content of up to 40%, and mean particle sizes anywhere in the 28M x 0 range.

Laboratory scale testing was conducted on a batch basis with a sample size of only 1 kg. The laboratory screening test yielded only an indication of relative mullability. The mixing action of the laboratory equipment could not be duplicated at the commercial scale, the process could not be tested

on a continuous basis and the laboratory samples were not large enough to do any meaningful testing for stability or handling characteristics.

In 1992 a 500 lb/hr Mulled Coal pilot plant was installed in one of the Energy International minerals preparation laboratories. The pilot plant was used to test barrel size samples on a continuous basis, and to evaluate the overall design for feeders, mixing equipment and the reagent delivery system. By the end of 1992, preliminary design work was completed, and the pilot plant circuit was actually equipped with scale models of machinery which could be scaled up to 75 TPH. Through the use of the pilot plant we developed a much clearer understanding of reagent formulation and reagent dose, and we produced Mulled Coal in sufficient quantities to do bench scale testing for handling and storage characteristics with sample sizes up to 200 lb.

By the end of 1992 the development of the technology had advanced about as far as it could go toward commercialization based on laboratory scale and bench scale testing. There are some major shortcomings in evaluating mullability and handling characteristics based on barrel sized samples being processed at the rate of 500 lb/hr.

- The physical characteristics of fine wet coal products can change dramatically from the time the sample is taken in a preparation plant until the time a sample container is opened in the Energy International laboratory. These changes can have a profound effect on test results.
- Bench scale tests designed to evaluate the behavior of Mulled Coal in such environments as open ground storage, silo and bin storage, rail transportation, and wet and freezing weather conditions yield results which are not completely reliable because it is difficult to reproduce or simulate those environments on a bench scale basis.

We had identified the types of wet fine coal products where the process worked well, we had established preliminary equipment designs, and we had a fairly good understanding of how to go about designing reagent formulations and doses. However, due to shortcomings in laboratory and bench scale testing, the technology was not quite ready for commercialization.

In order to move to the next step in commercial development it would be necessary to test the process:

- On a continuous basis at a convincing rate of production.
- At the point of wet fine coal production.
- In a commercial operating environment.
- Over an extended period of time.

This project was designed to advance the technology from the status of a process which works well in the laboratory to the status of a technology which is fully ready for commercialization. Project objectives were to:

1. Prove the concept that the technology can be used to produce Mulled Coal of a consistent quality, on a continuous basis, at a convincing rate of production, and at a major preparation plant which produces fine clean coal on a commercial basis.
2. Prove the concept that Mulled Coal, either as a blend with coarser clean coal or as a stand-alone fuel, will successfully pass through a representative cross section of conventional coal storage, handling and transportation environments without causing any of the problems normally associated with wet fine coal.
3. Test the design and reliability of Mulled Coal circuit equipment and controls.
4. Test the circuit over a wide range of operating conditions.
5. Project scale-up designs for major equipment components and control circuits.
6. Forecast capital and operating costs for commercial circuits ranging from 25 TPH to 75 TPH.

We tried to approach the project as if we were a commercial coal producer which was considering and then subsequently installing a Mulled Coal plant addition. There were some added tasks due to the experimental nature of this project, but basically we went through the normal steps of pre-testing, design engineering, cost projection, procurement, construction and operation.

The following sections describe the work, the test results, and our conclusions at each step along the way.

2.0 HOST SITE DESCRIPTION

The Mulled Coal circuit was installed in an empty bay of the Chetopa preparation plant which is located in the Warrior River Basin about 15 miles northwest of Birmingham in Graysville, Alabama (Figure 1). The plant and adjacent deep mining complex are owned and operated by Drummond Company, Inc.

The plant, built in 1966 and modified several times since, is sited on a large level tract of land with plenty of room for coal storage, refuse disposal and a makeup water reservoir. The slope belt head of the adjacent deep mining complex is within several hundred yards of the cleaning plant (Figure 2).

Seventy-five percent of plant feed is produced from the Chetopa deep mine in the Mary Lee seam. The balance of plant feed comes from the high ash portion of the production from two of Drummond's nearby surface mines which produce in the Mary Lee, Blue Creek, New Castle, Americal, Nickel Plate and Pratt seams.

Normally, plant feed consists of a 75/25 blend of deep mined Mary Lee with the various surface mined coals, but on some occasions, the plant will process straight deep mine coal, and at other times the blend can reach 50/50.

The plant is serviced by rail but in recent years, all clean coal has been trucked to nearby customers or one of Drummond's Warrior River loading docks.

Plant feed is about 500 TPH of 2" x 0 raw coal, with a heavy media washer for the +1/2" size fraction, a heavy media cyclone circuit for the 1/2" x 28M fraction and a froth flotation circuit for 28M x 0 coal. Coarse coal is dewatered in a vibratory centrifuge, and fine coal (28M x 0) is dewatered with a vacuum filter (Figure 3). The plant is scheduled to produce 5 days per week for 17 hours per day.

Figure 1

Chetopa Preparation Plant Location

CHETOPA PREPARATION PLANT
GENERAL ARRANGEMENT

CHETOPA PREPARATION PLANT SIMPLIFIED CIRCUIT

3.0 CHARACTERIZE PROJECT FEEDSTOCK

Project feed coal was to be provided by a 3 TPH slipstream of the normal Chetopa 28M x 0 clean coal product. 28M x 0 ROM coal in the Chetopa plant is separated from the coarser size fractions with 4 cross flow screens and 4 lowhead desliming screens. The fine coal is washed in a parallel circuit of two banks of froth flotation cells (Denver - 4 cell, 300 cu ft each; Wemco - 3 cell, 300 cu ft each). Froth concentrate is dewatered by a 12' 6" diameter by 14 disc Peterson vacuum filter (Figure 3).

Preliminary screening tests indicated that the Chetopa 28M x 0 clean coal product had a fairly narrow ash range (11% to 13% dry ash) and about a 4% moisture range (23% to 27%).

In order to design a Mulled Coal circuit which could be expected to perform well over the full range of variations in feed quality and size distribution, we decided to verify the results of preliminary screening tests and Drummond historical records through a series of two bulk samples which spanned up to three consecutive shifts of plant operation.

From time to time, the Chetopa plant adds flocculent to froth concentrate in an attempt to improve vacuum filter dewatering performance. The use of flocculent is not an every day occurrence, and when it is used, dosages vary depending on operating conditions. There was some indication from preliminary screening tests at Chetopa, that the presence of flocculent on filter cake, especially in the case of an overdose, could have an adverse effect on the mulling process.

Because of potential problems with flocculent and some mechanical considerations which will be explained later, we were not certain of just where we would pull off the slipstream, so it was decided that one of the bulk samples for feedstock characterization would represent only filter cake which had been treated with flocculent, and the other would represent only froth concentrate which had not been treated with flocculent.

It was relatively simple to collect incremental full stream cuts of filter cake from the belt head of the filter cake collecting belt. Collecting representative full stream cuts of froth concentrate was more of a problem. By the time the concentrate from individual flotation cells was collected into one pipe, there was no place to sample the stream between that point and the point where flocculent is added.

For purposes of the feedstock characterization and subsequent tests, we had to be certain that our composite froth concentrate sample would be representative of the full stream of 28M x 0 clean coal. We tested individual flotation cells and made calculations of the percentage of the total amount of concentrate coming off each cell. Then we could sample the concentrate stream coming off individual cells and combine the samples in the proper proportion to produce a representative composite. We verified the procedure by comparing the quality and size distribution of the concentrate sample to filter cake sample results where we were certain that we had a representative cross section of the full stream of 28M x 0 coal (Figure 4).

Figure 4

SIZE DISTRIBUTION ANALYSIS

3.1 Filter Cake

The first bulk sample targeted was a filter cake treated with flocculent. The sample amounted to five full drums of filter cake (approximately 2000 lbs) gathered in 10 lb increments from the belt head of the filter cake collecting belt. It was gathered by EI personnel on March 8 and 9, 1994. Characterization tests (ash, moisture and size distribution) were performed at the EI mineral preparation laboratories during the period of March 15, 1994 to April 6, 1994.

This first sample was to be used as a marker for the main source of plant feed, so the plant ran on straight Mary Lee deep mine coal for the duration of the test.

The objectives of the characterization tests were to establish the full quality range of the project feedstock as to ash moisture and size distribution, and to determine whether or not there was a predictable relationship between any of those characteristics.

Each drum of the first sample was cored, and the cores were combined to form a composite sample covering the entire sampling period. A cut of the composite sample was sent to a commercial laboratory for proximate analysis (Figure 5). Then the drums were cored again, and the drum cores plus the composite samples were individually tested for: (Figures 6).

ash
moisture
wet screen analysis (6 size fractions)
differential volume analysis (microtrac) on the 28M x 0 fraction

Test results indicated that, for the duration of the tests, there was a very narrow range in the key feedstock characteristics which might affect the performance of a Milled Coal circuit.

Characteristic	Range		
	Low	Average	High
Ash (% dry)	11.32	11.76	12.11
Moisture (%)	22.00	24.00	26.00
325M x 0 (% of total)	20.20	21.24	22.94
Mean Particle Diameter (microns)	198.45	204.93	216.95
Calculated Surface Area (m ² /cc)	0.165	0.172	0.183

The ranges for the tested characteristics of the filter cake were so narrow that it can be assumed that the quality of the 28M x 0 clean coal product remained virtually unchanged throughout the two shift time period covered by the sample.

Figure 5

GHA, TEK, RWG
PRJ**COMMERCIAL TESTING & ENGINEERING CO.**

GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • TEL: 708-953-9300 FAX: 708-953-9306

Member of the SGS Group (Société Générale de Surveillance)

March 22, 1994

PLEASE ADDRESS ALL CORRESPONDENCE TO:
P.O. BOX 32, CHARLEROI, PA 15022
TEL: (412) 483-8548
FAX: (412) 483-0882

Energy International Inc.
135 William Pitt Way
Pittsburgh PA 15238

Sample identification by
Energy International Inc.

FC 016 038
3/18/94

Kind of sample COAL SAMPLE
reported to us

Sample taken at --

Sample taken by SUBMITTED

Date sampled -----

Date received March 18, 1994

Analysis Report No. 43-146778

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	
% Moisture	22.11	XXXXX	
% Ash	9.25	11.88	
% Volatile	23.48	30.14	
% Fixed Carbon	45.16	57.98	
	100.00	100.00	
Btu/lb	10494	13473	MAP 15289
% Sulfur	1.06	1.36	

FREE SWELLING INDEX = 7.5

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

Manager, Charleroi Laboratory

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS, TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES
1/04/94
11 Watermarked For Your Protection

TERMS AND CONDITIONS ON REVERSE

Figure 6

CHARACTERIZATION TESTS - FILTER CAKE CONDITIONED WITH FLOCCULENT

Pre Production Feed Source Testing Filter Cake																		
Lab No.	Date	Sample Location	Sample ID	Moisture	Size Distribution													
					+16 Mesh		16M x 28M		28M x 100M		100M x 200M		200M x 325M		325M x 0		Composite	
					% WT	%ASH	%WT	%ASH	%WT	%ASH	%WT	%ASH	%WT	%ASH	%WT	%ASH	%WT	%ASH
016-39A	3/24/94	2	Drum 1	22.00	0.11	*	10.59	7.60	46.76	11.00	13.97	12.50	8.06	12.30	20.51	14.80	100.00	11.73
016-39B	3/24/94	2	Drum 2	23.00	0.20	*	11.61	7.70	46.55	11.40	13.68	12.40	7.76	10.90	20.20	15.30	100.00	11.86
016-40A	3/24/94	2	Drum 3	24.00	0.15	*	10.38	7.40	46.79	11.00	13.97	12.70	8.25	12.00	20.46	15.10	100.00	11.79
016-40B	4/5/94	2	Drum 4	25.00	0.19	*	9.98	7.60	44.99	11.10	13.97	13.20	7.93	11.50	22.94	15.60	100.00	12.11
016-41	4/6/94	2	Drum 5	26.00	0.13	*	9.12	7.20	46.25	10.30	14.20	11.60	8.22	10.50	22.08	15.30	100.00	11.32
			Average	24.00	0.16	*	10.34	7.50	46.27	10.96	13.96	12.48	8.04	11.44	21.24	15.22	100.00	11.76
016-38	3/17/94	2	Composite	23.00	0.20	*	11.06	7.90	46.52	11.40	13.75	12.90	7.95	13.20	20.52	15.40	100.00	12.18

Sample Location

2. Filter Cake Belt Head
3. Froth Cells Launder

Sample ID

1. Filter Cake
2. Froth Concentrate

3.2 Froth Concentrate

The second bulk sample was limited to froth concentrate which had not been conditioned with flocculent. The sample was gathered by EI personnel on May 23 and 24, 1994. The sampling period covered 24 continuous hours of plant operation, over which 4 drums of decanted froth concentrate were collected and shipped to the EI minerals preparation laboratory in Pittsburgh. Characterization tests were conducted during the period of June 10-24, 1994.

The size distribution and quantity of coal in the concentrate discharging from individual cells in a bank of froth cells varies significantly from cell to cell (Figure 7), and is influenced by such factors as feed characteristics, amount and type of chemicals used, and cell design and method of operation. From previous screening tests at Chetopa, we expected about 60% of the concentrate to be coming off the feed end cell, 20% off the next cell, 15% off the next cell and 5% off the tailings end cell.

In gathering the froth concentrate bulk sample, individual cell discharges were sampled in accordance with the proportions determined in the screening tests. The individual cell samples were combined in each drum in accordance with the predetermined proportions and the composite ash and size distribution of each drum compared very favorably with the results of filter cake samples (Figure 6) indicating that the bulk sample was representative of the full stream of 28M x 0 clean coal.

In order to conserve space and obtain as much coal as possible for subsequent parametric mulling tests, we decanted each sample grab from the froth cells. For each grab, 3 to 4 gallons of concentrate was collected in a 5 gallon bucket. The bucket of dilute concentrate was then set aside and allowed to settle for 20 to 30 minutes. Excess water was poured off, and the decanted sample was transferred to the 55 gallon drums used to collect the bulk sample. By this method we were able to increase percent solids from the 30%-35% range which was normal for dilute concentrate up to 54%-58% for the bulk sample.

For purposes of the characterization tests, each of the four concentrate drums was sampled while being stirred, and the individual samples were tested for ash, wet screen analysis at 6 size fractions, and differential volume analysis (Microtrac). Test results indicated that the bulk sample accurately represented the full stream of 28M x 0 coal, and, for the duration of the test, there was a very narrow range of key feedstock characteristics which might affect the performance of a Mulled Coal circuit (Figure 8).

<u>Characteristic</u>	<u>Range</u>		
	<u>Low</u>	<u>Average</u>	<u>High</u>
Ash (% Dry)	11.23	12.03	13.21
325M x 0	18.21	19.78	21.07
Mean Particle Diameter (microns)	202.37	219.06	239.47
Calculated Surface Area (m ² /cc)	0.093	0.114	0.133

Figure 7

DENVER FLOTATION CELL PERFORMANCE

% Solids		38.00	34.00	27.00	24.00	
% Ash (Dry)	39.10	8.10	12.90	15.60	16.60	70.18
Size Distribution						
+ 28 Mesh	6.04	8.20	10.30	3.10	3.00	6.56
28M x 100M	29.82	36.70	56.40	41.60	19.40	15.54
100M x 200M	11.51	33.00	12.60	13.60	12.60	7.20
200M x 325M	7.20	8.30	7.20	10.70	13.60	5.66
325M x 0	45.43	13.80	13.50	31.00	51.40	65.04
KA Mulling Test						
% Moisture		25.00	22.00	28.00	28.00	
Reagent Dose (%)		2.00	2.00	2.00	2.00	
Uniformity Results						
+ 6 Mesh		-	-	13.47	25.75	
6M x 14M		4.72	14.03	47.63	61.01	
14M x 28M		38.39	38.74	31.88	12.69	
28M x 0		56.89	47.23	7.02	0.56	
Handleability Index		95.28	85.97	38.90	13.25	

Figure 8

CHARACTERIZATION TESTS - FROTH CONCENTRATE

Pre Production Feed Source Testing Froth Concentrate																		
Lab No.	Date	Sample Location	Sample ID	Ash %	Size Distribution													
					+16 Mesh		16M x 28M		28M x 100M		100M x 200M		200M x 325M		325M x 0		Composite	
					% WT	%ASH	%WT	%ASH	%WT	%ASH	%WT	%ASH	%WT	%ASH	%WT	%ASH	%WT	%ASH
016-77A	6/15/94	3	Drum 4	10.96	0.65	*	10.16	7.67	48.42	9.95	14.45	11.48	7.51	10.68	18.81	17.11	100.00	11.35
016-77B	6/16/94	3	Drum 3	10.82	0.34	*	8.20	7.37	45.24	9.69	17.09	9.88	8.06	11.27	21.07	17.12	100.00	11.23
016-78A	6/17/94	3	Drum 2	11.51	0.41	*	8.37	7.40	45.26	9.97	16.56	13.09	8.36	11.88	21.04	18.65	100.00	12.31
016-78B	6/21/94	3	Drum 1	13.12	0.51	*	11.30	7.98	48.03	11.71	14.83	12.75	7.12	13.75	18.21	20.56	100.00	13.21
		Average		11.60	0.48	*	9.51	7.61	46.74	10.33	15.73	11.80	7.76	11.90	19.78	18.41	100.00	12.02

Sample Location

2. Filter Cake Belt Head
3. Froth Cells Launder

Sample ID

1. Filter Cake
2. Froth Concentrate

It should be noted that plant feed for the filter cake sample was straight Mary Lee deep mine coal, but the plant feed during the concentrate sampling period was 75% Mary Lee deep mine with 25% coming from a combination of high ash surface mine coals. The ash and size distribution of the clean coal throughout both sampling periods was very similar with a narrow range; indicating that variations in this plant feed may not be sufficiently wide to have a significant impact on the operation of a Mulled Coal circuit.

4.0 EVALUATE ALTERNATIVE FEED SOURCES

The feedstock for the project was set at a nominal 3 TPH of 28M x 0 clean coal. This required cutting out a slipstream from the normal flow of 45-55 TPH in the Chetopa 28M x 0 clean coal circuit. The slipstream had to be cut out in such a way as to cause a minimum of interference with normal plant operations and to provide a controllable and representative cross section of the Chetopa plant fine coal product.

There were two alternative sources for the slipstream (Figure 9).

1. Dewatered filter cake at some point between the cake discharge chute on the vacuum filter and the point where 28M x 0 coal was combined with coarser clean coal products, or
2. Dilute froth concentrate somewhere between the bottom of the concentrate launder on the flotation cells and the point where the concentrate was discharged to the vacuum filter.

There were advantages and disadvantages associated with both alternatives. The objectives of this evaluation were to select the alternative which would provide a reliable and controllable feedstock which was compatible with other project objectives, and to select the exact take-out point and take-out mechanism which was most cost effective, while at the same time causing the least amount of interruption to normal Chetopa plant operations.

4.1 Filter Cake

From time to time the Chetopa plant adds flocculent to froth concentrate in an attempt to improve vacuum filter performance. The use of flocculent as a filter feed conditioner is not an every day occurrence, and when it is used, dosages vary depending on operating conditions and particular operators (dosages are set with manual controls). The presence of flocculent on filter cake, especially in the case of an overdose, could have an adverse effect on the mulling process.

We looked at three potential points where we could take off a filter cake slipstream:

1. The belt head of the filter cake collecting belt which was about 50' from the project bay.
2. From the top of the collecting belt somewhere near the project bay (the collecting belt ran parallel to and just above the project bay).
3. Under the vacuum filter cake discharge chute near the collecting belt tail piece. This point was within 25' of the project bay.

ALTERNATIVE FEED SOURCES

We encountered major obstacles at each potential location.

As is the case with many vacuum filter installations, the cake discharge chutes on the Chetopa filter would periodically hang up for a few blow cycles and then suddenly release the backed up material. This would result in the collecting belt carrying two to three times its normal load for a few seconds. It happened often enough that we knew that, if we selected filter cake for the project feedstock, we would often be presented with 30 second surges which were way beyond our set point. It was felt that the surges would probably be too great to be absorbed by the surge feeder which was selected for the project.

Even if we were able to handle surges, we ruled out taking the slipstream from the head of the collecting belt. There was not enough room for a splitter at the belt head, and there was no way to convey the material back to the project bay in a straight line.

Because the filter cake was so wet and sticky, we could not simply plow a slipstream off the top of the collecting belt as it passed by the project bay. The use of a rotating arm automatic sampler taking rapid grabs would have enabled us to take filter cake off the top of the collecting belt, and it would have solved the surge problem, but it would have been prohibitively expensive, and there was a possibility that the filter cake would hang up in the sampler.

We eventually decided that the best place to get a filter cake slipstream was from beneath the cake discharge chute in the vicinity of the last two filter discs. However, we recognized that the closer we got to the cake discharge chutes (which routinely hung up), the more risk we had of shutting down the entire plant as a result of our take-off equipment causing the cake discharge chutes to back up.

At the same time we were evaluating the mechanical considerations related to the filter cake alternative, we were proceeding with laboratory mulling tests to compare filter cake to froth concentrate, and to evaluate the effect of flocculent on mullability. We were also looking at the possibility of adding a centrifuge to the circuit if we selected froth concentrate as the feedstock. However, the closer we looked at taking off a slipstream of filter cake, the more concerned we became about the risk of interfering with normal Chetopa plant operations. Before completing the full feed source evaluation, we decided that, if the major project objectives could be achieved through the use of froth concentrate as the feedstock, we were definitely going to select that alternative -- even though it would mean adding a centrifuge to our circuit.

4.2 Laboratory Testing

In late 1993 and early 1994 we ran a series of 18 laboratory tests to compare the mullability of filter cake which had been conditioned with flocculent to that of froth concentrate which had not been treated with flocculent.

To conduct relative mullability tests at the laboratory scale, we mixed wet cakes and reagents under controlled conditions with specific equipment and procedures. This test, developed by EI in previous Mulled Coal research work, is known internally as the K.A. mulling test.

"K.A." in the name refers to Kitchen Aid. We use a heavy duty, stainless steel, laboratory grade Kitchen Aid mixer to simulate the mixing action of a Pug Mill. In the K. A. mulling test, one kg of wet cake, with known ash, moisture and size distribution, is placed in the stainless steel bowl and mixed for one minute to eliminate any agglomeration and packing which results from the way the sample had been stored. Reagent, in measured quantities, is added in one shot, and the material is mixed for 5 minutes at a set mixing speed.

At the completion of mixing the Mulled Coal is immediately removed from the mixer and tested for uniformity and whatever other handleability and stability tests have been prescribed. The uniformity test is the most reliable indicator of the relative quality of Mulled Coals. The test is a recognized procedure for the evaluation of the handling characteristics of bulk materials, however, we interpret test results a bit differently than one would for a non coal or drier material.

In the laboratory uniformity test, 50 grams of Mulled Coal is placed on the top deck of a stack of three screens with deck openings of 6 mesh, 14 mesh and 28 mesh. The material is dry screened with a rotap for 5 minutes and results are reported as the percentages of:

+6 mesh
6M x 14M
14M x 28M
28M x 0

The test is an indicator of whether or not agglomerated coal particles are completely covered with a thin membrane of reagent. If the mulling process is incomplete, agglomerated particles remain "sticky", as with most wet fine coals, and they tend to form marble sized balls, as do most wet fine coals, when they pass over vibrating screens. When the mulling process is complete, balls do not form, and a greater percentage of the sample freely flows through the screens to the bottom decks.

When a uniformity test is run on bone dry coal, virtually 100% of the material reports to the 14M x 0 size fraction. When the uniformity test is run on a mulled wet cake, the percentage of material reporting to the 14M x 0 size fraction is considered to be the Handleability Index for that sample - where 100 equals the Handleability Index of dry coal.

For the relative mullability tests, the following test conditions were maintained.

	<u>Filter Cake</u>	<u>Froth Concentrate</u>
Ash (Dry)	11.64	12.30
Reagent Dose (% by dry wt)	2.00	2.00
Mix Time (minutes)	5.00	5.00
Moisture Range (%)	23.00-27.00	23.00-27.00

There was a very significant difference between the mullability of filter cake and froth concentrate (Figure 10). Under the test conditions, the 23% moisture froth concentrate sample was converted into an excellent Mulling Coal with handling characteristics very similar to those of dry coal. The 23% moisture filter cake mull graded only fair. At higher moistures, the differences were even more significant. Throughout the entire moisture range the froth concentrate mulls remained in the excellent category, but the 25% to 27% moisture filter cake samples showed almost no improvement in handling characteristics as a result of the mulling process.

4.3 Flocculent

Since it was demonstrated in the feed characterization tests that filter cake and froth concentrate were essentially interchangeable, it was assumed that the presence of flocculent on the filter cake accounted for the differences in mullability between the two alternatives.

In order to verify that flocculent was the problem with filter cake mullability, we ran a special K. A. mulling test on froth concentrate with and without flocculent.

The flocculent used in the test was the actual dilute anionic flocculent used in the Chetopa plant to condition vacuum filter feed. Froth concentrate used for the test was the low ash concentrate coming off the feed end cell of the Denver cells. This particular concentrate was selected because a sample was available, and because it would be expected to form an excellent mull under normal circumstances.

The froth concentrate for this test had been decanted and filtered for other test purposes, and it was at a 28% moisture level at the beginning of the test. A 1000 gram split was set aside to air dry and be used in the concentrate without flocculent portion of the test.

Three thousand grams of the 28% moisture material was mixed with water (which had previously been filtered from froth concentrate - as opposed to tap water) to form a 29% solids dilute froth concentrate. Then dilute anionic flocculent was mixed in by hand and the flocculent conditioned sample was allowed to stand for one hour. Then the sample was refiltered and 1000 grams was split off for the K. A. mulling test.

Specific K. A. mulling test conditions:

	<u>Froth Concentrate</u>	<u>Froth Concentrate with Flocculent</u>
Sample Size (grams)	1000	1000
Ash (% dry)	8.10	8.10
Moisture (as tested)	25.00	23.00
Flocculent Dose (lb/ton)	-0-	3.00
Reagent Dose (% by dry wt of coal)	2.00	2.00
Mix Time (minutes)	5.00	5.00

Figure 10

Laboratory Mulling Tests - Filter Cake vs Froth Concentrate

UNIFORMITY TEST RESULTS

	<u>+6M</u>	<u>6M x 14M</u>	<u>14M x 28M</u>	<u>28M x 0</u>	<u>Handleability Index</u>
Froth Concentrate (with Flocculent)	36.74	62.12	0.95	0.19	1.14
Froth Concentrate (no Flocculent)	-0-	4.72	38.39	56.89	95.28

For purposes of this test, we used an obvious flocculent overdose, but it was felt that such a condition could occur at the Chetopa plant from time to time.

From available test data, we knew that the presence of flocculent had an adverse effect on the mullability of filter cake. We also knew from subsequent parametric testing that we could overcome those adverse effects with increased reagent doses and reagent additives. However, when poor mullability was coupled with the mechanical disadvantages of taking off a slipstream of filter cake, it was clear that we should select the froth concentrate alternatives if:

1. We could devise a way to fit a centrifuge into the Mulled Coal circuit within the scope of resources which were available to the project, and
2. The use of a centrifuge would permit us to control the feed in such a way as to test the Mulled Coal circuit over a wide range of operating conditions.

4.4 Centrifuge

By April of 1995, it was clear that froth concentrate which had not been conditioned with flocculent was the preferred feed source for the project. Since concentrate came off the Chetopa flotation cells at about 70% moisture, it would be necessary to dewater it to test the Mulled Coal Process over the moisture ranges which are common in commercial 28M x 0 coal preparation circuits.

We considered vacuum filters, filter presses and centrifuges; all of which should be capable of drying at least 3 TPH of 28M x 0 clean coal to a 20% to 27% moisture range - all without the use of flocculent. We quickly abandoned vacuum filters and filter presses due to cost and space limitations.

In May of 1995, Decanter Machine Inc. of Johnson City, TN agreed to furnish an 18" x 42" screen bowl centrifuge at no cost to the project. Decanter Machine is one of the major suppliers of screen bowl centrifuges to the coal industry. Their 18" x 42" machine was normally used for trial demonstrations, and it was not previously booked for use during the months scheduled for the operation of the Mulled Coal circuit.

The 18" x 42" machine capacity was an ideal match for the project. It was rated at 50 GPM, and it was fully capable of dewatering 2.5 - 5.5 TPH of froth concentrate with the solids content encountered at the Chetopa plant.

We made a quick survey of space, power, pumping, piping and chute requirements for the centrifuge. It was determined that the machine would fit easily and economically into our circuit, and its use would create an absolute minimum of interference with normal Chetopa operations. The actual setup for the centrifuge, and the slipstream take-out mechanism will be discussed in the narrative sections of this report which deal with design engineering.

5.0 EVALUATE THE APPLICATION OF THE MULLED COAL PROCESS

In this important pre-operations test procedure, we were attempting to make certain that the design of the Mulled Coal circuit would permit us to successfully and continuously produce a handleable fine coal product over the full range of feed conditions which could be reasonably expected at the Chetopa plant and other similar 28M x 0 coal preparation circuits. The test procedure involved running an extensive series of laboratory scale parametric mullability tests, and measuring various handleability and stability characteristics of the Mulled Coal produced in each test. We were searching for predictable relationships between such parameters as Mulled Coal quality, feed ash, feed moisture, feed size distribution, reagent formulation, equipment configuration, and feed rates.

The primary sample used for parametric testing was a one ton bulk sample of decanted froth concentrate which was gathered over three consecutive production shifts on May 23-24, 1994. During the same sampling period, the following 5 gallon and 10 gallon side samples were collected:

- Raw coal feed to the Denver flotation cells
- Concentrate discharge from the feed end Denver cell
- Concentrate discharge from the 2nd Denver cell
- Concentrate discharge from the 3rd Denver cell
- Concentrate discharge from the tailings end Denver cell
- Concentrate discharge from the feed end Wemco cell
- Dilute anionic flocculent as used in the Chetopa plant

Characterization tests (ash, moisture and size distribution as previously reported) on the bulk froth concentrate sample were completed in late May and early June.

In June and July we concentrated on the analysis of the side samples from the flotation cells. Our primary objective in evaluating flotation cell performance was to be certain that the take-off point selected for the slipstream would yield a representative cross section of the 28M x 0 clean coal product.

In late July and early August we began filtering the decanted froth concentrate sample to reduce moisture from the 50% level to the 20% to 27% range which was required for parametric sampling. Filtering the bulk sample was a slow process, but, as soon as some filtered material was available, testing began. However, the actual parametric K. A. mulling tests did not begin until early August, and they were not completed until December.

The time line for parametric sampling is presented here because a significant problem developed which affected the entire series of tests. By the time we actually ran the K. A. mulling tests, the sample was between 90 and 180 days old. As the sample aged, mullability deteriorated, and tests run under exactly the same conditions but at different times would yield entirely different results.

Even though we realized right away that we had a serious problem, we continued with and completed the parametric test series. We were more interested in relative results than absolute values,

and while absolute results were sometimes very confusing, relative results for most tests conducted within two days of each other yielded meaningful information.

Our original parametric test objective was to establish a predictable relationship between Mulled Coal quality and reagent dose at various levels of feed ash, moisture and size distribution. We were able to establish with a high degree of certainty that the Mulled Coal process would work successfully over the full range of feed ash, feed moisture, and feed size distribution which we expected to encounter. We were unable to predict the exact reagent dose to apply at various levels of feed quality, but we were able to verify that particular levels of feed quality required a higher or lower reagent dose.

On September 16, 1994 we ran a repeat K. A. mulling test on a sample of froth concentrate which had been collected from the feed end cell of the Denver flotation cells. This sample was chosen for repeat testing because it was originally a small sample (5 gallon bucket) taken over a short period of time (5 minutes), and we were fairly certain that we would be retesting the exact same product. In addition, the sample, as originally tested, converted into an excellent grade of Mulled Coal. While not all of the samples deteriorated to the same extent or at the same rate as this sample, the results of the retest are indicative of the extensive deterioration which was taking place over time.

<u>Test Conditions</u>	<u>Original Test</u>	<u>Repeat Test</u>
Date sampled	May 24, 1994	May 24, 1994
Date tested	May 27, 1994	Sept. 16, 1994
Age at testing (days)	3	115
% Moisture	23	23
% Ash	8.10	8.10

Uniformity Test Results

+6 mesh	0.00	19.22
6M x 14M	4.72	75.42
14M x 28M	38.39	5.36
28M x 0	56.89	0.00

<u>Handleability Index</u>	95.28	5.36
----------------------------	-------	------

During the period between May 27, 1994 and September 16, 1994 (the period between the original test and the retest) the pH of the water in the 38% solids froth concentrate dropped from 7.9 to 2.5. Apparently some sort of oxidation was taking place, and the oxidation process was in some way shielding hydrophobic sites on the coal particles. In order for the Mulled Coal process to work properly, there must be hydrophobic sites available for the reagent to attach itself to coal particles and agglomerates.

Not all of the samples deteriorated as rapidly or as completely as the concentrate sample from the feed end of the Denver cells. All of the froth concentrate samples were highly mullable when

containers were first opened and tested, and we were certain that the aging problem with samples would not affect our field operations or the stability of the Mulled Coal we were to produce.

The cause of the aging problem remains a mystery. We decided that as long as we were certain that the problem would not interfere with original project objectives, it was not necessary, nor was it within the scope of our work, to spend additional time or money looking for a plausible explanation. As it turned out, there was never a problem with mullability during the three month production demonstration. We were unable to predict reagent doses as a result of parametric testing of oxidized samples, but even if none of the samples had oxidized, we would not have been able to predict reliable reagent doses. The full scale Mulled Coal circuit, as demonstrated, was far more efficient than our laboratory K. A. mulling procedure, and we ended up using far less reagent than the amounts predicted from laboratory test results on fresh samples.

5.1 Flotation Performance Tests

The objectives of the flotation performance tests were to:

1. Insure that the slipstream take-off point would yield a representative cross section of the 28M x 0 clean coal product.
2. All of the bulk samples of filter cake and froth concentrate fell within a very narrow range of ash and size distribution. Since it was expected that there would be cell to cell differences in concentrate quality, we would be able to run K. A. mulling tests at several different ash and size distribution levels without having to make up artificial levels.
3. We wanted to look at flotation cell efficiency to see if we could develop an idea of the range of feed quality we might expect as a result of major changes in plant feed rate, raw coal quality or changes in flotation chemical dosages.

Froth concentrate is discharged from one side of the Wemco cells and both sides of the Denver cells. Flocculent is inserted directly into the concentrate launder on the feed end of the Wemco cells (Figure 11). Taking a slipstream from the Wemco cells would have required moving the flocculent insertion point somewhere downstream from the slipstream take-off point. It had been reported that the clean coal product from the Denver and Wemco cells was about the same. The easiest and most cost effective point to take off our slipstream was somewhere between the Denver cells launders and the point where they joined the flocculent treated material from the Wemco cells. In order to verify that the products from the Denver and Wemco cells were about the same, we sampled and compared several characteristics of the concentrate coming off the feed end cells on both machines (Figure 12).

There were differences in some characteristics, but it must be taken into account that the Wemco machine has only three 300 cu ft cells, while the Denver machine has four 300 cu ft cells. It would be expected that the concentrate from the feed end of the Wemco cells would be higher in ash, lower in percent solids, and higher in 325M x 0. Since it is higher in ash it would also be

DENVER CELLS

WEMCO CELLS

29

AVAILABLE AREA
For Slip Stream Take Off Point

→ TO FILTER

ELEV 488' - 0

ELEV 467' - 0

ELEV 458' - 6

20'

8'

20'

(B)

(C)

(D)

(E)

Figure 12
DENVER CELLS vs. WEMCO CELLS

	Denver	Wemco
Cell Location	Feed End	Feed End
% Solids	38.00	30.00
% Ash	8.10	10.60
Size Distribution		
+ 28M	8.20	7.42
28M x 100M	36.70	46.14
100M x 200M	33.00	15.41
200M x 325M	8.30	9.18
325M x 0	13.80	21.85
K.A. Mulling Test		
% Moisture	25.00	24.00
% Reagent Dose	2.00	2.00
Uniformity Test Results		
+ 6 Mesh	-	4.69
6M x 14M	4.72	18.01
14M x 28M	38.59	45.03
28M x 0	56.89	32.27
Hand. Index	95.28	77.30

expected that it would have a lower handleability index from a K. A. mulling test. Since there were no surprises in the comparison between the Wemco and Denver cells, it was safe to assume that we would have a representative slipstream if we took it from the Denver cells.

During the early planning stages for a froth concentrate slipstream, we considered inserting a false launder inside the main launder on one side of the Denver cells. Under this scheme we would install a false launder to cut out about 25% of the concentrate flowing off one side of the cells (3 TPH). In order to find out if there was one area along the length of the launder where we could take out a representative slipstream, we decided to test and compare the characteristics of the concentrate coming off each cell along the length of the launder (Figure 13).

Due to significant differences in quality and flow rates along the length of the launder, we abandoned the alternative of using a false launder.

On May 24, 1995 we took samples of feed, concentrate and tailings from the Denver flotation cells. The various products were tested for ash and size distribution, and then recoveries were calculated for each size fraction (Figure 14). Flotation feed ash was 39.10, concentrate ash was 12.00 and tailings ash was 70.18. This is considered to be a very efficient operation for a plant producing steam coal where the operating emphasis is on product recovery.

In order to confirm flotation circuit efficiency, a complete flotation release analysis was run on a split of the feed sample collected in May (Figure 15). The flotation circuit operating point (actual concentrate ash and recovery rate) fell very close to the theoretical release curve - confirming that the circuit was operating very efficiently.

Our conclusions from the series of tests of flotation circuit performance were that the circuit had more than adequate capacity to handle swings in plant feed rate, and that it did a very efficient job of separation. We could expect a very narrow ash range in the feed to the Mulled Coal circuit, and therefore it would not be necessary to constantly adjust reagent dosage to compensate for wide swings in feed ash.

5.2 Repeatability Tests

Parametric testing began with a short series of repeatability tests to see if the results of a K.A. mulling test of the same wet cake sample, run at the same time, and under the same conditions would repeat within an acceptable margin.

The standard laboratory procedure for the parametric test series was to use 1000 g of untreated wet cake for a K. A. mulling test. After adding reagent and mixing in the Kitchen Aid mixer for 10 minutes, 50 g of the Mulled Coal produced was tested for uniformity. The percentage of Mulled Coal which reported to the 14M x 0 size fraction (the Handleability Index) was the principal characteristic used to describe the quality of Mulled Coal produced in that particular K. A. mulling test.

Figure 13

DENVER FLOTATION CELL PERFORMANCE

% Solids		38.00	34.00	27.00	24.00	
% Ash (Dry)	39.10	8.10	12.90	15.60	16.60	70.18
Size Distribution						
+ 28 Mesh	6.04	8.20	10.30	3.10	3.00	6.56
28M x 100M	29.82	36.70	56.40	41.60	19.40	15.54
100M x 200M	11.51	33.00	12.60	13.60	12.60	7.20
200M x 325M	7.20	8.30	7.20	10.70	13.60	5.66
325M x 0	45.43	13.80	13.50	31.00	51.40	65.04
KA Mulling Test						
% Moisture		25.00	22.00	28.00	28.00	
Reagent Dose (%)		2.00	2.00	2.00	2.00	
Uniformity Results						
+ 6 Mesh		-	-	13.47	25.75	
6M x 14M		4.72	14.03	47.63	61.01	
14M x 28M		38.39	38.74	31.88	12.69	
28M x 0		56.89	47.23	7.02	0.56	
Handleability Index		95.28	85.97	38.90	13.25	

Figure 14

DENVER FLOTATION CELLS

PERFORMANCE ANALYSIS

SAMPLE DESCRIPTION	FROTH FEED GRAB SAMPLE		CONCENTRATE COMPOSITE		FROTH TAILS GRAB SAMPLE	
	% WT	% ASH	% WT	% ASH	% WT	% ASH
+ 28 MESH	6.04	12.38	10.00	7.61	6.56	30.00
28 M. x 100M	29.82	15.43	46.73	10.33	15.54	39.2
100M x 200M	11.51	25.16	15.73	11.80	7.20	60.4
200M x 325M	7.20	27.45	7.76	11.89	5.66	71.4
325M x 0	45.43	63.96	19.78	18.41	65.04	82.6
TOTALS	100.00	39.10	100.00	12.00	100.00	70.18

ASH ONLY

SIZE FRACTION	FEED	CONCENTRATE	TAILS	RECOVERY
+ 28 MESH	12.38	7.61	30.0	78.7
28M x 100M	15.43	10.33	39.2	82.3
100M x 200M	25.16	11.80	60.4	72.5
200M x 325M	27.45	11.89	71.4	73.9
325M x 0	63.96	18.41	82.6	29.0
TOTALS	39.10	12.00	70.18	56.1

Figure 15

FLOATATION RELEASE ANALYSIS

Repeatability was not simply one 1000 g K. A. mulling test with two 50 g splits of the same Mulled Coal used for uniformity testing. For each repeatability test the entire procedure was completed beginning with the 1000 g. K. A. mulling test.

Results of the repeatability tests are shown in Figure 16. The variation in the Handleability Index from test to test was considered acceptable, but we would have preferred a narrower margin. Since our database up to that point consisted of all 50 g uniformity tests, we decided to complete the parametric test sequence with the same procedures. During the production phase of the project we increased the amount of Mulled Coal for uniformity tests to 250 g, and we achieved much more uniform results from test to test.

The differences in Mulled Coal quality between the 10.96 ash test and the 13.12 ash test (the samples came from different drums which were collected at different times during the 36 hour field sampling period) was one of the first indicators that there was a problem with the bulk samples. Although we did not realize at the time that the problem was oxidation, we knew from past experience that the difference of a few percentage points in ash could never account for such a wide difference in Mulled Coal quality.

Coal from these particular drums was selected for the parametric testing series because it represented the lowest and highest ash levels encountered in the 36 hour sampling cycle.

The two drums had either been opened at different times, handled differently after opening, or there was something very different about the coal in the higher ash drum. What we later recognized as an oxidation problem had for some reason progressed at different rates. The coal in the higher ash drum probably did not account for the difference because eventually all of the bulk sample deteriorated to the point where it could not be converted to an acceptable grade mull in either a laboratory or pilot plant test.

In any event, while absolute test results from drum to drum or from time to time were meaningless, we felt that relative results from sample to sample taken from the same drum at the same time would give us information we could use to design the reagent delivery system for the project.

5.3 Parametric Testing

In this series of tests we attempted to evaluate the effects on mullability which result from variations in size distribution, reagent dose, moisture, ash, and temperature.

5.3.1 Size Distribution

From previous testing we know that generally:

Mullability improves as the mean particle size of a wet cake decreases.

Mullability declines as the ash content of a wet cake increases.

The ash content of froth concentrate increases as the mean particle size decreases.

Figure 16
Repeatability Of Uniformity Tests

Lab No	Ash	Moisture	Reagent Dose	Size	Uniformity Test Results				
					+6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
016-81A	10.96	23	2.00	28M x 0	3.07	25.34	49.33	22.26	71.59
016-81B	10.96	23	2.00	28M x 0	5.34	16.98	42.37	35.31	77.68

Lab No	Ash	Moisture	Reagent Dose	Size	Uniformity Test Results				
					+6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
016-82B	13.12	22	2.00	28M x 0	18.13	67.48	14.39	0.00	14.39
016-82C	13.12	22	2.00	28M x 0	11.22	72.25	15.94	0.59	16.53

In the first series of size distribution tests, K. A. mulling tests were run on various size fractions from wet screen analyses. Generally, mullability improved as the particle size decreased, but the effect was offset somewhat because the ash of the various size fractions ranged from 9.55% for the coarsest (28M x 100M) to 16.85% for the finest (325M x 0) (Figure 17). There were anomalies in the test results for the various size fractions which in hindsight were attributed to the aging process on the various samples selected for the tests.

In order to hold ash at the same level for tests in two different size ranges, a froth concentrate sample was wet screened to produce about 2000 g in the 28M x 100M size range. Half of the sample was tested at 28M x 100M. The other half was ground and retested at 100M x 0. The Handleability Index went from 19 on the 28M x 100M fraction to 91 on the 100M x 0 fraction (Figure 17, second table). We expected a substantial improvement, but nothing on the order of 19 to 91. We attribute a significant portion of the improvement to the aging process of the various samples, and the fact that we exposed fresh hydrophobic surfaces in the grinding process.

5.3.2 Moisture

Increases in moisture had the most profound effect on mullability of any of the parameters tested. However, with the Mulled Coal process, the effect of increased moisture can be offset by increasing the reagent dose.

The results for parametric testing for the effect of moisture are shown in Figure 18. Again, it is apparent that the aging of the samples had a significant effect on absolute values for this series of tests. Separate tests were run on the lowest and highest ash portions of the May 23-24 bulk sample.

While absolute values for the moisture series are of little value, relative differences show the profound effect of moisture on mullability. We were not able to use these test results to predict the actual dosages of reagent which would be required at different moisture levels, but the results reinforced our initial guess that moisture was the parameter we would use to automatically control reagent dose.

5.3.3 Reagent Dose

By the time we started parametric testing for reagent dose (8/10/94), the bulk samples had oxidized to the point where test results were meaningless. We were aware at the time that there was a problem with the bulk samples, but we did not know what it was, and we did not know how significant it was. We went ahead with the reagent dose series hoping that relative results would yield information we could use to design the reagent delivery system for the production phase of the contract.

The results of reagent dose testing are shown in Figure 19. There are two tables which summarize reagent dose test results. The difference in absolute values from one table to the other illustrated the trouble we were having with oxidation.

Figure 17

EFFECT OF SIZE DISTRIBUTION ON MULLABILITY									
Lab No	Ash	Moisture	Particle Size	Reagent Dose	Uniformity Test Results				
					+6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
016-89	16.85	24	325M x 0	2.00	3.74	33.65	24.67	37.94	62.61
016-87B	15.26	23	200M x 0	2.00	6.04	30.77	29.12	34.07	63.19
016-86B	13.36	23	100M x 0	2.00	18.39	32.57	31.99	17.05	49.04
016-81C	10.96	23	28M x 0	2.00	5.21	35.57	49.72	9.50	59.22

EFFECT OF SIZE DISTRIBUTION ON MULLABILITY									
Lab No	Ash	Moisture	Particle Size	Reagent Dose	Uniformity Test Results				
					+6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
016-86A	13.96	23	100M x 0	1.50	6.55	37.96	43.74	11.75	55.49
016-86B	13.96	23	100M x 0	2.00	18.39	32.57	31.99	17.05	49.04
016-87A	13.96	23	100M x 0	3.00	5.08	31.83	45.20	17.89	63.09
016-13	9.30	23	100M x 0	2.00	0.78	8.24	20.00	70.98	90.98

EFFECT OF SIZE DISTRIBUTION ON MULLABILITY									
Lab No	Ash	Moisture	Particle Size	Reagent Dose	Uniformity Test Results				
					+6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
019-9B	9.55	23	28M x 100M	2.00	13.04	67.49	17.58	1.89	19.47
019-10A	9.93	23	28M x 200M	2.00	2.63	30.57	42.51	24.29	66.80
019-10B	9.93	23	28M x 200M	1.50	3.35	55.51	30.71	10.43	41.14
019-11A	9.93	23	28M x 200M	3.00	5.99	53.97	32.88	7.16	40.04
019-11B	10.00	23	28M x 325M	2.00	13.04	51.16	31.13	4.67	35.80
019-12A	10.00	23	28M x 325M	1.50	7.65	39.02	45.49	7.84	53.33
019-12B	10.00	23	28M x 325M	3.00	12.21	48.29	34.54	4.96	39.50

Figure 18

EFFECT OF MOISTURE ON MULLABILITY								
Lab No	Ash	Moisture	Reagent Dose	Uniformity Test Results				
				+ 6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
016-85B	13.12	19	2.00	4.22	56.62	38.20	0.96	39.16
016-85A	13.12	20	2.00	11.75	55.30	31.60	1.35	32.95
016-82C	13.12	22	2.00	11.22	72.75	15.94	0.59	16.53
016-84A	13.12	26	2.00	49.03	49.81	1.16	0.00	1.16
016-84B	13.12	29	2.00	72.68	27.32	0.00	0.00	0.00

EFFECT OF MOISTURE ON MULLABILITY								
Lab No	Ash	Moisture	Reagent Dose	Uniformity Test Results				
				+ 6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
016-88	10.96	20	2.00	8.37	63.94	26.10	1.59	27.69
016-81C	10.96	23	2.00	5.21	35.57	49.72	9.50	59.22
016-83A	10.96	26	2.00	9.62	52.64	31.51	6.23	37.74
016-83B	10.96	29	2.00	17.88	78.27	3.85	0.00	3.85

Figure 19

REAGENT DOSE - EFFECT ON MULLABILITY

Lab No	Ash	Moisture	Reagent Dose	Uniformity Test Results				
				+ 6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
016-90A	10.96	23	0.50	41.29	55.41	3.30	0.00	3.30
016-90B	10.96	23	0.75	33.67	61.95	4.38	0.00	4.38
016-91A	10.96	23	1.00	38.59	57.80	3.61	0.00	3.61
016-91B	10.96	23	1.25	19.22	75.42	5.36	0.00	5.36
016-92A	10.96	23	1.50	17.90	75.43	6.67	0.00	6.67
016-92B	10.96	23	1.75	34.74	59.93	5.33	0.00	5.33

Lab No	Ash	Moisture	Reagent Dose	Uniformity Test Results				
				+ 6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
016-94A	10.96	23	1.75	2.36	27.11	55.79	14.74	70.53
016-94B	10.96	23	2.25	4.60	35.44	50.19	9.77	59.96
016-95A	10.96	23	2.50	2.70	14.50	56.65	26.20	82.85
016-95B	10.96	23	2.75	6.41	30.10	44.46	19.03	63.49
016-96A	10.96	23	3.00	3.28	12.36	52.12	32.24	84.36
016-96B	10.96	23	3.50	4.32	25.36	58.09	12.23	70.32
019-6A	10.96	23	4.00	3.29	17.92	57.22	21.57	78.79
019-6B	10.96	23	5.00	5.88	30.00	52.94	11.18	64.12

Both tables show test results on samples taken from the same drum of the bulk sample. Our standard procedure was to take two 5 gallon buckets of decanted froth concentrate from the bulk sample drum. Next the sample would be filtered in the lab to produce about one 5 gallon bucket of 23% wet cake. Filtrate would be saved and used (instead of tap water or distilled water) to adjust moisture if it was necessary.

A series of tests would be run until all of the filtered wet cake in the bucket had been consumed. Then another sample would be pulled from the bulk sample drum, and the filtering and testing process would begin again.

Lab test No. 016-92B was run on 8/11/94 on the last remaining 23% moisture wet cake in a 5 gallon bucket. The following day, a new sample was pulled from the same bulk sample drum and again filtered to 23% moisture. Late that same day (8/12/94), the newly filtered wet cake was tested under exactly the same conditions as 016-92B. The Handleability Index for the new test (016-94A) was 70.53, but the Handleability Index for 016-92B was only 5.33.

Obviously the oxidation process was accelerated once a sample was pulled from the bulk sample drum, and especially after it was exposed to air in the filtering process.

While results of the reagent dose series were disappointing and of little use in designing the circuit, there was no concern that the poor mullability we were experiencing with aged samples would cause any problems in the production phase of the project. Every time a fresh sample of froth concentrate was tested, an excellent mull was produced, and the quality and stability of the Mulled Coal was not deteriorating to any significant extent as a result of the aging process.

In the final analysis, we had to rely on testing from previous projects to estimate reagent dosages at various moisture levels. As it turned out, no amount of laboratory work (even with samples which were not oxidizing), would ever have prepared us for the reagent doses which were actually required in the production phase of the project. In actual operation, we used only a fraction of the reagent dosage predicted from all previous testing. There were economies of scale in mixing and in delivering reagent at higher flow rates and higher pressure which never could have been predicted with laboratory testing.

5.3.4 Temperature

Our production demonstration was scheduled for the coldest months of the year, and it is not unusual to have sub-freezing weather in Birmingham during those months. To insure that there would be no weather related problems with the production phase of the project, and to get some idea of how colder climates might affect the process, we did a short series of tests to evaluate the effect of temperature on both the mulling reagent and the wet cake.

We discovered that the cloud point for the reagent we intended to use for the project was about 40°F. At temperatures between freezing and 40°F, the reagent would form a thick gel. Because of the low reagent flow rates for the 3 TPH demonstration circuit, we used reagent spray nozzles with very small openings in order to get the system pressure that we needed to atomize the

reagent. We did not want waxing or any other temperature related problem to result in a plugged up reagent delivery system. Since we were using 55 gallon drums as the reagent reservoir, we provided drum heaters to maintain reagent temperatures above 40°F.

The project was delayed a few months. Run-in testing did not begin until March, and production did not start until early April. There were only a few daily lows in the sub-freezing area in March, and there was always enough heat in the project bay to maintain reagent at above 40°F, so the drum heaters were never used.

With the minimum reagent temperature established, we decided to determine if hot weather would affect the process, so we set up a short parametric test series to compare test results at ambient temperatures with results at the extreme temperatures of 40°F and 100°F. Test results are shown in Figure 20. Although test results are mixed due to the aging problem, there is a strong indication that the temperature range expected for the project and for other commercial installations will not have any significant effect on the process.

5.4 Pilot Plant Testing

Under the best of circumstances, 1000 g laboratory tests determine mullability characteristics in only relative terms. In order to study the Mulled Coal process under more realistic conditions, EI has set up a pilot plant circuit which is capable of continuously processing wet fine coal at a rate of 150 kg to 250 kg per hour. The major components of the pilot plant are actual scale models of equipment we planned to use for the proof of concept circuit.

The pilot plant is a simple circuit which consists of (Figure 21):

Surge Feeder

A volumetric stainless steel feeder with a manually charged 50 kg hopper which is capable of precisely and continuously feeding even the most problematic wet cakes at a rate of 0-750 kg per hour. The machine is equipped with an open spiral type feed auger which discharges wet cake through a close tolerance tube. There is also a larger diameter intromitter auger running concentric with the metering auger which keeps the material in the feed hopper "live", and prevents the bridging and plugging which is normally associated with moving wet fine coal through a hopper.

Pug Mill

A twin counter rotating shaft type with a total capacity of 0.5 m³, a working capacity of 0.3 m³ and a wet cake processing capacity of about 600 kg per hour. All wetted parts are stainless steel, and the counter rotating shafts are equipped with adjustable paddle blades which mix and move the material through the mixing chamber. Shaft speed and paddle angle are varied to change retention time and mixing conditions.

Reagent Delivery System

The system includes a small (1 liter) reagent tank, a positive displacement metering pump and the required hoses, valves, etc. to deliver 30 to 90 ml/minute to two cone spray nozzles which are located at the feed end of the pug mill. Reagent is delivered in such small quantities, that compressed air is used to atomize the reagent droplets.

Prior to starting a test run, the surge feeder is preset to meter a steady flow of wet cake into the circuit (usually about 160 kg/hour). Pug mill speed and paddle configuration are preset to a certain mixing procedure and retention time. The reagent delivery system is calibrated and set to deliver reagent to the circuit on the basis of a set percentage of the dry weight of coal being fed into the circuit.

When testing, the circuit is operated manually. Wet cake can be charged to the surge feeder hopper by transferring sample to 5 gallon buckets and dumping them in, or by dumping directly from 55 gallon sample drums. As much as 50 kg of wet cake can be added in a few seconds, but the feeder will continue to discharge at the preset rate. The surge feeder, pug mill and reagent pump are started manually, and the tests usually run continuously for between 15 and 45 minutes. Mulled Coal is collected in 20 kg wash tubs as it is discharged from the pug mill. Feed rate, retention time and reagent dose can be changed on the fly. Charging wet cake and collecting the finished product is also done on the fly. The only circuit adjustment requiring a plant shut down is a change to the pug mill paddle angles.

We used the pilot plant to run mullability tests, but we also used it to study capacities and power requirements for the feeder and pug mill so that we could make the necessary calculations to scale the system up to 4 TPH. Mullability test results will be reported here. Capacity and load tests will be discussed in Section 6.0.

Due to the aging problem with bulk samples, only one valid mullability test was run with the pilot plant circuit. Feed coal was a froth concentrate sample which was fresh, and the test was conducted within two days of first opening the sample drums. In the case of all other bulk samples, initial test work was limited to size distribution analysis and laboratory scale mulling tests. By the time we were ready to conduct continuous testing, the mullability of the bulk samples had deteriorated to the point where no useful information could be learned from a continuous pilot plant test.

The feed characteristics, the circuit set up, and the test results for the one valid pilot plant test were as follows:

Feed Characteristics

Source	Filtered Froth Concentrate
Ash	12.10%
Moisture	24.00%
Size	As Received (nominal 28M x 0)
pH of Water	7.5

System Settings

Reagent Dose	2% by dry weight of coal (48.5 ml/min)
Feed Rate	159 kg/hr
Feeder Setting	(10% capacity)
Pug Mill RPM	125
Elapsed Time	25 minutes

Totals

Reagent Used	1.70 liters
Mulled Coal Produced	93 kg

Uniformity Test Results

Time	+6M	6M x 14M	14M x 28M	28M x 0	Hand. Index
1st 10 minutes	2.64	25.66	51.51	20.19	75.70
2nd 10 minutes	3.14	36.97	47.69	12.20	59.89
3rd 10 minutes	4.63	34.45	51.11	9.81	60.92
Average	3.47	32.36	50.10	14.07	65.50
Marker Test*	7.51	26.09	48.02	18.38	66.40

*Immediately prior to the pilot plant test, we ran a lab scale K.A. mulling test on the same sample to see how uniformity test results would compare from the lab scale test to the pilot plant test.

The system set up, the feed rate and the reagent dose for this test are considered standard starting points for pilot plant testing. The Mulled Coal produced in this test was considered to be very good quality. Unfortunately there was not enough unoxidized sample to continue pilot plant testing with adjusted system settings to see if we could improve quality or reduce reagent dosage.

The pilot plant test did give us renewed confidence that the Mulled Coal circuit was going to work well on Chetopa fine coal. As it turned out, the full scale demonstration circuit worked far better than any of our lab scale or pilot plant testing would have indicated. Even if we had available additional unoxidized sample, more pilot plant tests would not have been of much help in establishing system settings for the production phase of the project.

5.5 Stability Tests

A series of stability tests was conducted on the Mulled Coal produced in the pilot plant test. The objective was to predict how Mulled Coal might behave in the normal commercial coal storage, transportation and combustion environment. Certain marker characteristics of Mulled Coal were compared to those same characteristics of untreated wet cake and bone dry coal.

5.5.1 Resistance to Freezing

Three 50 g samples each of Mulled Coal and untreated wet cake (before mulling) were loaded in identical sample pans and placed in a freezer at 5°F for 24 hours. Each "frozen" sample was removed from the freezer and evaluated with a simple drop shatter test. The "frozen" sample was raised to a height of 1M and dropped into a 100 cm x 200 cm x 300 cm stainless steel pan. When the sample struck the pan it shattered. Frozen material tended to shatter into large pieces. Unfrozen or loosely frozen material retained its approximate original size distribution. The extent of shatter was evaluated by hand screening the material in a three screen stack with 6M, 14M, and 28M openings. Results of the tests were averaged and are presented in Figures 22 and 23.

Mulled Coal does not present any problems when exposed to freezing temperatures. It appears not to be frozen at all, but moisture encapsulated within individual agglomerates may actually freeze, however, the reagent coating prevents individual ice crystals from bonding. On the other hand, the unmulled wet cake forms a solid block of ice when exposed to freezing temperatures.

5.5.2 Bulk Density

Good quality Mulled Coal always has a lower bulk density than the same coal as measured before mulling. Mulled Coal is down in the 36-39 lb/ft³ range and untreated wet cake is up in the 44-50 lb/ft³ range. Samples in the 44-50 lb/ft³ range generally have a Handleability Index of under 10, and Mulled Coal samples in the 36-39 lb/ft³ range generally have a Handleability Index of over 60. Results of bulk density testing are as follows:

Mulled Coal	Time	Bulk Density (lb/ft ³)
	1st 10 minutes	38.57
	2nd 10 minutes	38.74
	3rd 10 minutes	39.62
Mulled Coal	Average	38.98
Untreated Wet Cake		45.94

ASTM bulk density tests require 1 ft³ of sample for a bulk density test. The bulk density comparison between the Mulled Coal produced in the pilot plant test and untreated wet cake is based on 0.35 ft³ size samples.

5.5.3 Propensity to Slide

The slide characteristics of the Mulled Coal produced in the pilot plant test were compared to those same properties of unmulled coal and dry coal from the same bulk sample, and are reported in Figure 24.

The test series included angle of repose, angle of fall, angle of incipient slide and angle of slide. This series of tests in general is used universally to evaluate flow properties of bulk materials. Laboratory procedures and equipment used for the tests were designed specifically to do before and after testing on Mulled Coal, so absolute results cannot be used to design slide angles in fuel handling

Figure 22

FREEZE RESISTANCE DROP SHATTER TEST

Figure 23

UNIFORMITY TEST RESULTS

Mulled Coal Before & After Freezing

systems, and the test results for Mulled Coal cannot be compared to tests of other bulk materials done at other laboratories. However, relative results are a good indication of the improvement which takes place as a result of the Mulled Coal process, and they are a good way to compare one Mulled Coal to another.

A brief description of each test is as follows:

- a. Angle of Repose - This is a universally accepted indicator of the flowability of a bulk solid. It is a measurement of the included angle between the slope of a cone shaped pile and the horizontal. As the angle of repose decreases, the material is deemed to be more flowable. The angle of repose for dry coal is generally expressed as 37° .

We use about 200g of sample and pour it gradually on to a stainless steel plate from a height of about 15 cm.

- b. Angle of Fall - This test uses the same conical pile used for the angle of repose measurement. The pile is jarred by dropping a weight onto the base plate somewhere near but not at the base of the slope. The pile will fall creating a new and shallower angle between the slope and horizontal. The difference between the two angles is considered a measurement of flowability. The way the pile falls is also of special interest. If particles fall and spread out along the base of the pile, only a degree of flowability is indicated. If the entire pile collapses, it is a sign that the material contained entrained air, and the material could be prone to flood flow.
- c. Angle of Incipient Slide and Angle of Slide - The angle of slide is the angle at which material will completely slide down a flat surface due to its own weight. The angle of incipient slide is the angle at which the material first begins to move.

About 50 g of material is placed in a stainless steel pan measuring about 10 cm x 18 cm with shallow lips on three sides. At the beginning of the test the pan is set exactly horizontal. The pan is gradually rotated with a geared down motor. The lab technician closely observes the procedure and stops the rotation at the appropriate spots to take angle measurements. This is a subjective test, and we rely on the same lab technician to produce repeatable results.

- d. Dispersability - Dispersability is the measurement of the "dustiness" of a fine coal sample. The apparatus used for this test includes a 10 cm ID tube which is about 33 cm long. The tube is supported vertically with a ring stand; with the bottom of the tube located about 10 cm above the lab table. Directly beneath the tube is a 10 cm watch glass resting on the lab table. A 50 g sample is dumped through the tube "en

Figure 24

Propensity To Slide & Dispersability Test Results

Test / Material Tested	Unmulled Coal	Mulled Coal	Dry Coal
Propensity To Slide			
Angle Of Insipient Slide (Deg.)	29	23	18
Angle Of Slide (Deg.)	49	42	32
Angle Of Repose (Deg.)	44	36	36
Angle Of Fall (Deg.)	40	28	21
Dispersability (%)	2.31	1.66	7.17

masse" from a point about 61 cm above the lab table or 18 cm above the top of the tube. Material remaining in the watch glass is weighed, and the remaining material is considered to have been dispersed. Results are expressed in terms of the percentage of material which was dispersed.

As would be expected, very little of an unmulled 24% moisture wet cake will be dispersed. The interesting comparison in this test is how Mulled Coal will measure up against dry coal. What we look for is a Mulled Coal which has handling characteristics close to dry coal, but is not as dusty as dry coal.

6.0 PROCESS DESIGN ENGINEERING

This phase of the project included designing the Mulled Coal circuit and adapting it to prevailing conditions at the Chetopa plant. The primary objective was to design and locate circuit equipment and controls in such a way that we could meet project objectives, and at the same time cause a minimum of interference with Drummond's normal operations.

6.1 Site Survey

The Chetopa plant was built in 1966 by Alabama By-Products Corporation. In the mid-1980's Alabama By-Products was purchased by Drummond. The plant began as a fairly standard heavy media washer/concentrating table operation. Over the years there have been a number of plant additions to increase capacity and modernize the washing circuit. The latest addition (1987) included a heavy media cyclone circuit for 1/2" x 28M coal, and it doubled the capacity of the flotation circuit and vacuum filter. There are detailed structural steel, machinery plan and elevation drawings for recent plant additions, but original structural steel drawings and elevation and plan drawings for areas not involved in recent additions or currently in use are limited.

On our first visit to the site with Drummond personnel, we identified an empty machinery bay in a corner of the plant at a lower elevation which was completely isolated from the current plant operation (Figure 2). It was decided that, if at all possible, the Mulled Coal circuit would be located in that bay.

The empty bay measured 5-1/2M x 6M with a ceiling height of 2.5M. It contained no unused equipment or old piping. It was located close to and below the fine coal circuit, and it was situated in a place where it would be easy to get the Mulled Coal production out of the plant.

The proposed project bay would be very tight quarters for the project equipment and controls, and structural steel floor supports for the bay immediately above the project bay were very complicated. It would require a very precise layout to fit in the project equipment, chutes, etc. without disturbing the plant structure.

We gathered available drawings from the Drummond engineering department, and then we went in independently and located column lines, structural floor and wall supports, machinery, pipe lines, chute work, etc. in all areas which might be affected by project equipment and activities (Figures 25 and 26).

After making a few preliminary layouts, it was clear that the project would fit in the proposed location. While there were a few access problems, the empty bay represented the best possible location for the project. Drummond gave us permission to proceed with that location, and we began adapting the circuit to fit the space.

FIGURE 25

Figure 26

CHETOPA PREPARATION PLANT
TRACKSIDE ELEVATIONS

6.2 Interface Design

The interface with the Chetopa plant, or the points where we took material out of or put it back into the normal plant circuit, was the critical part of the design work. It had to be designed so that, from an operational standpoint:

1. We would cut out a representative cross section of the full stream of froth concentrate.
2. We would have complete control over the amount of froth concentrate which we were removing from the full stream.
3. When we were broken down or shut down, froth concentrate would completely bypass the Mulled Coal circuit.
4. Slurry pipes and valves would not plug up.
5. We had ready and quick access to all valves and pipes in case of an emergency.

From the standpoint of interfering with normal Chetopa operations:

1. There would be sufficient back-up and redundancy in the control circuit so that no kind of emergency or mechanical problem with the Mulled Coal circuit could result in shutting down the entire preparation plant.
2. We took coal and water out of the circuit and returned effluents back into the circuit in such a way that we would not cause any solids or hydraulic imbalance in the plant circuit.
3. The handling, trucking, weighing and storage of Mulled Coal would not interfere with normal Chetopa stockpiling and shipping operations.

From laboratory testing, it had been determined that the feed source must be concentrate from the Denver flotation cells. It must be taken after the concentrate from all four Denver cells was combined in one pipe, and it must be taken out ahead of the point where concentrate from the Wemco cells joins concentrate from the Denver cells. This narrowed the available sites for the take off point to an 11M section of 25 cm diameter pipe running from the Denver cells to the vacuum filter (Figure 27).

Decanter Machine, the manufacturer of the centrifuge, advised that, for the best possible slurry flow conditions, the slipstream should come off the main pipe at a 45° angle, and the take off point should be as close as possible to the centrifuge.

DENVER CELLS

TRIUMPH

WEMCO CELLS

Figure 27

ELEV 488' - 0

ELEV 467' - 0

ELEV 458' - 0

The position of the centrifuge could not be changed without altering major structural floor supports, so the initial criteria established for the take off point narrowed the location to a specific point on the 25 cm line running from the Denver cells to the vacuum filter. As it turned out, the target point was an ideal location for the pipe tap, valves, reducers, fittings, etc. which were required to direct a slipstream from the 25 cm line to the centrifuge.

When the Chetopa plant was built, rail cars were loaded directly beneath the plant. The side track ran between column lines (1) and (2), and the side track area was open from ground elevation (438'-6") up to elevation 458'6", which was the floor elevation for the main bay for the Mulled Coal circuit (Figures 2 and 26). The side track is still there, but it is not currently in use. In order to make smooth roadways for rubber tired equipment, the tracks have been covered up, making a perfect haul road directly beneath the project bay. Getting Mulled Coal out of the plant was simply a matter of cutting a hole in the floor and dropping Mulled Coal from the pug mill directly into a chute which discharged into a small (6.5 tonne) dump truck. The dump truck was leased by the project, and was used exclusively to haul Mulled Coal from the plant, across the Chetopa scales, and then to the Mulled Coal stockpile area. The round trip was less than one mile.

The Chetopa stockpile area is quite large (over 100,000 tons capacity), but there was never more than 5,000 to 20,000 tons of clean coal on the ground during the life of the project. There was plenty of space available, and the Mulled Coal stockpile was located on a corner of the main stockpile area which was well clear of any Chetopa traffic.

6.3 Pug Mill Design

For several years EI had used a Patterson Pump Company model 10 pug mill in a 275 kg/hr Mulled Coal pilot plant. The machine is equipped with a stainless steel mixing chamber measuring 25 cm wide by 1M long by 25 cm deep. The machine is rated at 1.6 ft³ total capacity and 0.9 ft³ working capacity. Mixing is provided by a set of stainless steel shafts which are mounted parallel, are counter rotating, and are equipped with a set of overlapping and adjustable stainless steel paddles.

Over the years several other types of mixers had been used at low capacities including pin type, ribbon type and lobe type mixers. After extensive experimentation, it was determined that the counter rotating shaft pug mill with a "half figure 8" mixing chamber configuration represented the best alternative for producing good quality Mulled Coal at an affordable price. This type of mixer is in common use in a wide variety of minerals processing applications, and it would be a rather straightforward matter to scale up from the pilot plant, to the proof-of-concept and then on to the commercial size.

The nominal feed rate for the project was established at 3 tons per hour of dry coal or 4 tons per hour of 25% moisture wet cake. We wanted the circuit to be capable of handling 150% surges, so the capacity design point for the pug mill was set at 6 tons per hour. A capacity of 6 tons per hour does not simply mean the amount of material which can be moved through the mixing chamber. It means the amount of material which can be moved through the mixing chamber under ideal mixing conditions which are generally "mid point" settings for retention time, RPM and paddle angle.

We normally operated the pilot plant at a wet cake feed rate of 160 kg/hr, but the feed rate was not controlled by the capacity of the pug mill. Pilot plant feed rate was limited by the capacity to deliver reagent and the capacity of a single lab technician to manually charge buckets of wet cake and remove tubs of Mulled Coal. In a series of capacity tests run in June of 1995, it was determined that the pilot plant pug mill had a processing capacity of about 600 kg/hr.

Based on a target capacity of 6 tons per hour, we needed a machine with about 10 times the capacity of the pilot plant pug mill. The capacities and dimensions for this type of pug mill as offered by Patterson Pump Company are shown in Figure 28. The pilot plant pug mill is a Model 10. The Model 18 machine is about 10 times the capacity of the Model 10, so the Model 18 was the design used for the project. The design of mixing chamber, paddles, etc. from the 5.5 tons/hr machine clear up to the 60 tons/hr machine is exactly the same, so we expected equal or better mixing efficiencies as we moved up in capacity.

6.4 Surge Feeder Design

From whatever type of device used to mechanically dewater fine coal (vacuum filters, filter presses, centrifuges, etc.) wet cake discharges are generally subject to short term surges and bursts in material flow. The surge feeder is included in the Mulled Coal circuit to level out feed rate spikes, and deliver wet cake to the feed end of the pug mill at a smooth even flow rate. A smooth feed rate is especially important at this point because this is where reagent is added to the wet cake, and since the reagent dose is only a small fraction of the total feed (less than 2%), even application is critical.

The surge feeder design presented a challenge because the machine must mechanically overcome all of the bridging, plugging and fouling problems normally associated with wet fine coal -- the very problems which the Mulled Coal process was designed to eliminate. Early in the development of the process, we experimented with various types of vibrating, reciprocating and solid screw feeders. None of them proved satisfactory. It was finally determined that wet cakes could best be conveyed or fed with an open spiral auger working in a close tolerance tube. However, the open auger by itself would not feed wet cake from a hopper bottom because the material is notorious for bridging over in a hopper or bin bottom configuration.

We decided to look at open auger type feeders which were equipped with some type of larger diameter rotating mechanism which was designed to prevent bridging. We sent typical wet cake samples to a number of manufacturers who made such a machine. They all responded that their machine would not handle wet cake, and they advised against using a surge feeder in our process.

Conventional wisdom was telling us that it could not be done, but we finally located a manufacturer's representative who was willing to give us a short term lease on an auger type feeder to see if we could modify it in some way that it could handle feeding wet fine coal. Before setting up the feeder, we ordered a standard part which slightly modified the large diameter rotating device. When the part arrived, we installed it and tested the machine on a particularly sticky wet cake (50% moisture and <325 mesh). The feeder began immediately to do an excellent job of feeding even the most problematic wet cakes, and the bridging problem was completely eliminated.

Figure 28

Model	A	B	C	D	E	Total Capacity Cu. Ft.	Max. Working Capacity Cu. Ft.
10	10"	Per Application	3'-0"	Per Application	9½"	1.6	0.9
14	14"		7'-6"		12"	7.5	5
18	18"		10'-0"		15"	17	10
25	2'-1"		10'-0"		19"	30	20
33	2'-9"		10'-0"		2'-0"	50	35
39	3'-3"		10'-0"		2'-4"	70	50
44½	3'-8½"		10'-0"		2'-8"	88	65
56½	4'-8½"		10'-0"		3'-2"	130	100
66½	5'-6½"		10'-0"		3'-6"	185	150

That particular feeder, an Acrison Model 105Z with a slightly modified intrumitter auger (larger diameter concentric auger) is now part of the EI Mulled Coal pilot plant. The machine is rated by Acrison at 200 ft³/hr. In capacity test work conducted in June of 1995 it was determined that the 105Z feeder would feed wet fine coal at the rate of 1590 kg/hr operating at 100% and 1200 kg/hr operating at 75%. This translates to about 95 ft³/hr and 70 ft³/hr respectively. We elected to specify a feeder which would deliver 6 tons per hour while operating at 75% capacity. Based on Acrison figures, we were looking for a feeder with 4.6 times the capacity of the Model 105Z or a capacity of 920 ft³/hr. We selected a 900 ft³/hr model with almost exactly the same design features as the pilot plant feeder.

6.5 Reagent Delivery System Design

The reagent delivery system was one of the most important considerations in the design phase of the project. In most cases, reagent cost will exceed 80% of the total cost of owning and operating a Mulled Coal circuit, and the precisely controlled and even application of the proper reagent dose is the key factor in maintaining Mulled Coal quality. Design considerations included reagent dose, major component design (pump, flow meters, valves, nozzles, etc., the integrated delivery system and system controls).

6.5.1 Reagent Dose

As explained in Section 5.0, we expected to use the results of a series of parametric K. A. mulling tests to predict the required reagent dose at various levels of feed ash, feed moisture, and feed size distribution. Due to the oxidation problem with bulk samples from Chetopa we were unable to use K. A. muller test results to make precise reagent dose predictions. However, we learned a number of things which were useful in designing the reagent delivery system:

1. We could expect a very narrow range of feed ash (11%-13%), and the ash range did not have a significant effect on mullability or required reagent dose. Therefore, it would not be necessary to continuously monitor feed ash in order to make adjustments to reagent dose.
2. We could expect a very narrow range of feed size distribution, and the range would have no significant effect on mullability or required reagent dose.
3. As would be expected, changes in moisture had the most profound effect on mullability, but the effect of moisture could be offset by raising and lowering the reagent dose. We would need to make changes to dose based on changes in moisture, and we would need to offset reagent flow based on TPH changes in feed rate.
4. We expected to run the demonstration circuit over a moisture range of 20% to 26%. There is not a linear relationship between moisture and mullability throughout the full 6% moisture range. Increases in moisture at levels above 23% require larger increases in reagent dose than increases in moisture down in the 20%-23% range.

5. From previous Mulled Coal research, it was determined that a reagent dose of about 2% of the weight of dry coal in the wet cake generally produced a good quality mulled level. That rule of thumb appeared to hold true with Chetopa coal only at the 23% moisture coal. Combining the valid data from the K. A. muller tests on Chetopa coal with previous Mulled Coal research, we calculated the required reagent dose at different levels of production and moisture (Figure 29). These calculations were programmed into the system control circuit. However, due to the inconsistency of Chetopa sample results and the experimental nature of the project, we also provided for a wide variety of automatic and manual adjustments which would virtually permit the circuit operator to apply any desired reagent dose at any time.

As it turned out the calculations made from Chetopa data and previous research work were not valid. The process is much more efficient at 3-5 tons per hour than it is in laboratory tests, and the reagent use was only about one-half of what was originally predicted.

6.5.2 Major Reagent System Component Design

1. Reagent Pump - The system required an extremely reliable positive displacement type pump which was capable of producing reagent flow over the full calculated range, and at nozzle pressures sufficient to properly atomize the reagent. The calculated flow range was 3-33 GPH, and we knew from laboratory testing that optimum dynamic pressure for proper atomization over the full flow range was 18-35 PSI.

We wanted to control reagent dose within +/- 0.1% of the dry weight of coal in the wet cake feed. This translates to controlling pump speed within 50 RPM.

The wide flow range at the anticipated pressures, coupled with control requirements, established a fairly difficult duty for the pump.

For reliability we wanted a magnetically coupled pump. To eliminate pulse flow we wanted a gear pump. For control purposes, we wanted an electrically commutated (brushless DC) pump drive.

Figure 30 shows the performance curve for the magnetically coupled, variable speed gear pump which was selected for the project.

2. Flow Meter - The relatively low flow rate, the wide flow range, and the viscosity of the reagent suggested a gear type positive displacement flow meter. The precise control target suggested that we use equipment manufactured by Max Machinery, a leading manufacturer of precision low flow meters and totalizers.

Figure 29

REAGENT USAGE

6.5.3 The Integrated Delivery System

Figures 31, 32 and 33 show sketches of the general arrangement of the reagent delivery system and the reagent spray manifold which was used on the feed end of the pug mill.

Due to the experimental nature of the project, we decided to provide an option to use compressed air assisted "fog" nozzles to atomize the reagent as it was applied to the wet cake. We assembled the reagent delivery system in our Pittsburgh laboratory to test it before going into the field, and we were fairly certain that fog nozzles would not be required. However, we had compressed air available so we designed the system so that we could use either an unassisted fan spray or an air assisted fog nozzle. As it turned out, the unassisted, wide angle fan sprays produced ideal atomization at about 25 PSI, so we never used compressed air in the delivery system.

In Figure 32, all components from 3 through 14 were located in the circuit control room. This was done to keep manual valve controls and pressure gauges in full view of the circuit operator. Items 3 through 6 and 12 through 14 were located in a steel cabinet, and the valves and pressure gauges (7 through 11) were mounted on a manifold against the wall of the control room.

Reagent usage was less than one drum per shift, although original calculations indicated that we would use just under two drums per shift. Just prior to the start of a run-in testing, we moved about 18 full drums of reagent up to the project bay. The original plan was to remove empties and bring in full drums about every two weeks. The balance of the reagent inventory was stored on pallets in an outside supply yard located within a few hundred meters of the plant. As it turned out, we only replenished the reagent inventory twice during the life of the project; we brought in about 13 drums the first time and 9 drums the second time.

The reagent drum in use was cradled in a drum dolly which was spotted just outside one of the back walls of the control room (Figure 34). We had two sets of dollies, shut off valves, drum vents and quick disconnects, so the next full drum in line was set up and spotted immediately adjacent to the active drum. When the active drum was within a few gallons of being empty (we knew the exact amount of remaining reagent at any given time because of an automatic totalizer which could be set to zero at each drum change), the drums would be changed "on the fly". Changing drums was simply a matter of moving a quick disconnect hose from one drum to another. The procedure took only a few seconds. The remaining reagent in the drum which was changed out was transferred to a scavenger drum which was put back into the cycle when it was completely filled.

For inspection purposes, the pug mill mixing chamber was originally provided with three hinged top covers; with each cover spanning about 1/3 the length of the mixing chamber. We removed the hinged cover from the feed end of the machine and replaced it with the reagent spray manifold and covers shown in Figures 32 and 33. The fan spray nozzles produced a flat spray pattern with about a 100 degree included angle. The reason that the manifold and covers were raised above the level of the top of the pug mill was to insure that the spray pattern would cover the entire width of the mixing chamber.

1. SHUT OFF VALVE
2. QUICK DISCONNECT
3. SUCTION FILTER
4. PUMP
5. SYSTEM RELIEF VALVE
6. FLOW METER
7. SYSTEM PRESSURE GAUGE
8. BRANCH CIRCUIT SHUT OFF VALVES
9. LIQUID LINE PRESSURE REGULATORS
10. AIR LINE PRESSURE REGULATORS
11. AIR LINE SYSTEM PRESSURE GAUGE
12. AIR LINE FILTER
13. AIR LINE SOLENOID VALVE
14. AIR LINE SHUT OFF VALVE
15. PLANT AIR LINE
16. AIR ATOMIZING SPRAY NOZZLES
17. REAGENT DRUM

REAGENT DELIVERY SYSTEM

Figure 32

REAGENT SPRAY MANIFOLD

FEED END PUG MILL COVER

BEND PARTS FROM
16 GAGE SHEET METAL

WILL ATTACH COVER TO PUG
MILL WITH DESTAKO CLAMPS

SPRAY NOZZLE HOLES
TO BE PUNCHED
IN FIELD

BASE

SPRAY HOSE
HOLES
1 5/8" DIA.

TOP
COVER

5 1/2"

FRONT
COVER

BACK
COVER

Figure 34

ELEV 458'-6
MACHINERY PLAN
REAGENT DRUM LOCATION

REVISED 11/03/94

6.5.4 Reagent Control System

The reagent pump RPM (reagent flow rate) was controlled with a 4-20 MA signal from the PLC. An output device transmitted reagent flow rates directly to a flow meter/totalizer mounted in the face of the control panel, and to a computer screen through the PLC. The control loop was set up so that changes in moisture, as interpreted by an on line microwave moisture monitor, would result in automatic adjustments to reagent dose in accordance with the calculations shown in Figure 29. To adjust for changes in feed rate, there were offsets which could be made by clicking on buttons on the main computer screen. Finally, reagent dose was infinitely controllable with a manual switch located on the face of the control panel.

6.6 Slipstream Take-Off Design

Figure 35 shows the design of the slipstream take off point or the layout of the pipe taps, valves and piping to direct 3-5.5 tons per hour from the Chetopa fine coal stream to the Mulled Coal circuit.

Overall design criteria included:

1. On the advice of Decanter Machine, the main pipe tap should come off the 25 cm concentrate line at a 45 degree angle, and the tap should be as close as possible to the centrifuge. There was no pressure in the 25 cm line from the Denver flotation cell to the vacuum filter, but the rotation of the centrifuge would create a positive suction head. The shortest distance between the pipe tap and centrifuge would result in the most positive and controllable flow for the slipstream.
2. The percent solids in the froth concentrate could run as high as 35% which is a high solids content for a low pressure line. The distance from the main pipe tap to the manual ball valve was held as short as possible, because we knew that solids would settle out and plug that area during periods when the Mulled Coal circuit was shut down. A 1" pipe tap was welded into the main pipe tap (item 12 in Figure 35). It was connected to a high pressure fresh water line. Whenever the Mulled Coal circuit was to be started up after more than a 30 minute shutdown, high pressure water would be used to flush out the main pipe tap area before starting up. To provide for smooth, low friction flow from the valves to the centrifuge, we used fabricated sweep elbows and low friction high density polyethylene pipe. Victaulic couplings were used to splice in a short piece of 3" pipe so that we could quickly open up the pipe line to clear a blockage (item 10 in Figure 35). We got into the line at that point on occasion to gather feed samples, but the line never plugged up during operation.
3. The inlet flange on the centrifuge was 3" diameter, but we used a 4" pipe tap, 4" valves and a 4" to 3" reducer (items 1 through 4 in Figure 35). The reason for this is that 3" diameter is not a standard size for the type of knife gate valve used in the project, and the decision to go with 4" equipment was based on price and availability.

SLIP STREAM TAKE OFF POINT

4. The air activated gate valve (item 3 in Figure 35) is the principal component of the slipstream take-off system. The valve was in total control of feed rate to the Mulled Coal circuit. The valve ahead of it, the manual ball valve (item 2 in Figure 35), was always set either fully open or fully closed.

All wetted parts in the knife gate valve were stainless steel. From the standpoint of wear resistance, this was overkill for a short duration project, but we were concerned that corrosion in the valve body could exacerbate plugging problems.

For precise flow control the valve was provided with a V-port. It was also provided with an automatic positioning device and automatic position feed back unit, so percent opening from 0-100% always appeared on the computer screen, and precise adjustments (within +/- 1%) could be made quickly by simply clicking on buttons on the computer screen.

The automatic positioning unit consumed about 0.5 ft³/min at 80 PSI. In order to insure a clean, uninterrupted air supply, a small piston type air compressor was installed and made captive to the slipstream take-off system. (It should be noted that this same compressor would have supplied air for atomizing reagent spray nozzles should it have been required.)

Finally, there was a back up compressed nitrogen system (tank, regulator, hoses, etc.) which was available to operate the valve in the case of a loss of compressed air. The back up system was designed to operate only in emergencies or for a short duration (less than one shift). Midway in the project there was an air compressor failure, and the back up system was used to complete the production shift.

5. The manual ball valve (item 2 in Figure 35) was the last line of defense in insuring that no kind of failure in the Mulled Coal circuit could result in shutting down the entire Chetopa plant. The valve was run either fully closed or fully open. In case the knife gate valve ever got stuck in the open position (which actually happened when the air compressor failed), the ball valve could be closed to direct flow away from the Mulled Coal circuit. Closing the ball valve also allowed us to completely remove the knife gate valve or any other section of the slipstream take-off system for repairs (this was never necessary in the life of the project).
6. Item 6 in Figure 35 is a 1" pipe tap which was also connected to a high pressure fresh water line. The plan was to use this line to flush out the centrifuge should it become necessary, and to add dilution water to the feed in an attempt to control feed solids or product moisture. In actual practice, the line was useful for flushing out the centrifuge, but we were never able to effectively control moisture or feed solids from that point.

6.7 Chute Design

The design, arrangement and installation of chutes was a key consideration in designing the Mulled Coal circuit. The centrifuge product chute and the chute from the centrifuge to the surge feeder were to carry wet cake with wide swings in moisture content, the material which historically causes plugging problems in chutes. We established three principal criteria which were to be included in chute design.

1. The wet cake chutes should be absolutely verticle.
2. The materials of construction had to have a low coefficient of friction.
3. The wet cake chutes were to be installed in such a way that they could easily be cleaned out if they were plugged.

The Mulled Coal product truck loading chute was less of a design problem. The chute was to be lined with a low coefficient of friction material. It was to be installed at a slope angle of 40 degrees or less, because we always wanted to produce a Mulled Coal product which would slide freely at 40 degrees. If the chute began to back up or plug off, it would be an indication that we were producing an off standard product.

Figure 36 is a sketch of the general arrangement of the principal chutes in the circuit. Item 1 is the centrifuge product chute which is actually part of the centrifuge. Item 2 is the chute from the centrifuge to the feeder, and item 3 is the Mulled Coal truck loading chute.

The centrifuge chute is actually part of the centrifuge, but Decanter Machine generally used this centrifuge for short run trail demonstrations, and the chute was lined with corroded steel and some pieces of rubber belting. We wanted a better chute liner for this project, so we removed the steel and rubber and lined the chute with UHMW PVC.

We left a gap of 30 CM between the centrifuge chute and long chute to the feeder. The gap was left so that, without having to move or dismantle any structure, we could clean out the centrifuge chute from the bottom, and we could get at the top of the long chute if either one of them ever plugged up. To keep water and other foreign material out of the Mulled Coal circuit, we hung a transition skirt between the two chutes. The skirt was cut from a heavy, but flexible plastic brattice cloth which is commonly used in deep mine operations. Grommets were installed in the brattice cloth so that it would not rip when it was bolted to the chute frames.

The long chute from the centrifuge to the surge feeder and the Mulled Coal truck loading chute were both fabricated from the same 6 meter long piece of 46 cm diameter heavy wall, high density polyethylene pipe. Since the bottom of the rectangular centrifuge chute was about 60 cm wide and the pipe was only 46 cm in diameter, a high density polyethylene funnel shaped piece was fabricated

Figure 36

CHUTE ARRANGEMENT

and butt welded to the first section of pipe. There was not enough room to fit the long chute through the hole in the floor at elevation 476", so two flanged pipe joints were provided so that short pieces could be put in place and bolted together. It was also felt that it might be necessary to unbolt and separate the short pieces if the chute ever plugged up tight.

The long chute was terminated about 12" above the surge feeder hopper and a transition skirt was provided in the same fashion as the skirt under the centrifuge chute. Finally, the surge feeder was set on a heavy duty machinery table which was mounted on wheels. If we ever needed to get at the bottom of the long chute, we could simply wheel the surge feeder out of the way.

The attention to details in the chute designed paid off. At various times in the project we processed some very high moisture wet cake, and at other times there were some operator errors which resulted in plugged chutes. Most of the precautionary design measures were ultimately used, but there was never much production time lost in unplugging chutes.

A sketch of the type of design used for the Mulled Coal truck loading chute is shown in Figure 37. A piece of the polyethylene pipe was cut in half and bolted to a light angle and flat bar stock frame. We made one small field alteration. Due to high wind conditions during the time of the production phase of the project, and due to the fact that the empty side track bay under the plant acted like a wind tunnel, it was necessary to cover the top of the chute with sheet metal. At the discharge end of the chute we hung another brattice cloth skirt to reduce wind losses in the area where the Mulled Coal dropped into the haul truck.

There was one other small rectangular UHMW PVC chute used in the circuit. It simply surrounded the Mulled Coal stream where it dropped from the pug mill, through the floor and onto the truck loading chute. One side of the chute was removable so that we could reach into the coal stream from the project bay to take Mulled Coal quality control samples.

6.8 Access Design

Project equipment was to be located in four different bays which were stacked one on top of the other. The screen bowl centrifuge was to be located in the top bay at elevation 476'-0. This bay also contained concentrate lines and one end of the vacuum filter used to dewater Chetopa fine coal. The centrifuge effluent drains and sampling ports for the project were located in the next bay down at elevation 467'-0. This bay also contained the filter cake collecting belt and the vacuum filter drain line. The main bay at elevation 458'-6 contained the reagent system, the surge feeder, the pug mill and the control room. There was no Chetopa equipment in the main bay. The project haul truck traveled in the open bay immediately beneath the main project bay. There was no other equipment of any kind in this bay - it was an open roadway under the plant which was once used to load rail cars.

The successful operation of the project demanded quick and ready access between all of the bays with project equipment. The demonstration circuit operator and EI technicians would routinely be on the move between all of the project bays - especially between the control room and the outside to check on the status of the truck loading. (The truck was not manned during loading, but it would be necessary to advance the truck a few feet on three or four occasions during each loading.)

Figure 37

- ① 18" H D POLYETHYLENE PIPE (CUT IN HALF)
- ② 2" x 2" x 1/4" ANGLE ALL FOUR SIDES
- ③ 1/4" x 1 1/2" FLAT BAR STOCK (BOTH SIDES)
- ④ 1/4" x 2" FLAT BAR STOCK (EVERY 24")
- ⑤ DRILL THROUGH & BOLT EVERY 24"
- ⑥ BOLT EVERY 24" (1/2" MACHINE SCREWS)
- ⑦ EYE BOLTS FOR HANGING

MULLED COAL CHUTE

Prior to the start of the project, there was no quick way to get from the main project bay to the two bays immediately above, and there was no way to get from the main bay outside to monitor truck loading. In addition, the main personnel entrance to the Chetopa plant was over 100' from the main bay, and since that bay was in a remote, unused corner of the plant, getting from the plant entrance to the project bay required going up and down quite a few flights of stairs (Figure 38).

In order to provide fast access to all project equipment, we decided to incorporate two new sets of steps into the Mulled Coal circuit. One set was a new outside personnel entrance from ground elevation up to the control room, and the other connected the main bay to the one immediately above (Figures 39 and 40). The steps, along with a new door into the plant, would make it possible for our operators to travel from the slipstream take-off point to the haul truck in a matter of seconds.

There was no way to get the large pieces of project equipment (centrifuge, pug mill, surge feeder, reagent drums and control panel) into the plant without cutting holes in the plant siding. At the conclusion of the project, the equipment would have to be removed through the same openings. Also, there would be a need from time to time to hoist additional drums of reagent up into the main project bay. In order to get this equipment in and out, it would be necessary to open up the plant siding at elevations 458'-6" and 476'-0".

Drummond felt that they would also be able to use the same openings to move their own equipment and supplies in and out of the plant. It was decided that we would install permanent hoist doors at the appropriate locations, and that the hoist beam would be located at the highest possible plant elevation which was in line with the new hoist doors (Figure 39).

6.9 Circuit Control Design

The Mulled Coal circuit would rarely be used on a stand alone basis. It would most commonly be used as a final product conditioning step in a standard or advanced fine coal cleaning circuit, so we wanted to demonstrate a control circuit which used equipment and strategies which were similar to the systems used in modern coal preparation plants.

The design of the control circuit was based on the following considerations:

1. The Mulled Coal circuit control was to be completely independent of the control circuit for the overall Chetopa plant. In commercial practice, the two control circuits would have been integrated, but because of the experimental nature of the demonstration, we wanted to try out some fairly sophisticated controls and data acquisition and management which would not be used for normal commercial installations. We also wanted to be in complete control of the system at all times.

We did not want any interruptions in the demonstration circuit to affect the overall Chetopa plant in any way, and we did not want any interruptions in the Chetopa plant (emergency shutdowns, etc.) to affect the operation of the Mulled Coal circuit in any way.

CHETOPA PREPARATION PLANT GENERAL ARRANGEMENT

ACCESS STEPS & HOIST DOORS

79

Figure 40

ACCESS STEPS

Other than the slipstream take-off point, the only physical connection between the two circuits was that the main feed line to the Mulled Coal circuit originated in the overall plant motor control center. Therefore, if the overall plant lost power, the Mulled Coal circuit would lose power.

2. In order to be consistent with the type of equipment used to control modern coal preparation plants, the Mulled Coal circuit would be provided with a standard motor control center which could be operated in a manual mode. However, under normal circumstances, the circuit would be controlled with a programmable logic controller which was interfaced with a captive PC which was used for data entry, data acquisition and data storage. The PLC/PC system could be operated in either a full automatic or semi-automatic mode. This system would allow for three separate methods of operation. It was highly unlikely that any malfunction in the control system would result in lost production, and the system gave us the option of experimenting with a number of different methods of operation.
3. The PLC/PC system was to be provided with an off-the-shelf industrial automation software package which would operate in a Windows environment, and would give us the following capabilities.
 - (a) Data Acquisition - Communicate with I/O devices in the PLC and gather real time data on motor loads, valve settings, reagent flow and moisture readings.
 - (b) Data Presentation - Provide a series of simple and clear graphic display screens which would allow us to start, stop, and adjust the circuit, monitor the circuit in real and historical time, and adjust control logic.
 - (c) Data Control - Automatically apply algorithms that maintain process values within pre-determined limits.
 - (d) Alarming - Recognize and interpret exceptional events (overloads, circuit imbalance, etc.) and provide the operator with visual and audible alarms that the circuit or individual components were not performing within acceptable limits.
 - (e) Data Archiving - Store acquired data points in such a way that they could be retrieved from files at a later date and used to create trend displays of historical data.

4. **Process Control Design** - Since feed moisture had the most profound effect on Mulled Coal quality, we decided to control the process with a loop which would automatically adjust reagent dose based on feed moisture.

Moisture data was to be provided to the loop with an on line moisture analyzer which was guaranteed to continuously monitor feed moisture with an accuracy of (0.5% at the nominal set point of 23% moisture). Moisture data was interpreted with the computer, and reagent flow was automatically adjusted with an algorithm which produced the flow rates shown in Figure 41. This part of the loop controlled the process at a level feed rate.

Reagent dose also had to be adjusted because of changes in feed rate. Due to the short duration of the project and some space limitations, it was not economically feasible to install equipment specifically designed to monitor feed rate (weight belts, o/o solids monitors, etc.). However, each truck load of Mulled Coal would be timed and weighed, and historical data would be available which would show precise valve settings and motor loads throughout each loading cycle.

It was felt that, after some operating experience, we would be able to determine a predictable relationship between valve settings, motor loads and wet cake feed rate with enough accuracy to automatically adjust reagent dose. To begin the demonstration, we programmed in reagent dose offsets at 0.5 TPH increments which could be executed simply by clicking on a button on the computer screen.

5. **Operating Voltages** - The control circuit was somewhat complicated by the fact that the small size of some of the equipment prohibited the exclusive use of 480VAC, 3 phase motors which is a fairly standard utilization voltage in modern preparation plants. We were forced to provide circuits and control equipment for 480VAC 3-phase, 220 VAC 3-phase, 220 VAC 1- phase, 110 VAC phase, 250 VDC and 5 VDC.
6. **Contractor** - The design of the control circuit was to be fairly complicated, and we did not want communications between contractors to become a problem, so we decided that we would seek a single contractor with the capability to design, build, test, install and start-up the control circuit.

6.10 Control Room Layout

Figures 42 and 43 show the layout of the control room and the way it fit into the main project bay at elevation 458'-6. The control room was tight for space, but it was necessary to maintain adequate walkways around the equipment in the main project bay, and the control room was designated to be the maximum size for the space remaining. There was adequate room for an operator in the area of the motor control center and computer, along with another person conducting laboratory test work at the work bench.

Figure 41

REAGENT USAGE AT VARIOUS FEED RATES & MOISTURES								
% Moisture	20.00	20.20	20.40	20.60	20.80	21.00	21.20	21.40
Feed Rate Lb./Hr	Reagent Flow (GPH)							
5000	9.87	9.96	10.05	10.13	10.22	10.31	10.39	10.48
6000	11.85	11.95	12.06	12.16	12.27	12.37	12.47	12.57
7000	13.82	13.95	14.07	14.19	14.31	14.43	14.55	14.67
8000	15.80	15.94	16.08	16.22	16.35	16.49	16.63	16.76
9000	17.77	17.93	18.09	18.24	18.40	18.55	18.71	18.86
% Moisture	21.60	21.80	22.00	22.20	22.40	22.60	22.80	23.00
Feed Rate Lb./Hr	Reagent Flow (GPH)							
5000	10.56	10.64	10.73	10.81	10.89	10.92	10.89	10.86
6000	12.67	12.77	12.87	12.97	13.07	13.10	13.07	13.03
7000	14.78	14.90	15.02	15.13	15.25	15.28	15.24	15.20
8000	16.90	17.03	17.16	17.29	17.42	17.47	17.42	17.38
9000	19.01	19.16	19.31	19.46	19.60	19.65	19.60	19.55
% Moisture	23.20	23.40	23.60	23.80	24.00	24.20	24.40	24.60
Feed Rate Lb./Hr	Reagent Flow (GPH)							
5000	11.37	11.88	12.39	12.90	13.40	13.90	14.39	14.89
6000	13.65	14.26	14.87	15.48	16.08	16.68	17.27	17.87
7000	15.92	16.64	17.35	18.06	18.76	19.46	20.15	20.84
8000	18.20	19.01	19.83	20.64	21.44	22.24	23.03	23.82
9000	20.47	21.39	22.31	23.21	24.12	25.02	25.91	26.80
% Moisture	24.80	25.00	25.20	25.40	25.60	25.80	26.00	
Feed Rate Lb./Hr	Reagent Flow (GPH)							
5000	15.38	15.87	16.35	16.83	17.31	17.79	18.27	
6000	18.46	19.04	19.62	20.20	20.78	21.35	21.92	
7000	21.53	22.21	22.89	23.57	24.24	24.91	25.57	
8000	24.61	25.39	26.16	26.94	27.70	28.47	29.22	
9000	27.68	28.56	29.43	30.30	31.17	32.02	32.88

Figure 43

ELEV 458'-6
MACHINERY PLAN
STEPS LOCATION

REVISED 11/03/94

The control room was to be semi water and dust tight. The project was too short a duration to go to the expense of installing a completely tight and atmosphere controlled room. Our intention was to design a structure which would prevent water and dust from damaging the computer and lab equipment.

Maintaining the ceiling in a semi water tight condition was a challenge. Under normal circumstances, it would not have been much of a problem, but the Chetopa plant followed a clean-up procedure which resulted in a great deal of wash water flowing through the floor above the main project bay and onto the ceiling of the control room. In the plant all spills and routine clean-up were handled with high pressure/high flow fire hoses. The coal washed away in this manner would work its way down through the floors of the plant until it ran through the bottom floor and outside; where it could eventually be picked up and moved with a front end loader. This was a good clean-up system, but unfortunately, the control room ceiling was directly in the path of all of the wash down water from the fine coal side of the plant -- which is most vulnerable to overflow and conveyor belt spills.

The wash down water did not bother us out in the project machinery bays. If water and coal fines were washed down on the equipment from above, we simply cleaned out our own bays with a fire hose. All of the project equipment had good paint jobs or was of plastic or stainless steel construction, and all electrical enclosures (junction boxes, E stops, disconnect switches, etc.) were of NEMA 4 design, so we could wash them down with high pressure hoses.

The control room walls and ceiling were fabricated with galvanized sheeting which was framed in with light angle and bar stock. All seams were welded and sealed from inside and outside. The galvanized sheet ceiling was provided with a heavy plastic vapor barrier which was installed like a bonnet. Above the bonnet was an oversized sheet of corrugated steel which was completely sealed on the outside.

The corrugated sheet went in after we experienced some ceiling leaks during the run in phase of the project. After that, we never had another problem, and we never had a dust problem, but we had to clean up the control room at least two times each operating shift.

6.11 Preliminary Sketches

The final design engineering task was to prepare a series of preliminary sketches of structural additions and the general arrangement of equipment which was to be installed in the various machinery bays. The sketches were to be presented to Drummond for approval, and they were to be used to solicit bids for detailed engineering, electrical contracting, and actual erection and installation of the equipment. They were also used to prepare a detailed bill of materials for the project.

Although some of these sketches appear elsewhere in this report, they are shown here again as part of the series. The series includes:

Figure 44
Figure 45

Schematic Flow Diagram
Machinery Plan at Elevation 476'

Figure 44

POC PROJECT
SCHEMATIC FLOW DIAGRAM

DATE: JULY 5, 1994

1	8-15-94	REDIRECTED CENTRIFUGE EFFLUENT TO FLOTATION SUMP
2	10-4-94	ADDED KNIFE GATE VALVE FOR SLIP STREAM TAKE OFF
3	11-26-94	ELIMINATED SLURRY ANALYZER
4	1-15-95	REVISED SLIP STREAM TAKE OFF POINT
5	5-15-95	ELIMINATED ON-LINE MOISTURE MONITOR
NO.	DATE	REVISION

REVISED
11/04/94

Figure 45

ELEV 476'-0
MACHINERY PLAN

Figure 46

ELEV 467'-0
MACHINERY PLAN

REVISED 11/4/94

Figure 47

ELEV 458'-6
MACHINERY PLAN
STEPS LOCATION

REVISED 11/03/94

Figure 48

REVISED 11/03/94

7.0 DETAILED ENGINEERING

As a result of laboratory testing and the various design engineering tasks, we were able to identify specifications and sources for major equipment, and we were able to prepare preliminary bills of material for pipe parts, fabricated parts, structural steel and electrical parts. The preliminary bills of material along with the series of sketches of the project bays were used to solicit quotations from engineering, electrical, mechanical, and erection contractors.

7.1 Major Equipment Components

Screen Bowl Centrifuge

Manufacturer	Decanter Machine, Inc.
Model	18" x 42" Test Machine
Drive	50 HP, 460 Vac-3P, Turbo Clutch

Pug Mill

Manufacturer	Patterson Pump Company
Model	No. 18 Pug Mill Mixer
Drive	7-1/2 HP, 230/460 Vac-3P, Variable Frequency

Surge Feeder

Manufacturer	Acrison, Inc.
Model	140-R
Drive	Variable Speed DC

On-Line Moisture Monitor

Manufacturer	Berthold Systems, Inc.
Model	Mono-Moist 5800

Knife Gate Valve

Manufacturer	Orbe Valve
Size	4", V-Port
Actuation	Air
Accessories	Auto Position & Position Feedback

Compressor

Manufacturer	Ingersoll-Rand
Model	T10220P
Drive	2 HP, 110/220 Vac-1P

Reagent Pump

Manufacturer	Micropump Corporation
Model	HG 132

Reagent Flow Meter

Manufacturer	Max Machinery, Inc.
Model	221

Programmable Logic Controller

Manufacturer	Omron Electronics, Inc.
Model	C200H

Computer

Manufacturer	Gateway 2000
Model	486 DX2-66

Automation Software

Manufacturer	Intellution, Inc.
Model	FIX DMACS

7.2 Bills of Material

Figures 49 through 56 show the preliminary bills of material for the project. These initial documents were not 100% complete and not all specifications were exact. They were based on design engineering considerations and were only intended to be a starting point. Initially they were used to clarify bid requests from engineering, electrical and mechanical contractors. As the project progressed they were revised and expanded, and they were used internally to track cost and delivery.

7.3 Detailed Engineering

The series of project sketches in Figures 44 through 48, the bills of material in Figures 49 through 56 and a narrative description of the scope of work were sent to several engineering firms for bids. DeBardeleben and Associates, a local construction and erection engineering firm was selected to do the work.

The scope of work included:

1. Examine the structural steel in all bays housing project equipment and make recommendations for additions or improvements.

Figure 49

PRELIMINARY BILL OF MATERIALS						
Pipe & Plumbing Supplies						
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost	Status
Slip Stream Take-Off						
4" Steel Pipe Tap By 12" Long	1	Sch 40	X			
1" Weld On Pipe Tap	1		X			
150 lb. Floating Flange - 4"	1		X			
4" Stainless Steel Ball Valve	1	Flanged Ends	X			
4" x 3" SDR11 Tapered Reducer	1	Flanged Ends	X			
3" SDR Flange Adapter	2		X			
3" SDR Pipe by 36" Long, Plain Ends	1		X			
1" Saddle Type Pipe Tap For 3" Pipe	1		X			
3" Victaulic Couplings	2		X			
3" SDR 45° Ell, Fabricated, Flanged En	1		X			
3" SDR 90° Ell, Fabricated, Flanged En	1		X			
1" High Pressure Hose By 40' Long	1		X			
Connect Lines To Fresh Water System	Lot	1" Ball Valves, Fittings, etc.	X			
Centrifuge Push Water Line						
20' 3/8" Hose, Fittings, etc.	Lot		X			
Centrifuge Effluent Sampling Ports						
6" Flexible Hose By 3' Long	2		X			
6" To 4" Tapered PVC Reducer	2	Sch 40	X			
4" To 2" Tapered PVC Reducer	2	Sch 40	X			
2" x 2" x 2" PVC Tees	2	Sch 40	X			
2" x 2" x 1" PVC Tee	1	Sch 40	X			
2" PVC Ball Valves	3	Sch 40	X			
1" PVC Ball Valve	1	Sch 40	X			
2" PVC Pipe By 5' Long	1	Sch 40	X			
1" Hose & Fittings By 2' Long	1	Sch 40	X			
Fittings, Adapters, Glue, etc.	Lot		X			
2" Steel, Sch 40, Weld On Pipe Tap	1	Sch 40	X			

Figure 51

PRELIMINARY BILL OF MATERIALS						
Fabricated Parts						
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost	Status
Outside Steps						
48" Steps, Landings & Handrails	Lot	Elev. 438' -6 to 458' -6	X			
Structural Steel Supports For Above	Lot		X			
Inside Steps						
36" Steps & Handrails	Lot	Elev. 458' -6 To 467'	X			
Hoist Doors						
4" Rectangular Tubing	80'	Framing	X			
12" Channel	40'	Framing	X			
Industrial Hinges	8		X			
Steel Pipe & Angle	Lot	Personnel Guards	X			
Mono-Moist Mounting Brackets						
2" Angle & Bar Stock	Lot	Field Fabricated	X			
Machined Mounting Plates	Lot	Scin. Detector & Source	X			
Centrifuge Chute						
1/4" UHMW PVC Sheet	2	24" x 24"	X			
1/4" UHMW PVC Sheet	2	24" x 6"	X			
Chute From Centrifuge To Feeder						
24" to 18" Tapered Funnel, Flanged En	1	High Density Polyethylene	X			
18" SDR Pipe Section, Flanged Ends	2	High Density Polyethylene	X			
Mulled Coal Chute						
Rectangular PVC Transition Piece	1		X			
Half Round 18" Dia. Liner x 60"	1	High Density Polyethylene	X			
Light Angle & Steel Framing	Lot		X			

PRELIMINARY BILL OF MATERIALS						
Fabricated Parts						
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost	Status
Surge Feeder Tube Extension						
UHMW PVC, Machined Per Drawing	1		X			
Reagent Spray Manifold						
(2) Pieces Sheet Metal	Lot	Bent & Punched Per Dwg.	X			
Reagent Pump & Flow Meter Cabinet						
Sheet Metal Cabinet	Lot	Fabricated Per Drawing	X			
Doors						
Outside Access Door	Lot	Per Drawing	X			
Control Room Door	Lot	Per Drawing	X			
Control Room						
1/8" Galvanized Steel Sheeting	10	4' x 8'	X			
30" x 40" Plexiglass "Window"	1		X			
Light Angle & Steel Framing	Lot		X			
12' x 12' Heavy Plastic Bonnet			X			
10' x 10' Corrugated Sheeting			X			
Surge Feeder Hopper						
3/32" Sheeting, Bent Per Drawing			X			
Water Barrier Where Chute Intersects Floor						
20" x 36" Tapered Sheet Metal Cone		Field Fabricated	X			
Machinery Guards						
Centrifuge	2	Per Drawing	X			
Pug Mill	1	Per Drawing	X			

Figure 54

PRELIMINARY BILL OF MATERIALS						
Electrical Equipment						
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost	Status
Chetopa MCC To Project MCC						
150 Amp, 480 Volt AC Circuit Breaker	1		X			
2" Conduit & Fittings	120'		X			
Phase Wires & Ground Wire	480'		X			
Project MCC						
Control Cabinet	1	60" x 48" x 16"	X			
150 Amp Main Circuit Breakers	1		X			
Starters & Circuit Breakers For Equip.	Lot		X			
Distribution Transformer		480-120/240 Volt AC	X			
Current Trans. With 4-20 ma Output	Lot		X			
Constant Voltage Regulator			X			
Push Buttons & Selector Switches	Lot		X			
Misc Relays & Switches	Lot		X			
DC Power Supply	1		X			
Mushroom E Stop	1		X			
Programable Logic Controller	1		X			
Backplane	1		X			
I/O Modules	Lot		X			
I/O Module Computer Interface	Lot		X			
UPS	1		X			
Control Panel Wiring, Fuses etc.	Lot		X			
Wiring Diagrams	Lot		X			
Motor & Instrument Leads						
3/4" Conduit & Fittings	400'		X			
Motor Leads	600'		X			
Control Wire	1500'		X			

[illegible]

Figure 56

PRELIMINARY BILL OF MATERIALS						
Misc. Equipment						
Application/Description	Qty	Specs	Furnished By El Cont	Vendor	Cost	Status
Machinery Cart	1	36" x 72" 36" High	X			
Lab Bench	1	60" x 20"	X			
Drum Cradels	2		X			
Moisture Balance	1		X			
3000 Gram Electronic Balance	1		X			
K A Muller	1		X			
Electric Clock	1		X			
RO-TAP Vibrating Screen	1		X			
Hand Tools & Power Tools	lot		X			
Tool Cabinet	1		X			
Computer Desk 48" x 30"	1		X			
Dot Matrix Printer	1			X		
Fire Extinguishers	3		X			
First Aid Kit	1		X			

2. Verify measurements and equipment locations shown on EI sketches and drawings.
3. Design structural steel additions, steps, the control room, hoist doors and access doors.
4. Prepare a set of detailed construction and erection drawings.

The set of detail drawings are shown in Appendix C. There were several revisions which were made too late to be included in the final drawings:

Slipstream Take-Off Point

For several months we were considering alternative locations for the slipstream take-off point. Originally it was to be located directly beneath the flotation cell launder as shown on Drawing M-005 in Appendix C. From that point the slipstream would be piped a distance of about 30' to the centrifuge. We were concerned about solids settling out (when the demonstration circuit was not operating), and plugging off the first ball valve. From the original location we would have been able to flush out the first ball valve with a fire hose directed from the open top of the launder.

We ultimately decided to locate the take-off point as close as possible to the centrifuge, and provide dedicated flush water lines to clear up any plugging problems (Figure 35). There were distinct advantages to being close to the centrifuge, and, in practice, we never experienced any plugging problems which could not be cleaned up with the flush water lines.

Moisture Monitor Mounting Brackets

The original design of the mounting plate and brackets for the components of the on-line moisture monitor is shown on Drawing M-012 in Appendix C. This design severely restricted access at the key intersection where the surge feeder discharged into the pug mill. The mounting plate was to be structurally attached to the machine table for the surge feeder.

We ultimately decided to attach the mounting brackets to the base of the pug mill and eliminate the large mounting plate. Space was very limited in this area, so we decided that the changes would be fabricated by EI technicians in the field. The final design greatly increased access at this critical intersection.

7.4 Electrical Controls

The design considerations outlined in 6.9, the electrical bill of materials in Figures 54 and 55 and a narrative description of the scope of work were presented to several contractors for competitive bidding. The scope of work was to include the detailed design of the control circuit and all of its components, furnishing all control circuit materials (including the PLC, the PC and programming services), building and wiring the motor control center and computer interface, testing each

component at the point of manufacture, installing the circuit at the Chetopa plant (including all motor leads and control wires) and technical assistance with start up and system adjustments.

A contract was awarded, and drawings of the circuit (as designed and built by the contractor) are shown in Figures 57 through 60.

Figure 57

106

Figure 59

Figure 60

101

BLCON Electronic Control Technologies 108 Rochester Road Pittsburgh, PA 15229 U.S.A.		ENERGY INTL. CORP	
		HYTEK SALES ET9867E004	
Date by TT 11/15/94	Date by 11/15/94	Date by 11/15/94	Date by 11/15/94

8.0 PROCUREMENT

For purposes of erecting and installing the Mulled Coal circuit at the Chetopa plant, EI acted as the general contractor. In its role as general contractor, EI was responsible for the procurement of all equipment and supplies, except for the structural steel, heavy fabrications, and electrical components identified as subcontractor furnished items in Figures 51 through 56.

Major equipment components were procured well in advance with deliveries scheduled as they were needed. For all other materials such as pipe and electrical supplies, chute liners and light machining, local vendors were identified who could furnish whatever was needed on short notice. Space in the project bays was limited, so equipment and materials were brought to the job site only a few days before they were to be installed.

Due to the short duration of the project (only 6 months) we decided to lease major equipment components wherever possible. We were very fortunate in that Decanter Machine decided to donate the use of the screen bowl centrifuge - the single most expensive component of the circuit. We were able to lease the surge feeder, the on-line moisture monitor and the pug mill. All other equipment, supplies and services were purchased outright.

9.0 CIRCUIT INSTALLATION

The circuit was installed in February and March of 1995. The mechanical subcontractor made structural changes, set equipment in place and connected up the pipe work and chutes. When the equipment was in place, the electrical subcontractor began wiring up the control circuit. There were some scheduling and weather related problems, but, in general, the installation went very smoothly, and the circuit went in precisely as it had been conceived and designed.

9.1 Mechanical Subcontractor

Sketches of the project, preliminary bills of material, and a detailed description of the scope of work were presented to several contractors for competitive bids. The bid list was limited to contractors who had successfully completed small construction and erection jobs at Drummond plants in the Birmingham area.

A construction subcontract was awarded to J. R. Henderson Mechanical Contractors, Inc. in early December 1994. Approved drawings from the engineering contractor were released for construction in late December and the first week of January. Construction was scheduled to start sometime in the first week of January and completed in 5 or 6 weeks, or sometime in mid-February.

There were some administrative delays in January, and we were unable to get the mechanical contractor started until early February. Although the administrative delay was only a few weeks, it had the net effect of delaying the completion of construction by almost two months. By the time we got the mechanical contractor started in February, the company was committed to some other projects, and was never able to work on our project on a full time basis. The construction delay precipitated a chain reaction of delays with equipment vendors and the electrical contractor. Construction was not completely finished until April 4th, a full 8 weeks after the target date.

We attempted to make up some lost time by adjusting the construction schedule so that the electrical contractor could come onto the job a little earlier in the construction process. We also rearranged the construction schedule so that run-in testing could begin while the mechanical and electrical contractors were putting the finishing touches on their work. Doing the run-in testing early reduced the scheduled delay of one month for run-in tests, but there was a price to pay.

By the time we started up production we knew how to control the circuit and maintain Mulled Coal quality, but we had not learned the proper way to operate the centrifuge, and we did not have any experience with our trucking and stockpiling operation. We maintained good quality Mulled Coal right from the start, but daily production suffered in the early weeks as a result of short cuts in the run-in test work.

9.2 Electrical Installation

The electrical installation was divided into two separate tasks. The first task, which had to be done at the beginning of construction and on a weekend, was to install a new circuit breaker in the

Chetopa motor control center and run a new feed line over to the main circuit breaker for the Mulled Coal circuit.

The second, and by far the largest, task was to design, build, test and install a complete electrical system for the Mulled Coal circuit.

The new main power line was installed by Sheffield Electrical Contractors, a Birmingham contractor who was experienced with preparation plant wiring and related codes and regulations. A new 150 AMP, 480 VAC AC circuit breaker was installed in the Chetopa motor control center. The new power line was run in 1-1/2" conduit from the Chetopa MCC to within 3' of the location of the new control room for the Mulled Coal circuit (the new control room had not as yet been installed).

9.2.1 Main Electrical Subcontractor

As reported in 7.4, a set of sketches of the various machinery bays and the new control room, a set of overall design criteria, a preliminary electrical bill of materials and a narrative description of the scope of work were submitted to a number of Pittsburgh area contractors for competitive bidding on a design, build, test and install type of contract. We wanted to use a contractor located near the EI offices for good communications during the design and programming phases of the work, and we wanted EI personnel present for initial testing. A purchase order type of subcontract was awarded jointly to Hy-Tech Sales and Elcon Technologies. Hy-Tech Sales was to furnish the PLC and most of the motor control center hardware. Elcon technologies was to design the system, furnish a computer, printer and all hardware not furnished by Hy-Tech Sales, build the system, test it and send a crew to Alabama to install it and assist with starting it up.

9.2.2 Electrical Construction

The original construction schedule called for the electrical contractor to begin field installation work on February 8, 1995. Had construction gone according to schedule up until that date, all of the equipment would have been in place, the control room would have been built, and the mechanical contractor would have been down to finishing touches on pipe and chute work. As mentioned in 9.1, there were administrative delays, and construction did not get fully underway until February 1st, and by February 8th, the control room had not even been started, and we were just beginning to set equipment into place. On the other hand, the electrical contractor had other field commitments which would have delayed our project by over two months if we did not begin the electrical installation as originally scheduled. Even though we were not ready, we began the electrical installation as originally scheduled. We knew that starting early would slow down the work, and it would force the contractor to leave the job after completing only part of the work, and then come back after all pipe and chute work was completed for startup operations. Staying with the original schedule would bring the project in five or six weeks sooner, and, while the cost of the electrical installation would go way over original estimates, the overall cost of the project would not be as high as it would have been if it was delayed another five or six weeks.

On February 8th, the electrical contractor began stringing conduit and pulling lead lines and control wires. Although the equipment was not in place, we knew within a few inches where each

junction box would be located. At the same time, the mechanical contractor stopped other work and began building the control room. By the time the control room was finished, the conduit was in place, and the electricians moved in the new motor control center and began making control room connections. As the control room work progressed, the mechanical contractor got all of the equipment in place, and electricians were able to make connections to motors and process control equipment. Concurrently the electrical contractor installed the new overhead lighting system, and set and wired in all of disconnect switches and E-stops which were located out in the machinery bays.

The basic electrical work was completed in about 10 days, and, since nothing more could be done until the mechanical contractor completed all pipe and chute work, the electrical contractor left the job. On March 8th the electrical contractor was back with a different crew for the job of installing the computer, starting up individual motors, making last minute programming and logic adjustments, and testing the entire system. This final work took about 8 days. Starting before we were ready, and working side-by-side with the mechanical contracting crew in rather tight quarters resulted in some delay and grumbling. And there were some time consuming last minute adjustments and changes due to vendor supplied equipment not meeting original specifications. But under the circumstances the overall electrical installation went very well. The system went in almost exactly the way it was designed. It was flexible enough that changes could be made quickly and simply. It afforded us precise and reliable control over the Mulled Coal process. It could readily be integrated into the existing control circuit of a modern preparation plant, and it never caused a minute of downtime throughout the production demonstration.

10.0 SHAKEDOWN OPERATIONS

By March 13, 1995 all electrical connections were complete and, mechanically, the Mulled Coal circuit was in running condition except for the truck loading chutes (the leased haul truck was not due at the job site until the last week of March, and we kept the mechanical contractor busy with critical path jobs).

Shakedown operations were originally to cover about 70 hours of circuit operation over a 5 week period. This was a conservative estimate. We felt that the circuit was simple enough that we could complete shakedown tests in a much shorter time period. In the middle of the shakedown we would be forced to stop testing long enough to make the final installation and calibration of the on-line moisture monitor, which had to be done at a time when the circuit was available to produce coal, and it had to be done by Berthold factory technicians.

We had already lost so much time in the original schedule, we decided to drastically reduce the shakedown period. We set a target of April 5, 1995 for the production start date. This gave us only three weeks total, and four days would be spent installing the moisture monitor - so we essentially cut the shakedown period from five weeks to two weeks.

Generally the shakedown went very well, but the compressed schedule did not give us an opportunity to discover the best operating procedures for the screen bowl centrifuge, and, as a consequence, we paid for it in lost production time during the first three or four weeks of the production phase of the project.

Shakedown testing included about 8 hours of dry runs and 18 hours of wet runs. Shakedown test objectives were to:

- Eliminate any bugs or defects in either the equipment installation or control circuit.
- Make certain that the general arrangement of equipment and chutes allowed for the free flow of coal through the circuit (eliminate any plugging problems).
- Establish procedures for pre and post operation inspection; starting, stopping, and running the circuit; and servicing (greasing and other maintenance) the circuit equipment and controls.
- Make certain that the Mulled Coal circuit could produce in accordance with design capacity and quality.

The following is a brief description of shakedown test results. The installation and calibration of the on-line moisture monitor was by itself a major job, and some of the problems associated with it had a significant impact on the project, but it is described in this section because it was installed in the middle of the shakedown, and instrument calibration is really a part of the shakedown process.

10.1 Dry Run Tests

10.1.1 Light Running Motor Loads

The centrifuge, surge feeder and pug mill motors were started up and checked for proper directional rotation. After correcting for proper rotation, each motor was run a few times, and the light running motor load was recorded. The purpose of checking for light running loads was to make certain that there were no abnormally high loads resulting from mechanical problems (bad bearings, misalignment, etc.). Throughout the project we were on the lookout for changes in light running loads which might be an early indicator of a developing problem. Light load figures were also used to calculate the load which could be attributed to coal flow. Individual light running loads were as follows:

<u>Machine</u>	<u>Screen Bowl Centrifuge</u>	<u>Surge Feeder</u>	<u>Pug Mill</u>
Horsepower	50	3	7.5
Voltage	480 Vac - 3 p	220 Vac - 1p	480 Vac - 3 p
Light Running Load (amps)	22/24	3/3.5	1

10.1.2 Knife Gate Valve Operation

The reliable operation and precise control of the knife gate valve was a critical element of the project, and it was one of the first things we wanted to check in the shakedown. Our original plan was to operate the air actuated valve with a bottled nitrogen system and use compressed air from the Chetopa plant as a backup. When the system was designed, the valve manufacturer indicated that the valve positioning device would consume 0.5 ft³/min (at 65 PSI) when the valve was operating. We assumed that this was the air consumption only when the position of the valve was being changed.

When we hooked up the nitrogen system and began running positioning checks, it became apparent that, because of a pressure equalization system, the positioning device would consume 0.5 ft³/min at all times instead of only when the position was being changed. With this kind of consumption, we would have only gotten a few shifts out of each nitrogen cylinder, so early in the shakedown (March 14th) we switched the primary air supply over to compressed air, and planned to use the nitrogen system only as a backup.

Since compressed air became the primary air supply for the valve positioning system, we decided that we would not rely on the Chetopa plant air system (it was never intended to be used for instrument air). We purchased and installed a small compressor, water trap and line filter which was captive to the Mulled Coal circuit.

When the new air system was installed, we began a series of tests to compare the actual valve opening to the indicated valve position which appeared on the computer screen. There was a mechanically operated gauge on the valve itself. Throughout the entire range (0-100% open) there was perfect calibration between the indicated opening and the actual opening. In fact there were three figures to compare. The valve control had both a positioning device and a separate position

feedback device. In case the valve opening did not actually move to the specified set point, there were separate figures on the computer screen for "set point" and "actual opening". The two figures on the computer screen always remained the same, and they always matched the mechanical gauge reading.

10.1.3 Start/Stop Sequences

The control system could be operated in a manual mode (individual motor start/stop switches on the face of the motor control center), a semi-automatic mode (clicking on individual motor start/stop buttons on the computer screen) and full-automatic (clicking on auto start and auto stop buttons on the computer screen). All of the operating modes were checked and found to be in good operating order.

In full-automatic mode individual motors started and stopped according to a pre-determined time sequence. Basically, on startup the individual motors were started in the reverse order to the coal flow (the pug mill motor was the first to start and the knife gate valve was the last thing to open). On shutdown the gate valve was the first thing to close, and the pug mill was the last motor to stop. There were preset time delays between individual motors in the starting and stopping sequence which allowed motors to come up to speed before they were hit with coal flow and allowed machines to completely empty before shutting down. During the early wet runs, these time delays were adjusted.

10.1.4 Visible Disconnects & E-Stops

A visible disconnect (fuzed knife blade switch) was located within easy sight of each machine in the circuit. This allowed an operator to de-energize and lock out the power on a machine before working on it. The machine could not be re-energized or restarted before the lock was removed from the visible disconnect. The only shakedown test on these devices was to insure that there were no short circuits in the disconnect switch which would allow the machine to be energized while the switch was locked out. All of the disconnects were operating properly.

Each machine was also equipped with an emergency stop button which was located within easy reach of the machine. There was also an emergency stop button located on the face of the motor control circuit. Pushing any one of the emergency stop buttons would not simply shut down an individual machine, it would shut down all of the machines in the circuit. And it was not designed to shut the machines down in a sequence - everything would stop immediately when any one of the E-Stop switches was pushed. To restart, the E-Stop which was pushed to shut down the circuit had to be manually reset to the run position. These were safety devices, and they were not intended to perform any routine starts or stops. All of the E-Stops were found to be in good working order.

10.1.5 Reagent Delivery System

Shakedown of the reagent delivery system was not too complicated, and there were very few problems - we had assembled and tested the system in our laboratories before setting it up at the project site.

When the system was tested in our laboratories, we did not have the fan spray nozzles which were to be used in the project. When we first started up the system in shakedown, all three spray nozzles plugged up immediately. Five GPH nozzles have a very small spray orifice, and small pieces of debris (mostly little bits of thread tape) which remained in the lines after assembly, reported directly to the nozzles and plugged them up. Each nozzle had to be purged about three times on the day the system was started up. The system itself was tight and was equipped with a good suction filter. After the first day the system was started, there was never another plugged condition during the life of the project

During early testing we discovered that a dynamic pressure of between 18 and 28 PSI at the spray nozzle produced an ideal spray pattern. At flow rates of less than 10 GPH we were not able to keep pressure above 18 PSI, so we decided that, at low flow rates, we would only operate two of the three nozzles. We did not set up the switch from three to two nozzles to be automatic. The switch was to be made simply by closing a ball valve in the control room when the operator noticed that the process control was calling for less than 10 GPH.

Next we connected a potentiometer to the PLC so that we could simulate 4-20 ma output signals from the on-line moisture monitor. We simulated moistures in the 19% to 28% range to see if the moisture signals would cause the control loop to produce reagent flows at the rates set out in Figure 41. We also tested the reagent flow offsets which were activated by clicking on buttons on the computer screen. Finally, we disconnected lines in the flow meter and manually measured flow rates so that the manual rates could be compared to flow meter rates. The entire reagent delivery system checked out perfectly.

10.1.6 Alarm System

Data was available on the computer by way of the PLC on motor loads, knife gate valve setting and position, moisture, reagent flow demand and actual reagent flow. We programmed a series of alarms to be triggered based on such events as intolerable motor loads or moisture levels, and intolerable imbalances between the set position and the actual position of the gate valve, or the set position for reagent flow and the actual reagent flow as measured by the in-line flow meter.

The electrical contractor was able to electronically simulate events which would cause alarms and check to see that the appropriate alarm was triggered. The alarm system worked properly and based on actual operating experience, there were some adjustments made to motor load alarms.

None of the events which would have triggered an alarm ever occurred in the project, however, we did blow a few fuses - indicating that some of our motor overload alarms were set a little high.

10.2 Wet Run Testing

Wet run tests began on March 13, 1995 and extended through March 28th, but, from March 14th through March 19th, all work was limited to calibration tests for the on-line moisture monitor.

The truck loading chutes had not been installed, so all Mulled Coal production during shakedown testing was dropped through the floor of the main project bay onto the ground beneath the plant.

(In order to coordinate the schedules of the various contractors and vendors, the mechanical contractor had been strictly concentrating on getting the circuit ready to run mechanically. When shakedown testing began on March 13th, the mechanical contractor moved over to non critical tasks such as fabricating and installing hoist doors, stopping water leaks, and fabricating the loading chutes. The schedule called for completing the shakedown by March 29th and then shutting down for a few days while the truck loading chutes were installed and the roadway beneath the plant was improved.)

Because we were dumping Mulled Coal onto the ground in a limited space with poor drainage, no attempt was made during shakedown tests to run the circuit for extended periods of time. Individual tests were limited to the minimum amount of time required to obtain the desired information.

Shakedown tests (not including calibration tests for the moisture monitor) spanned a period of nine working days. There were about twenty individual test runs resulting in about 18 total hours of circuit running time. About 50 tons of Mulled Coal was produced and stocked on the ground beneath the plant. At the conclusion of the tests, the Mulled Coal was hauled away and blended into the Chetopa clean coal stockpile.

The following is a brief description of individual tests.

10.2.1 Overall Material Flow

One of our greatest concerns was that wet cake (before the mulling process) would hang up somewhere between the centrifuge and the pug mill. On the first startup, we ran the circuit for 1-1/2 hours. Then we shut down, and opened everything up to see if we could spot any problem areas in the chutes or equipment where wet cake was beginning to build up.

The main dry coal chutes, the surge feeder, and the feeder discharge tube extension were all perfectly clear, but wet cake had started to build up right where the screw conveyor discharges dry coal from the rotating portion of the centrifuge. We knew that this was a potential problem area with all centrifuges, and especially with the test machine, where the discharge chute was not designed to run unattended for extended periods of time.

We learned from this test, and numerous other inspections after short runs, that material would begin to build up in the 24" discharge chute almost immediately after startup. But paddles on the centrifuge would impart a significant force to move the wet cake down through the chute, and eventually the material would find a fairly small flow path (48 in² cross section flow path versus 124 in² cross section for the full chute) where it would continue moving down through the chute.

	<u>Test 1</u>		<u>Test 2</u>	
	Sample Wt (G)	% Retained	Sample Wt (G)	% Retained
+6 Mesh	2.08	0.79	3.17	1.24
6M x 14M	11.35	4.32	13.45	5.26
14M x 28M	86.50	32.96	83.59	32.70
28M x 0	<u>162.47</u>	<u>61.93</u>	<u>155.40</u>	<u>60.80</u>
	262.40	100.00	255.61	100.00
Handleability Index		94.89		93.50

Conditions of feed rate, moisture and reagent dose were not closely controlled for this test. No matter what the conditions were, the Mulled Coal quality was excellent. Although the results of quality control testing will be reported in a later section, it can be noted here that Mulled Coal quality remained excellent throughout the entire demonstration, and it exceeded our expectations based on laboratory testing.

10.2.3 Feed Rate Testing

We next ran a three hour test where we concentrated only on estimating the feed rate at various gate valve settings. During the test we collected a composite feed sample for percent solids and a composite Mulled Coal sample for percent moisture. At each gate valve setting (6 individual settings between 27% and 55% open) we measured the effluent flow rates from both the centrifuge solid bowl drain and the centrifuge screen bowl drain.

With feed solids, product moisture, and effluent flow rates, it is possible to make rough estimates of feed rates. Figure 61 shows the indicated feed rate (dry TPH) at progressive gate valve settings.

It should be noted that, at gate valve settings above 55% open, effluent flows from the solid bowl drain were too fast to measure with our simple 5-gallon bucket system, so feed rates at higher settings are based on regression curves. In order to simplify feed rate calculations, it was assumed that centrifuge effluents contained no solids. We know that the effluents did contain low percentages of solids, so actual feed rates would have been slightly less than those indicated on the chart. A final factor affecting the accuracy of the feed rate calculations was the fact that we used push water in the screen effluent drain, and the amount of push water had to be subtracted from each effluent measurement. Prior to starting up the circuit for this particular test we measured the push water flow rate by itself (3.8 GPM). However, our push water line was connected directly to the main plant makeup water line. It is possible that there could have been changes in the flow through the push water line because of fluctuating overall demand on the plant makeup water system.

Even with all the inaccuracies built into this test, the flow rate calculations proved to be fairly reliable when froth concentrate was running at about 30% solids. As it turned out, there were fairly wide and fairly frequent swings in solids content in the concentrate, and we came to rely more on the motor loading of the centrifuge as an indicator of plant feed rate.

Figure 61

10.2.4 Full Load Amps

In order to record motor loadings at about the maximum feed rate we gradually opened the gate valve until we hit the 65% open setting, and we ran that way for about one hour. Based on calculations from the previous test, feed rate should have been in excess of 5 TPH. Loadings on the main circuit motors were as follows:

	<u>Light Running Load (amps)</u>	<u>Full Feed Load (amps)</u>
Screen Bowl Centrifuge	23.0	33.0
Surge Feeder	3.3	8.5
Pug Mill	1.0	2.5

These were not the full load amp ratings of the various motors, but the apparent loads when the circuit was running at full capacity. The full load ratings of the motors were much higher, and circuit breakers were provided to kick off the motors when they reached full load amps.

We used settings of 2 amps higher than the full feed load to trigger audible and visual alarms on the computer screen. In this way we would have a warning if we were beginning to overload the system, or if a mechanical problem was developing which was resulting in a low level overload.

As it turned out, the results of this brief test were very reliable, and we used the marker overloads throughout the project. If we momentarily exceeded them or started to approach them too closely, we backed off on the gate valve setting. We learned the hard way early on in the project, that, if we exceeded them for any length of time, we usually got into trouble.

10.2.5 Moisture Control

Our primary target for the project was to demonstrate the effectiveness of the Mulled Coal process over a moisture range of 20% to 26% (the surface moisture range one would expect on a 28M x 0 clean coal product which was dewatered on a vacuum filter). A secondary objective was to determine the highest moisture levels where the process would be effective on the Chetopa fine coal product.

The screen bowl centrifuge we were using to dewater the slipstream was capable of producing product moistures down in the 14% to 18% range when operating at maximum drying efficiency. Early in the planning stages for the project, we knew that it would be necessary to operate the centrifuge at levels which were well below maximum drying efficiency. After consultation with the centrifuge manufacturer, we decided that it would be possible to maintain surface moisture in the target range by closely controlling the amount of water which was permitted to escape from the solid bowl effluent drain.

In theory, water in the centrifuge feed must either come out with the effluent or the coal. Precise control on the effluent side would give us precise control of surface moisture. We also felt that operating at less than maximum drying efficiency would eliminate some of the fine coal product losses which are normally associated with the operation of a screen bowl centrifuge.

We had also determined that another way to control product moisture was to precisely adjust percent solids in the feed by adding dilution water just ahead of the centrifuge. The theory was that, since we could precisely limit the amount of effluent, slight adjustments to water in the feed would translate into adjustments to product surface moisture. A 1" fresh water dilution line had been tapped into the pipe line just inches from where the slipstream entered the centrifuge.

All of the moisture control plans ultimately relied on controlling effluent, but there were three separate approaches under consideration:

1. With feed conditions remaining the same, raise and lower dams which control the effluent pool height.
2. With the effluent pool height set, increase or decrease feed with adjustments to the opening on the slipstream take-off valve.
3. With the effluent pool height set, add or subtract dilution water.

In this important phase of the shakedown all three moisture control methods were tested. Results were mixed and inconclusive.

Raising and Lowering Dams

Figure 62 is an exaggerated schematic representation of the principles involved in adjusting the effluent pool height in the centrifuge. There are four rectangular holes (measuring about 4" x 6" in the project machine) in the end flange of the solid bowl section which allow effluent to discharge from the rotating solid bowl section into the effluent drain. Steel dams can be bolted onto the face of the end flange to cover a portion of the drain holes and restrict the flow of effluent. This results in raising the height of the effluent pool in the machine. The dams are made with slotted bolt holes so that they can be raised and lowered.

In normal practice, restricting effluent flow with dams is done to improve product recovery. In our case we were raising the effluent pool height to force more 325M x 0 coal and water into the screen bowl section of the centrifuge and thereby raise product moisture.

Based on the percentage of 28M x 0 coal in the slipstream, we expected that when running "flat out", the centrifuge would be capable of producing a product moisture in the 15% to 18% range. We wanted to establish this point of maximum efficiency right away, so when we first started the full circuit, we left the effluent drain holes wide open (no dams).

Figure 62

SOLID BOWL SECTION - DISCHARGE END FLANGE

(The relative relationship of the pool height and drain holes when running "flat out" is schematically represented by the view of the end flange at the bottom left side of Figure 62. It should be noted that the dimensions of the various pool height adjustments are greatly exaggerated for illustration purposes.)

When we ran flat out, surface moisture was lower than expected. At low feed rates, the lowest moisture recorded was 12.5%. As feed rates were increased, there was a corresponding increase in moisture. However, even at fairly high rates, moisture only got up into the 14.5% to 15.5% range. This was obviously too low for the project, so immediately after the first wet run, we installed the set of dams which were furnished by the centrifuge manufacturer.

When we first installed the dams, we set them to give us an effluent pool height which was about midway between wide open and the height of the screen section of the centrifuge (approximately in the position illustrated in the center view of the end flange in Figure 62).

Setting the dam height was a trial and error process. We were always able to set each of the four dams at exactly the same height to keep the machine in balance, but from the outside of the end flange it was impossible to gauge the exact elevation of the screens. Our initial approach was to try to "bracket in" the proper dam settings. It should also be noted that, as we approached the ideal dam height, very slight adjustments in the dam height (as little as 0.062 in.) could result in major swings in moisture.

We ran several hours at the first dam setting. Moisture increased, but it was still nowhere near our target range. During this run we reached moistures in the 19% to 20% range.

We next raised this original set of dams to the maximum height obtainable which was somewhere between the arrangements illustrated in the center and right hand views of the end flange on Figure 62. At this maximum pool height set point, we were able to get moisture up over 21%. We knew we were on the right track, but we felt that we could not get the pool height high enough with the original set of dams.

We had a local shop machine a new set of dams which would allow us to cover another one inch of the effluent drain openings. The extended dams were ready in a few days, but the schedule was so compressed that the shakedown period was over. We ended up installing the extended dams during the four day shutdown between shakedown and production when the truck loading system was installed.

(Although subsequent dam height adjustments all took place, throughout the three month production phase of the project, they are reported here, because they were really an extension of the shakedown process.)

The extended dams were installed on April 3rd during the shutdown period while loading chutes and the truck haulway were being prepared for production operations. The new dams were set for an effluent pool height which was 1/2" above the maximum reach of the original dams (the approximate position illustrated in the right hand view of the end flange in Figure 62).

The truck loading chutes and road improvements were not completed until late in the afternoon of April 4th, and production was officially scheduled to start the next day. There was no opportunity to run the circuit at the new dam setting and make further adjustments under the more relaxed conditions of shakedown testing. We did decide to delay the official start of production until 10:00 AM on April 5th, so that gave us a few hours to experiment with the new dam settings.

It should be noted here that we did not have the option of delaying the start of production. We were already a month behind schedule, and we had made a firm commitment to return the project centrifuge to the manufacturer on June 19th for a very important test for one of their customers. Starting up on April 5th gave us only 44 available production days as opposed to the 60+ days provided in the original schedule. We were concerned that we would fall well short of the total production target if the start of production was delayed beyond April 5th. We were fairly certain that the circuit could handle almost any reasonable moisture, so we were not too concerned that we would be starting into production without good control over surface moisture. We felt that it would not take too long to find proper set points and control procedures, and, in the meantime, we were equipped to handle the ups and downs in moisture while we were "bracketing in" on proper settings.

When we started up the circuit on April 5th, for the quick test of extended dam settings, we ran through ten individual gate valve settings between 40% and 55% open. Through the progression of feed rates, moisture increased from 18% to over 50%. As we got into gate valve (feed rate) settings above 45, moisture was extremely unstable. At the same gate valve setting, moisture might hold very steady at 23% for about 15 minutes. Then, suddenly, moisture would shoot over 50% and stay there until we lowered the gate valve setting.

This change in moisture resulted from an effluent pool height adjustment of 1/2". It was the first time we had been able to get surface moisture over 21%. Although the moisture was now too high, we were satisfied that we had finally "bracketed in" the ideal setting. We felt that we could then reduce surface moisture at high feed rates down to the 27% range by simply making fine adjustments to the dam height settings. In the meantime we thought that we could start up the production phase of the project by running at lower feed rates and maintaining moisture in the 23% range. Immediately after the short run test on the morning of April 5th, we started up, and considered the project to be officially in the production phase. Being in the production phase meant keeping accurate and detailed records of operations, producing as much Mulled Coal as possible in the available time, loading and weighing trucks, and dumping all production on the Mulled Coal stockpile.

When we officially started up production on April 5th we ran the circuit for about 3-3/4 hours and partially loaded and weighed two trucks. At feed rates of between 40 and 43, we

averaged 22% moisture, but the measured feed rate was only 2 TPH. At feed rates higher than 43, the moisture immediately went up into the low 30% range.

The effluent pool height was obviously too high after the first setting of the extended dams. It took as long as 1-1/2 hours to open up the centrifuge and adjust the dam height. We did not immediately shut down each time an adjustment was indicated. An adjustment would be scheduled for some time during the next 8 hours of production. If there was a plant breakdown or any other interruption during that period, we would have the opportunity to make the adjustment without losing production time. If there were no breakdowns during the eight hour period, we would shut down the circuit and make the adjustment.

On April 6th, during a plant shutdown, we adjusted the dam height to lower the effluent pool by 1/8". The adjustment allowed us to run at a 2.4 TPH feed rate at 22% moisture, but higher feed rates still resulted in moistures over 30%. We needed another adjustment which would allow us to hold moisture in the target range while producing Mulled Coal at a rate of over 3 TPH.

Over the next month of production, we made about 15 more adjustments to the dam heights looking for the ideal setting. Within a few days we hit a point where a .125" adjustment took us from too wet to too dry. The next 12 adjustments were in the 0.062" range, but we could never find a spot where we could produce over 3 TPH in the target moisture range.

We would have situations where we would lower the dams by about 0.125", and find that we could get the feed rate up to well above 5 TPH, but we could not get moisture above 20%. Then we could raise the dams by about 0.032", and find that we could not produce over 2.75 TPH and hold moisture below 30%. In the cases where moisture was too high, it was usually also very unstable. We could be running along for an extended period of time at 27% moisture, and suddenly the feed would go to a slurry state (moisture over 50%). Sometimes when this would happen, we would back off the feed rate by about 5% and find that we could no longer hold the moisture above 20%-22%.

We finally came to realize that we were never going to find the "ideal" dam height setting which would allow us to produce in complete control at the target feed rates and within the target moisture range. We were evidently operating at a pool depth which was right on the edge of the screen elevation. When the pool height exceeded the screen elevation by just a fraction of an inch, too much water was forced over the screen with the dry coal. When the pool height dropped just a fraction of an inch under the screen elevation, we could not force enough water over the screen to get moisture above 22%.

When we were operating at effluent pool depths which were right on the edge of the screen elevation, the amount of effluent discharging from the centrifuge was essentially fixed at a certain GPM. With a 30% solids feed, at a feed rate of 3.5 TPH and a product moisture of 27%, the effluent from the centrifuge was about 27 GPM. Any change in feed conditions to the froth cells, or any change in froth cell performance could completely upset moisture control. Under the

foregoing conditions, a decrease of only one percent in solids content in the concentrate could cause product moisture to jump from 27% to 32%. A 1% increase in solids content could cause moisture to jump 5% the other direction.

For the duration of the production phase of the project we were continuously looking for that "ideal" dam setting, or a combination of dam setting, feed rate and dilution water, which would allow us to produce 3-5 TPH in a controllable moisture range of 20% to 27%. We never found it. When we were looking for over 3 TPH at moistures in excess of 23%, no matter whether we were working with dam settings, feed rate or dilution water, we always arrived at the same point - a pool height on the edge of the screen elevation and loss of moisture control.

We ended up lowering the effluent pool height on some days and producing low moisture coal (19%-23%). On other days we went into the centrifuge, raised the dam height and produced high moisture coal (23%-30%). During the periods when we were producing high moisture coal, we did not have good control over moisture due to the unstable condition which existed when the effluent pool height was raised to the level of the screen elevation.

Due to the stability problem, the circuit was much harder to operate in the high moisture range, and we failed to reach the weighted average moisture target of 23%. Weighted average moisture for the 966 tons produced in production demonstration was only 19.3%, but we succeeded in testing the circuit over a moisture range of 17.5% to 32%, and we produced Mulled Coal with excellent handling characteristics throughout the entire moisture range.

It should be noted that the problems we had with the centrifuge have no bearing on a conventional screen bowl centrifuge application. Our problems were all related to attempting to produce coal with an arbitrarily high moisture content, and to do so, we were forced to operate just above the top edge of the capacity of the test machine. Had we been interested in the standard objective of producing the lowest possible moisture at the highest possible recovery, effluent pool heights would have been much lower, feed rate would have been reduced, we would have been producing a product with about 14% surface moisture, and we would not have experienced any of the operating problems encountered in this project.

10.2.6 On-Line Moisture Monitor

Moisture, ash and size distribution are the three most important wet cake characteristics which must be considered in designing a Mulled Coal circuit. Of the three, surface moisture is the principal feed characteristic which determines the amount of reagent required to improve the handleability of the end product. And, of the three, surface moisture is the characteristic which will usually vary the most in a fine coal preparation circuit. From the earliest planning stages for this project, we decided to use an on-line moisture monitor which would be tied into a process control loop which would control reagent flow rates.

In September 1992, we obtained a budgetary quote on a microwave type on-line moisture analyzer from the principal supplier of this type of equipment to the coal industry. At the time,

the cost of the analyzer was \$63,000, and it was available for short term lease at \$2,500 per month. By the time we began soliciting actual quotes for furnishing equipment for the project (May 1994), the purchase price of the analyzer had risen over 25%, and the manufacturer had a new policy which prohibited lease arrangements on that particular instrument. There was no way we could justify an outright purchase at the current price. The moisture analyzer would have cost over three times as much as any other major component in the project.

In discussions with the manufacturer, we learned that they had a new scaled-down model of the microwave type analyzer which they were just then introducing to the market. The cost of the scaled down unit was less than one-third of the cost of the model originally quoted, and leasing terms were available. Factory representatives had tested the new unit on coal in Germany, and they thought that it might work in our application.

According to the manufacturer, the main difference between the two models was one of accuracy and the ability of the more expensive unit to read accurately in the face of wide swings in density and moisture. The less expensive unit operates with only two measuring frequencies in a narrow frequency band; while the more expensive unit uses about 48 frequencies in a very wide band, and reliably interprets moisture within 0.3%. We only required an accuracy of $\pm 1\%$, so we decided to do some testing to see if the scaled down unit would work for our project.

We submitted three known moisture samples of dewatered froth concentrate from the Chetopa plant. One sample was at 20% moisture, one was at 25% and one was at 30%. The scaled down unit read the individual samples within 1%, so we arranged to lease the unit for the duration of the project.

Figure 63 shows a schematic representation of how a microwave type moisture analyzer is normally installed in a coal preparation plant, and the right hand view shows how it was installed for this particular project. Accurate readings cannot be obtained when microwaves are transmitted through metal surfaces, so the microwave transmitters and receivers are normally located above and below the carrying side (top belt) of the clean coal belt conveyor. Since coal thickness or bulk density on the conveyor can change from time to time, a radiometric mass compensation unit is installed nearby with the nuclear source and scintillation detector in the same relationship to the belt conveyor as the microwave transmitting and receiving antennae.

There was no belt conveyor in the Mulled Coal circuit, and from the time dewatered wet cake left the centrifuge until the time it was discharged to the pug mill, the material was always completely enclosed in a metal machine or free falling through an enclosed plastic chute. We decided to provide a place to install the moisture analyzer by adding a flanged plastic extension to the end of the discharge tube on the surge feeder (Figures 64 and 65). In fact the surge feeder manufacturer agreed to shorten the normal length of the discharge tube and auger, and provide a steel companion flange which allowed us to bolt the tube extension onto the feeder. To provide for the best possible surfaces for mounting equipment and interpreting signals, the tube extension was made rectangular in shape. To provide the least resistance to pushing the material through, the tube extension was made from UHMW PVC material.

CONVENTIONAL APPLICATION

PROJECT APPLICATION

Figure 64

130

FEEDER DISCHARGE TUBE EXTENSION

DRILL TAPERED HOLE IN FLANGE. $7.625"$ DIA
ON OUTSIDE & 6.750 DIA. ON INSIDE.

WELD SQUARE TUBE ONTO FLANGE.

Prior to approving final drawings for the tube extension, we made an 8" extension for the discharge tube on the 1000 lb/hour surge feeder in our pilot plant (a scale model of the machine to be used in the project). We learned that not only would the auger push the material through the extension with ease, we would actually be presenting wet cake to the analyzer in a much better configuration than on a belt conveyor. Since a belt conveyor always travels at the same speed, any change in feed rate causes the level of coal on the conveyor to rise or fall. But when the wet cake moved through the extension with nothing pushing it but the material coming in behind it, it quickly filled the rectangular cross section of the extension and always kept the same shape. Changes in feed rate would simply change the velocity of the material as it moved through the extension.

Although fitting in the moisture analyzer components, the transfer chute and the related guards all together at the confined intersection of the pug mill and surge feeder would be a tight squeeze and would require a complicated support structure, we felt that we had created an ideal setup for accurate measurement, and we were taking the measurement at the proper spot - just inches ahead of the reagent spray nozzles.

During the construction phase of the project the plastic tube extension was installed on the feeder, all mounting hardware was fabricated and installed at the feeder/pug mill intersection, the microprocessor for the moisture analyzer was installed in the control room and wired into the main control circuit, and conduit for analyzer component leads was extended from the control room to within a few inches of the final location of each component.

Actual installation of the components, connecting leads and calibrating the microprocessor was the responsibility of the manufacturer's field technicians, and this final work could not be done until the circuit was running and processing coal.

Installation of the moisture analyzer was scheduled for the first week of the shakedown operations.

The equipment was all installed according to schedule on the first two days of the week. On the third day the circuit was operated and moisture readings were compared to field moisture measurements run on an infrared moisture balance. Based on the comparison of analyzer readings against actual moisture (the comparison was not good) the manufacturer's representative decided to realign the microwave antennae. As luck would have it, the preparation plant was broken down the entire shift on the fourth day. Calibration tests resumed on the fifth day, and based on comparisons between analyzer readings and actual moisture (which again were not good), a new calibration curve was programmed into the microprocessor. The factory representative left the job site that day.

With the latest calibration curve we were still getting differences by as much as 11% moisture between actual and analyzer unit readings. We decided to start up the production phase of the project by controlling moisture input to the process control loop manually. (This procedure turned out to be a satisfactory method of controlling the process. It will be explained in detail in the section of this report dealing with production operations.) In the meantime, the on-line

analyzer would be left on - it just was not connected to the control loop. We would continue to record analyzer versus actual moisture readings and forward the data to the manufacturer. The manufacturer would calculate a new curve, and forward the information back to the job site. We would program the new curve into the microprocessor (a simple procedure) and begin a new comparative data series.

The first new calibration curve was based on a series of comparisons covering the first ten (10) operating days. It was the end of April by the time the new calibration curve was entered into the microprocessor. The new calibration curve narrowed the gap between actual and analyzer readings, but the readings still differed by as much as 3%, and there were rare occasions where the analyzer reading would be off by as much as 10%. Calibration was definitely better, but we were still nowhere near the point where we could connect the analyzer to the process control loop.

For the next ten operating days we collected a new comparative data series, but we decided that it would not serve any useful purpose to calculate and enter a new calibration curve. By the time we could be operating with a new calibration curve, the production phase of the project would be nearing an end.

At the same time we were having good success with operating the process control loop manually. The control loop was set up so that at any given level of moisture, the reagent pump would deliver a predetermined dose of reagent. These predetermined reagent doses were based on previous experience and parametric testing conducted at the beginning of this project. The predetermined doses were programmed into the computer and PLC.

As previously reported, we actually used far less reagent than originally anticipated or as originally programmed into the control circuit. In operating the control loop manually, we did not input the same moisture reading as the one determined on the infrared moisture balance. Instead, we knew the reagent flow rate we wanted at different moisture levels, so we manually adjusted moisture input until reagent flow hit the desired rate. To get the desired reagent flow, manual moisture input was always lower than actual moisture.

This explanation of manual operation is included here because, even if we would have achieved perfect calibration on the on-line moisture analyzer, we would not have been able to connect the analyzer to the control loop. Setting up the process control loop for complete automatic operation would also have required reprogramming the computer and PLC for lower reagent doses. Only 44 days of scheduled production did not give us enough time to fine tune the process control circuit.

Given enough time, we may have achieved perfect calibration with the moisture analyzer. In the worst case the more expensive multi-frequency unit (which would be much more affordable for a permanent full scale installation) would certainly have worked (it is currently working in many coal preparation plants). While time constraints prevented going to "full automatic" on the process control loop, we were able to demonstrate that the overall design of the control loop was appropriate, and we were able to deliver reagent at about the right dose for the full range of moisture and feed rate conditions.

Figure 67

PRODUCTION & DELAY SUMMARY MAY 1995														
Date	Production	Scheduled Hours Of Operation												
	(Tons)	Operations				Delays (Non Circuit)			Delays (Circuit)				Total Sch. Hours	
		Run Time	Haul Coal	Svc. Equip	Tot. Oper.	Chetopa	Slip Stream	Total Non Cir	Feeder	Pug Mill	Electric Controls	Other	Total Circuit	
5/1/95	15.94	4.12	0.50		4.62	2.53	0.38	2.91					0.00	7.53
5/2/95	18.77	5.67	1.00	0.63	7.30		0.42	0.42				0.28	0.28	8.00
5/3/95	27.29	7.70	1.33	0.17	9.20	0.75	0.97	1.72				0.12	0.12	11.04
5/4/95	16.80	5.63	0.96		6.59		0.42	0.42					0.00	7.01
5/8/95	9.58	5.20	0.50		5.70		2.16	2.16				0.13	0.13	7.99
5/9/95	17.86	5.07	1.60	0.22	6.89		1.13	1.13					0.00	8.02
5/10/95	26.46	5.03	1.00		6.03	1.00		1.00					0.00	7.03
5/11/95	14.63	3.82	0.38		4.20	0.58	3.22	3.80					0.00	8.00
5/12/95	10.58	2.68	0.33		3.01		1.40	1.40					0.00	4.41
5/17/95	19.99	5.10	1.43		6.53	0.33	1.13	1.46					0.00	7.99
5/18/95	20.91	5.45	0.95		6.40		0.77	0.77					0.00	7.17
5/19/95	36.38	6.88	1.53		8.41			0.00					0.00	8.41
5/22/95	29.54	5.62	1.69		7.31	0.58		0.58					0.00	7.89
5/23/95	30.50	5.40	1.44		6.84	0.52		0.52					0.00	7.36
5/24/95	36.73	6.06	1.61	0.12	7.79			0.00					0.00	7.79
5/25/95	34.51	6.18	1.43		7.61	0.38		0.38					0.00	7.99
5/26/95	21.38	3.79	0.71		4.50		1.22	1.22					0.00	5.72
5/31/95	35.81	6.22	1.44		7.66	0.35		0.35					0.00	8.01
TOTALS	423.66	95.62	19.83	1.14	116.59	7.02	13.22	20.24	0.00	0.00	0.00	0.53	0.53	137.36
Scheduled Hours Of Operation				137.36					Available Circuit Hours				117.12	% Total
Available Plant Hours				130.34										
% Plant Availability				94.89					Run Time				95.62	81.64
Available Slip Stream Hours				117.12					Haul Coal				19.83	16.93
% Slip Stream Availability				89.86					Service Equipment				1.14	0.97
									Equipment Breakdowns				0.00	0.00
									Other Delays				0.53	0.45
									Totals				117.12	100.00

Figure 68

PRODUCTION & DELAY SUMMARY JUNE 1995														
Date	Production	Scheduled Hours Of Operation												
	(Tons)	Operations				Delays (Non Circuit)			Delays (Circuit)				Total Sch. Hours	
		Run Time	Haul Coal	Svc. Equip	Tot. Oper.	Chetopa	Slip Stream	Total Non Cir	Feeder	Pug Mill	Electric Controls	Other	Total Circuit	
6/1/95	36.81	6.51	1.68		8.19			0.00					0.00	8.19
6/2/95	28.05	5.07	1.81		6.88	1.10		1.10					0.00	7.98
6/5/95	34.99	5.97	1.35		7.32	1.20		1.20					0.00	8.52
6/6/95	25.34	4.65	1.40	1.17	7.22	0.79		0.79					0.00	8.01
6/7/95	27.38	5.05	1.41		6.46			0.00					0.00	6.46
6/8/95	27.68	4.68	1.49	1.08	7.25	0.28		0.28					0.00	7.53
6/9/95	20.83	3.66	1.20		4.86			0.00		0.10			0.10	4.96
6/12/95	12.77	2.63	0.70		3.33	4.00		4.00					0.00	7.33
6/13/95	28.95	5.53	1.24		6.77	0.44		0.44					0.00	7.21
6/14/95	28.90	5.26	0.95		6.21	1.80		1.80					0.00	8.01
6/15/95	37.33	6.77	1.85		8.62			0.00					0.00	8.62
6/16/95	6.73	1.40	0.33		1.73			0.00					0.00	1.73
TOTALS	315.76	57.18	15.41	2.25	74.84	9.61	0.00	9.61	0.00	0.10	0.00	0.00	0.10	84.55
Scheduled Hours Of Operation				84.55				Available Circuit Hours					74.94	% Total
Available Plant Hours				74.94										
% Plant Availability				88.63					Run Time				57.18	76.30
Available Slip Stream Hours				74.94					Haul Coal				15.41	20.56
% Slip Stream Availability				100.00					Service Equipment				2.25	3.00
									Equipment Breakdowns				0.10	0.13
									Other Delays				0.00	0.00
									Totals				74.94	100.00

Figure 69

PRODUCTION & DELAY SUMMARY APRIL, MAY & JUNE 1995														
Date	Production	Scheduled Hours Of Operation												
	(Tons)	Operations				Delays (Non Circuit)			Delays (Circuit)					Total Sch. Hours
		Run Time	Haul Coal	Svc. Equip	Tot. Oper.	Chetopa	Slip Stream	Total Non Cir	Feeder	Pug Mill	Electric Controls	Other	Total Circuit	
April	226.91	72.97	11.38	1.61	85.96	11.42	17.50	28.92	0.00	0.00	0.00	0.47	0.47	115.35
May	423.66	95.62	19.83	1.14	116.59	7.02	13.22	20.24	0.00	0.00	0.00	0.53	0.53	137.36
June	315.76	57.18	15.41	2.25	74.84	9.61	0.00	9.61	0.00	0.10	0.00	0.00	0.10	84.55
Totals	966.33	225.77	46.62	5.00	277.39	28.05	30.72	58.77	0.00	0.10	0.00	1.00	1.10	337.26
Scheduled Hours Of Operation		337.26				Available Circuit Hours			278.49					% Total
Available Plant Hours		309.21												
% Plant Availability		91.68							Run Time					225.77 81.07
Available Slip Stream Hours		278.49							Haul Coal					46.62 16.74
% Slip Stream Availability		90.07							Service Equipment					5.00 1.80
									Equipment Breakdowns					0.10 0.04
									Other Delays					1.00 0.36
									Totals					278.49 100.00

Figure 70

Non Circuit Delay Summary
Chetopa Plant

Date	Hours	Delay Description
4/6/95	1.62	Hole In Vibrating Screen
4/10/95	0.75	Sheared Pin In Vacuum Filter
4/18/95	1.50	Hole In Bottom Of Froth Cell
4/19/95	1.00	Vacuum Filter Overflow
4/20/95	3.46	Out Of Raw Coal
4/24/95	1.67	Out Of Raw Coal
4/28/95	<u>1.42</u>	Safety Meeting, Pile Up, Switching Feed
Total April	11.42	
5/1/95	2.53	Eimco Cells Plugged On Bottom
5/3/95	0.75	Raw Coal Belt
5/10/95	1.00	Clean Up Spill
5/11/95	0.58	Four Operators Off Sick
5/17/95	0.33	Clean Up Spill
5/22/95	0.58	Safety Meeting
5/23/95	0.52	Clean Up Spill
5/25/95	0.38	Out Of Raw Coal
5/31/95	<u>0.35</u>	Sheared Pin On Vacuum Filter
Total May	7.02	
6/2/95	1.10	Heavy Media Washer
6/5/95	1.20	Broken Belt
6/6/95	0.79	Out Of Raw Coal
6/8/95	0.28	Clean Up Spill
6/12/95	4.00	Vacuum Pump Down
6/13/95	0.44	Safety Meeting
6/16/95	<u>1.80</u>	Froth Cells & Screen Drive
Total June	9.61	
Summary		
	8.23	Vacuum Filter
	6.30	Out Of Raw Coal
	5.83	Froth Cells
	4.99	Conveyors & Screens
	<u>2.70</u>	Other
Total	28.05	

Figure 71

Non Circuit Delay Summary
Slip Stream Take-Off

Date	Hours	Delay Description
4/7/95	0.70	Adjust Effluent Pool Height On Centrifuge
4/8/95	1.00	Adjust Effluent Pool Height On Centrifuge
4/8/95	5.00	Replace Blow Out Plug In Centrifuge Turbo Drive
4/11/95	1.58	Check & Repair Main Gasket On Centrifuge
4/13/95	1.00	Finish Replacing Main Gasket On Centrifuge
4/13/95	1.06	Adjust Effluent Pool Height On Centrifuge
4/13/95	1.00	Centrifuge Chute Plugged Up
4/19/95	1.03	Adjust Effluent Pool Height On Centrifuge
4/20/95	0.53	Adjust Effluent Pool Height On Centrifuge
4/21/95	1.06	Centrifuge Chute Plugged Up
4/24/95	0.62	Adjust Effluent Pool Height On Centrifuge
4/27/95	1.00	Centrifuge Chute Plugged Up
4/28/95	1.00	Centrifuge Chute Plugged Up
4/28/95	<u>0.92</u>	Adjust Effluent Pool Height On Centrifuge
Total April	17.50	
5/1/95	0.38	Adjust Effluent Pool Height On Centrifuge
5/2/95	0.42	Adjust Effluent Pool Height On Centrifuge
5/3/95	0.97	Centrifuge Chute Plugged Up
5/4/95	0.42	Adjust Effluent Pool Height On Centrifuge
5/8/95	2.16	Remove Scale From Centrifuge Feed Pipe
5/9/95	1.13	Adjust Effluent Pool Height On Centrifuge
5/11/95	1.00	Adjust Effluent Pool Height On Centrifuge
5/11/95	2.22	Centrifuge Chute Plugged Up
5/12/95	1.40	Check Centrifuge Feed Tube
5/17/95	1.13	Adjust Effluent Pool Height On Centrifuge
5/18/95	0.77	Centrifuge Chute Plugged Up
5/26/95	<u>1.22</u>	Slug Of Wet Coal Plugged Main Chute
Total May	13.22	
Total June	0.00	
Summary		
	10.34	Adjust Effluent Pool Height On Centrifuge
	8.02	Centrifuge Chute Plugged Up
	5.00	Replace Blow Out Plug In Centrifuge Turbo Drive
	2.58	Check & Repair Main Gasket On Centrifuge
	3.56	Remove Scale From Centrifuge Feed Pipe
	<u>1.22</u>	Slug Of Wet Coal Plugged Main Chute
Total	30.72	

Figure 72

Circuit Delay Summary

Date	Hours	Delay Description
4/25/95	0.47	Blown 10 Amp Fuse On Surge Feeder
5/2/95	0.28	Blown 10 Amp Fuse On Surge Feeder
5/3/95	0.12	Blown 10 Amp Fuse On Surge Feeder
5/8/95	0.13	Replaced 10 Amp Fuse With 20 Amp Fuse On Surge Feeder
6/9/95	<u>0.10</u>	Pug Mill Shut Down - Operator Error
Total	1.10	

Summary

	1.00	* Surge Feeder Fuses
	<u>0.10</u>	Operator Error
Total	1.10	

* The surge feeder was supplied by the factory with a 3 HP DC gear motor which was controlled with a very sophisticated SCR/DC controller - more sophisticated than what was required for this project. When the machine was first connected, the motor would not start. The problem was traced to a faulty circuit board. The factory furnished a replacement board, and it was also faulty. We removed the factory controller and replaced it with a less complicated DC drive which was purchased locally. The machine started right up with the new drive, but the new drive, which was rated at 1 - 3 HP, was equipped with a 10 amp fuse which was only good for 1 HP. When the surge feeder fuse blew for the first time, we knew that we needed a heavier fuse, but it took over one week to get the 20 amp fuses which were required. In the meantime we used 10 amp replacement fuses which blew every time the load got up into the 2HP range.

available raw coal and other plant operating conditions, the coal solids in the froth concentrate would range from 15% to 32%, but under normal conditions froth concentrate ran about 30% solids. With feed solids at 32%, we could produce up to 7 tons/hour of Mulled Coal at 20% moisture.

However, when the centrifuge was operated to produce high moisture (23% to 27%), a condition in which the effluent was restricted (effluent pool heights close to the screen elevation - see Section 10.2.5), the machine could only handle up to 25 GPM of water plus whatever amount of coal (% solids) was coming with the froth concentrate. With feed solids at 32% we could only produce about 3 TPH in the 23%-27% moisture range, and, even at that low feed rate, it was difficult to prevent moisture from shooting up over 30%.

The 3 to 7 TPH feed rate limits at various target moistures in the 20% to 27% range were only developed after about 6 weeks of experience in operating at various effluent pool depths and a variety of feed solids conditions.

With experience we were able to estimate current feed rate from motor loadings and visual observations, but we never knew the exact feed rate until a loading cycle was completed and the truck was weighed and dumped. By the middle of April (6 weeks into the production phase of the project) we had built up enough historical data to determine feed rate limits. Prior to mid-April, we had always gotten into trouble when a feed rate limit was exceeded. Either we lost control of product moisture, the centrifuge was overloaded, or excess wet coal caused the centrifuge chute to plug up. On some occasions all three problems occurred simultaneously. After mid-April, we completely eliminated these problems by maintaining feed rate within prescribed limits.

Feed rate for the entire project was 4.3 TPH of wet Mulled Coal, but as we gained more and more experience, we were able to operate just under the top edge of the feed rate limit. By the end of the project we had moved the average up over 5 TPH.

11.2 Daily Production

Between April 5, 1995 and June 16, 1995, there were 45 scheduled production shifts. Figure 73 shows a record of the production for each scheduled shift, and a cumulative production line shows the daily progress toward the 1000 ton production target. We missed the production target by 34 tons; producing a total of 966 tons during the period.

The Chetopa plant produced coal for 16 hours each day. Production was scheduled for the day shift and the afternoon shift. Maintenance was scheduled for the midnight shift. The day shift started at 7:00 AM. Normally, the plant was started and up to full production by 7:30 AM.

The Mulled Coal circuit production shift was normally scheduled to begin at 7:30 AM and end at 3:30 PM. However, due to travel and visitor schedules, there were six shifts during the period where less than 6 hours of production was scheduled (short shift average production time was 4.5 hours). There were also two shifts where production time was scheduled for a little over 11 hours on each shift. For the balance of the scheduled shifts (37), production time averaged just under 8 hours per shift.

Figure 73

DAILY PRODUCTION RECORD

Figure 74 shows the daily production for only the 37 shifts which were scheduled for a full eight hours. It also shows the progression of the moving average daily production during the period. The final average for the full production shifts ended up at 22.6 tons per shift versus a target of 22.7 tons per shift.

As can be seen in Figure 74, production was way below average for the first five weeks and way above average for the last five weeks. The difference in daily production between the two periods is primarily related to our going through a learning curve with the screen bowl centrifuge. The problems we experienced with the operation of the centrifuge will be explained in detail in Section 11.6.2 which deals with delays to production.

11.3 Manpower

Due to the experimental nature of the project, the operation of the Mulled Coal circuit was completely isolated from the rest of Chetopa plant operations. EI was responsible for furnishing all necessary manpower to operate and maintain the circuit and to haul the Mulled Coal product from the plant to the project stockpile.

The operation normally required two people. One was an EI representative who was scheduled to be present during all hours of scheduled operation. His duties included liaison with Drummond personnel, scheduling production and maintenance, starting and stopping the circuit, controlling moisture and reagent dose, analyzing quality control and moisture samples, and keeping accurate records of daily operations.

The second operator was a temporary employee from the Birmingham area who was also scheduled to be present during all hours of scheduled operations. His duties included opening and closing manual valves during start and stop sequences, advancing the haulage truck under the chute during the loading cycle, hauling Mulled Coal, changing reagent drums, gathering samples, servicing equipment and keeping the project bays clean and free of hazards. The temporary employee was also trained to do most of the control room duties of the EI representative (starting and stopping the circuit, etc.), and from time to time he controlled the circuit for short periods of time.

A second EI representative, who was fully trained and capable of performing all tasks in the operation of the circuit, was present at the job site for about 20% of the scheduled production days. During these periods, there would be three operators available during the morning hours, and we took advantage of the extra manpower by doing special sampling and maintenance projects which required a third set of hands. During the afternoon hours one of the EI representatives concentrated on off site administrative activities such as purchasing parts and supplies, shipping samples, meeting with Drummond and compiling field data.

The operation of the circuit was a full time job for two people, but that should not be interpreted to mean that two people would be required to operate a commercial Mulled Coal circuit. One of our operators spent most of his time in the control room, and the other spent most of his time in the haul truck, gathering samples or doing other tasks which were strictly related to the experimental nature of the project. In a commercial installation, the circuit would be controlled from

Figure 74

a central control room along with other plant equipment, and Mulled Coal circuit equipment (feeder, pug mill, reagent delivery system) is essentially designed to run unattended. One plant operator, such as a froth cell operator, would be assigned to watch over the circuit along with his other duties. Total manpower required to operate, service and maintain a commercial circuit would probably be less than one man shift per scheduled production shift.

11.4 Hauling Mulled Coal

The original plan was to use a 20 ton dump truck to haul Mulled Coal from the plant, across the Chetopa scales, and onto the stockpile. The round trip was about one mile.

To begin the project, the truck would hold almost a full shift of production. As soon as it was full it would be dumped and spotted back under the loading chute. Then the circuit would be started up and run for the balance of the shift, and the partial load would be left in the truck overnight. The normal procedure would be to dump one load each day, and gradually the partial load at the end of the day would increase. Eventually two loads would have to be dumped on the same day.

Original cost estimates for leasing a 20 ton truck were based on prevailing conditions in the Western Pennsylvania coal hauling market. It just so happened that the start of the project coincided with a small industrial boom in the Birmingham area. There were very few trucks in the 15-20 ton range available in the area, and the cost of the few which were available was prohibitive.

We finally settled on a month to month lease on a small dump truck which was rated at 10 tons for rock. The cost was less than 10% of the cost of a full size dump truck. Even with the addition of higher side boards, the haul truck topped out at about 7.5 tons for Mulled Coal.

The round trip from the loading chute, to the scales, to the stockpile and back to the loading chute was less than one mile. With no interruptions, the round trip should have taken less than 15 minutes. However, the Chetopa plant was shipping all of its production by truck. All coal hauling was done between the hours of 6:00 AM and 2:30 PM and they ran as many as 60 trucks; with each truck making multiple round trips each day. Inevitably queues would form at the scales, and we felt that our haul truck would routinely be held up.

We ended up hauling 149 trucks with an average of 6.4 tons per load. Average round trip haul time was just under 19 minutes per load. Using the smaller truck probably resulted in the loss of about 75 tons of production over the life of the project, but it created significant cost savings.

11.5 Stockpile

The Mulled Coal stockpile was located at an out of the way corner of the main Chetopa coal yard (Figure 2), and it was situated about mid way between the loading chute and the scale house. Each day all truck loads of Mulled Coal would be dumped along the inside edge of the base of the stockpile. At least every other shift, one of the Chetopa end loader operators stacked the Mulled Coal up on to the stockpile. By the end of the production period there was 966 tons on the stockpile.

It was in the approximate shape of a triangular prism - being about 18 ft. high, 40 ft. across the base and 50 ft. across the side.

11.6 Production & Delay Time

Over the production phase of the project, there was a total of 337.26 hours of scheduled production time. Obviously the Mulled Coal circuit could not have operated for 100% of the available time. There were non-scheduled delays due to breakdowns, and there were scheduled delays due to the various elements of production such as hauling coal and servicing equipment. A breakdown of what actually transpired during the 337 hour period is as follows:

	<u>Hours</u>	<u>% of Total</u>
Plant Delays	28.05	8.31
Slipstream Delays	30.72	9.11
Mulled Coal Circuit Delays	1.10	0.33
Run Coal	225.77	66.96
Haul Coal	46.62	13.81
Service Equipment	<u>5.00</u>	<u>1.48</u>
	337.26	100.00

We produced at an average rate of 3.12 TPH when the Chetopa plant was running. When the slipstream was available as far as the surge feeder, we produced at an average rate of 3.46 TPH. When the mulling part of the circuit (surge feeder, pug mill, reagent delivery system) was actually running, production averaged 4.28 TPH. The difference between the 4.28 TPH and 3.12 TPH production rates results from lost production due to non-scheduled and scheduled delays.

The following is a brief description of each major time element, and some comments about its overall impact on the production phase of the project.

11.6.1 Plant Delays

Plant delays were totally beyond the control of project personnel. These were breakdowns and other delays which resulted in shutting off the raw coal feed to the plant. Figure 70 is a description and summary of Plant Delays. There were 23 individual delay events resulting in 28.05 hours of down time. Plant availability on this basis was almost 92% which is acceptable, but real plant availability during the period was actually much higher.

Each time the plant was started, we allowed an additional 15 minutes for the solids content in the froth cells and froth concentrate to reach a state of equilibrium (we had problems with the centrifuge when we were shooting for a high moisture, and the solids content in the froth concentrate was low). The plant actually ran for 5.75 hours more than we credited.

Additionally, we have identified 6.5 hours of delays due to the plant being out of raw coal. While being out of coal was a delay from the standpoint of the project, it should not be counted against plant availability.

When these two figures are factored out, plant availability becomes 95%, which is a very respectable availability for a coal preparation plant - especially one that was built in 1966.

11.6.2 Take-Off Delays

All production delays were assigned to either the plant, the slipstream take-off system or the Mulled Coal circuit. Plant delays did not involve project equipment and were beyond the control of project personnel. Delays assigned to the slipstream take-off system and the Mulled Coal circuit did result from equipment installed for the project, and were under the control of project personnel. However, the delay categories were separated because the slipstream take-off system was installed simply as a convenient means of supplying a reduced flow feedstock for the Mulled Coal circuit, and the slipstream take-off system which was used would never be part of a commercial Mulled Coal installation.

Figure 71 shows a breakout and summary of slipstream delays. The vast majority of all circuit delays resulted from the slipstream take-off system (slipstream system 31 hours versus 1 hour for the Mulled Coal circuit). The slipstream valves, slurry lines, water lines and sample ports were all well designed and were trouble free throughout the project. Most of the problems were related to the operation of the screen bowl centrifuge. They resulted from a combination of our own inexperience with the operation of a centrifuge, our attempts to operate a centrifuge to produce an arbitrarily high product moisture, and the fact that the centrifuge we were using was only a test machine, and it was not designed for permanent installation and continuous operation.

There were 13 individual delays assigned to adjusting effluent pool height. As described in Section 10.2.5, these adjustments were required to raise or lower the product moisture so that the Mulled Coal process could be tested over the full 20% - 27% moisture range. Adjusting effluent pool height involved removing guards, opening up the centrifuge and adjusting the height of four individual dams. The operation normally took between 30 and 45 minutes. Effluent pool heights were adjusted many more than 13 times. In fact, they were adjusted on almost a daily basis, but in most cases, the adjustments were made when the plant or circuit was down for some other reason. When there was any kind of delay that we expected would last up to 30 minutes, we normally opened up the centrifuge and adjusted the dams. It should be noted that every time the centrifuge was opened up for a pool height adjustment the other operator cleaned out the product discharge chute.

One of the most perplexing problems in the production phase of the project was coal plugging up the centrifuge discharge chute. The machine we were using was a test machine which was normally only used for short duration trial runs. It was not set up for permanent installation or continuous operation; which was the way we were using it in our project. Coal hanging up in centrifuge discharge chutes is an age old problem, but the latest centrifuges have discharge chute designs which eliminate or greatly reduce the plugging problem.

The test machine we were using had a fairly restricted discharge chute. From the condition of the machine when it arrived, we could see signs that plugging had been a problem in the past, so we removed the original steel and rubber chute liners and replaced them with a low coefficient of friction plastic.

We knew from shakedown testing that material would begin building up in the discharge chute immediately after the circuit was started. Very quickly a large portion of the chute would blind off, but paddles on the centrifuge would impart a significant force which would move the coal down through the chute in a very restricted flow path. The machine would run like this for quite some time, but eventually there would come a time when the chute would completely blind off. We would normally spot this happening because of a rapid rise in motor load. We would shut down, open up the centrifuge, clean out the chute and start up again.

Because of our inexperience, it took almost six weeks to figure out a way to operate the centrifuge with a minimum of lost time due to plugged chutes. We finally learned to interpret motor load signals which were telling us that a plugging problem was developing. And we learned that if the chute was cleaned out early enough and often enough, it was not necessary to open up the centrifuge to clean it out. It could be cleaned out from the bottom by reaching in through the gap between the centrifuge chute and the main verticle chute (see Section 6.7). This alone saved us at least 30 minutes every time the chute was cleaned. Finally, we completely eliminated plugging problems by cleaning out the chute after each load while we were shut down to haul the load to the stockpile. The time required to clean out the chute was not recorded as a delay, because it took place while the circuit was down to haul coal to the stockpile.

11.6.3 Mulled Coal Circuit Delays

As long as there was a slipstream available, the Mulled Coal circuit ran with virtually no interruptions for the entire production phase of the project. Figure 72 lists and summarizes Mulled Coal circuit delays which amounted to only a little over one hour out of a total of 228 hours. One hour was lost because one of the controllers was originally equipped with a fuse which was rated too low for the load on the machine, and we lost six minutes because an operator inadvertently leaned against a stop switch in the control room.

We expected nothing less than trouble free operation. Mechanically the Mulled Coal circuit was very simple. There were only two machines and a small pump - all of which were more than adequately designed to meet their respective duty cycles. We also went to great lengths in terms of redundancy and other safeguards to make certain that there would be no lost time related to the sophisticated control circuit.

11.6.4 Run Coal

When there was a slipstream available, and when there was a truck under the chute to be loaded, actual production operations ran very smoothly. But that does not mean that the operators sat down for 226 hours and watched a computer screen or watched a truck bed fill up. On the contrary, the operators were the busiest when the circuit was producing Mulled Coal. Routine tasks

in a production cycle included constantly scanning real time data, constantly imputing moisture and reagent data, gathering and analyzing samples, adjusting manual valves, changing reagent drums, advancing the haul truck under the loading chute, and observing the operation of individual machines. This frantic activity was routine for the project, but most of it would not be required for a commercial installation. It was mostly related to the facts that the project was isolated from other plant activities, circuit feed was a slipstream, and Mulled Coal was discharged directly into a small truck.

11.6.5 Haul Coal

The dump truck had a capacity of 7-1/2 tons of Mulled Coal. During the production phase of the project we were forced to shut down production 150 times to haul loads - as opposed to the 50 or so loads which would have been required had we used a full size (20 ton) dump truck. There is no question that hauling 100 extra loads resulted in lost production, but all of the time saved by 100 fewer round trips to the stockpile would not have been available as production time.

After the middle of May, we began cleaning out the centrifuge chute after each loading cycle (while the truck was away dumping). That meant cleaning out the centrifuge chute after every 1-1/2 hours of running time. It would have taken over five hours of running time to fill a 20 ton truck, but we would never have been able to run for 5 straight hours without cleaning out the centrifuge chute. At the very least the chute would have to have been cleaned out once in the middle of the load, and while the truck was away being dumped. Cleaning out the centrifuge chute required a 15 minute shutdown. Using a 20 ton truck would probably have resulted in an additional 15 hours of production time.

The greatest savings from using a 20 ton truck would have been time savings for the second operator. It was important to get the maximum amount of Mulled Coal on each one of the 7-1/2 ton truck loads. In order to get a full load, the small truck had to be precisely positioned under the loading chute, and it had to be advanced a few feet on four separate occasions for each load. Coming up a little short on a 20 ton load would not have been as important, and, because of the shape of the bed, positioning the truck under the loading chute would not have required nearly as much of the operator's time.

11.6.6 Service Equipment

There were only four pieces of circuit equipment which required routine servicing - the air compressor, the centrifuge, the surge feeder and the pug mill. During shakedown operations a service manual was prepared which set out servicing time, check points, grease and lube points, and oil and grease grades for each piece of equipment. For instance, the centrifuge was to be greased every 8 hours of operation, crank case oil in the compressor was to be checked twice per week, etc. We used only three different grades of gear oil and one grade of grease.

Servicing was a simple and straightforward task which required very little time. There were not very many grease points and gear oil levels rarely had to be replenished. Only 5 hours of delay was assigned to servicing equipment. In reality much more time was spent on servicing equipment, but most servicing was done while the circuit was down for some other reason.

11.7 Quality Control

Mulled Coal quality was measured in the field at least on a daily basis, and more often if there was a visible change in quality. The quality control test procedure was a modified uniformity test. The uniformity test is a widely recognized procedure used to evaluate the flow characteristics of dry bulk solids. We adapted the test procedure and interpretation of results to wet fine coal products, and over the years we have found the modified procedure to be a reliable indicator of Mulled Coal quality.

In the field uniformity test, 250 grams of freshly produced Mulled Coal is placed on the top deck of a stack of three screens which had deck openings of 6 mesh, 14 mesh and 28 mesh, respectively. The material is dry screened for 5 minutes, after which the amount of material retained on each screen is weighed. Results are reported as the size distribution percentages of:

+6 Mesh
6M x 14M
14M x 28M
28M x 0

In terms of Mulled Coal, the test is an indicator of whether or not agglomerated coal particles are completely covered with a thin membrane of reagent. If the mulling process is incomplete, the agglomerated particles remain "sticky", and they tend to form marble sized balls when they pass over vibrating screen decks (this is very common behavior for wet fine coal). When the mulling process is complete, agglomerates are not "sticky", balls do not form, and a greater percentage of the sample freely flows through the screens to the bottom decks.

When a uniformity test is run on dry coal, virtually 100% of the material reports to the 14M x 0 size fraction. When the test is run on Mulled Coal the amount of material reporting to the 14M x 0 size fraction is considered to be the Handleability Index for that sample - where 100 equals the Handleability Index for dry coal.

Listed below are uniformity tests results for three forms of the Chetopa fine coal product:

Wet cake feed at 23% moisture (unmulled)
Mulled Coal at 23% moisture
Wet cake feed at 0% moisture (unmulled dry coal)

These samples all represent Chetopa fine coal at the same size distribution and the same starting moisture, but they are not three splits of the same sample. Field quality control samples were used only for Mulled Coal. Unmulled coal and dry coal were only tested a few times during the project, and test results were only considered as markers. Test results are listed here only to illustrate the relative differences in the Handleability Index for the three products. Mulled Coal results are based on the average of all quality control samples for the project. Unmulled coal and dry coal results are based on the average of only two tests.

COMPARATIVE UNIFORMITY TESTS

	<u>UnMulled Coal</u>	<u>Mulled Coal</u>	<u>Dry Coal</u>
+6 Mesh	49.02	10.94	0.00
6M x 14M	50.01	4.98	0.24
14M x 28M	0.39	58.52	9.61
28M x 0	0.58	25.56	90.15
Handleability Index	0.97	84.08	99.76

From past testing experience we know that wet fine coal with a Handleability Index of under 25 will almost definitely cause handling problems. Mulled Coal with an index in the 25-45 range is marginal, and it could cause problems in certain situations. An index of over 45 generally means that the material is "free flowing", and it will not cause problems in conventional coal handling, storage and transportation systems. An index of over 60 places the Mulled Coal in the excellent category, and handling characteristics will approach those for dry coal (without the dust problems normally associated with dry fine coal).

It should be noted that these interpretations are very subjective, and they have not all been tested in the real world, but they continue to be the best method we have of grading Mulled Coal. This project was the first time Mulled Coal was tested on a full scale basis in a real world coal handling environment. It passed with flying colors, and nothing about the demonstration would cause us to change our interpretation of uniformity test results.

From the first test run in the shakedown operation, through the last ton produced for the project, Mulled Coal quality was maintained in the excellent category. Quality control tests (uniformity tests) were run on a daily basis plus any time there was either a significant change in moisture or a significant change in the visible appearance of the Mulled Coal.

There was very little change in Mulled Coal quality from day to day or even hour to hour. There were some changes when we were experiencing rapid and wide swings in feed moisture, but the lowest Handleability Index recorded for the project was only 61.26. There were only two QC samples under 70, and the average index was over 80.

Figure 75 shows the average Handleability Index for all of the QC tests run at each moisture level in the target range of 20%-27%.

11.8 Reagent Consumption

The level of reagent dose required to produce excellent quality Mulled Coal over the target moisture and feed rate ranges proved to be the greatest and most pleasant surprise in the project. Based on all previous laboratory experience with the Mulled Coal process, and the results of preliminary sampling for this project, we estimated that we would be using reagent doses in the 1.7%

Figure 75

QUALITY CONTROL TEST RESULTS

to 3.5% range (that is 1.7%-3.5% of the weight of dry coal in the slipstream feed). In fact we used only 0.4% to 2.0% doses, and we actually tested the process over a wider moisture range than originally anticipated (design range of 20% to 26% versus the actual range tested of 19% to 28%).

For the entire production phase of the project, we produced about 775 tons of dry coal and consumed just over 5 tons of reagent. Pre-project design calculations would have called for a reagent consumption of about 13 tons.

Figure 76 shows the projected versus actual reagent doses throughout the target moisture range.

The relationship between reagent dose and feed moisture is not linear for 28M x 0 wet cakes which have an overall ash in the 9%-13% range, and which have a size distribution which includes 18% to 25% in the 325M x 0 size fraction. There is a breakover point at about 23% moisture. Moisture increases above 23% require a greater percentage increase in reagent dose than equal moisture decreases below 23%.

In Figure 76, it is indicated that the actual reagent dose set point curve becomes completely flat at moistures below 22%. Reagent dose requirements at moistures under 22% were probably less than those indicated on the curve, but the system was not capable of efficiently delivering reagent flow rates of under 5 GPH (doses below 0.4%). We designed for flow rates in the 10 GPH to 30 GPH range. At flow rates of under 5 GPH the system would not deliver enough pressure to atomize the reagent at the spray nozzle. Proper reagent droplet size is equally as important as flow rate.

Reagent cost accounts for over 80% of the total ownership and operating costs of a Milled Coal circuit. The discovery that actual reagent doses for this project were less than half of projected requirements has a major impact on the commercial viability of the process (see Section 14.4.3).

11.9 Special Samples

In addition to routine moisture and quality control samples, there were 23 special samples taken during the production phase of the project. All special samples were shipped to EI's Pittsburgh laboratories for analysis. Special sampling was concentrated in two areas:

- Determining product losses which result from using a screen bowl centrifuge.
- Evaluating moisture and heat value changes which result from open ground storage.

11.9.1 Product Losses

There is always a certain amount of 325M x 0 coal lost to effluents when using a screen bowl centrifuge to dry fine coal. Under normal circumstances, losses increase as one attempts to lower product moisture (effluent drains wide open/moderate feed rate - see Section 10.2.5). In this project we were not attempting to produce the lowest possible moisture. In fact, we were attempting to run at an arbitrarily high product moisture (effluent drains restricted/dams at highest possible setting - see

Figure 76

REAGENT USAGE

Section 10.2.5). We expected lower product loss than normally experienced with the operation of screen bowl centrifuges.

On several occasions we attempted to quantify product losses by simultaneously sampling effluents, the centrifuge product and the normal Chetopa vacuum filter product. At the same time we recorded feed rate, water flow rates and percent solids in the effluents. The vacuum filter product represented the feed before product losses. The effluents represented the losses, and the centrifuge product represented the material after losses to effluent. With all flow rates, % solids in the effluents, and feed rates, we could then run a size distribution analysis for each product and calculate material and hydraulic balances for the circuit. The results of these tests were mixed and inconclusive.

There were four separate sample points, and three of the four samples required two operators. We could not actually get simultaneous samples. There was a gap of at least 15 minutes between the first and last sample, and we had to assume that there were no significant changes in feed conditions or the operation of the froth cells during the 15 minute time span. In order to calculate product losses, effluent samples had to be timed. Effluent samples were collected in four grabs. Sample weights were averaged, and the fourth grab was retained for percent solids and size distribution analysis. Samples were collected in 5-gallon buckets, and due to the high flow rate in the solid bowl drain, the duration of the sample was only 12 seconds. There is room for error in trying to cut a full stream with a 5-gallon bucket and remove it in exactly 12 seconds.

Figure 77 entitled Product Reconstruction Test, represents the closest we came to reaching a material balance for this type of sampling. The test indicated an 11.41% product loss which was primarily in the 325M x 0 size fraction. However, the measured amount in the 325M x 0 size fractions for the vacuum filter (feed) and centrifuge (after product loss) do not jibe with an 11.41% product loss. Assuming that the figure is correct for the vacuum filter, the centrifuge product should have contained over 16% in the 325M x 0 fraction instead of the 12.88% actually measured.

Figure 78 is a summary of all of the size distribution analyses run on the centrifuge product. The average 325M x 0 size fraction amounted to 17% of the total sample. The average for the 325M x 0 size fraction in the numerous filter cake samples analyzed for this project was 20% of the total. Comparing these average figures would indicate that there was an average product loss of about 3% during the project. Based on visual observations and numerous effluent grab samples, a product loss of 3% is much more realistic than the 11.41% calculation in the Product Reconstruction Test.

The wide range in the 325M x 0 size fraction (8.34% to 29.61%) in the summary of centrifuge product analyses (Figure 78) suggests that there may have been another problem. We ran numerous size distribution analyses on both froth concentrate and filter cake. The 325M x 0 size fraction averaged 20% of the total product, and the range for all of the samples was very narrow (from a low of 18% to a high of 22%). We were constantly opening the centrifuge effluent sample ports to make sure that flow rates and solids content were visibly in the proper ranges. We definitely were not experiencing wide enough swings in effluent losses to cause the 325M x 0 size fraction in the centrifuge product to range from 8% to 30%.

Figure 77

PRODUCT RECONSTRUCTION TEST

Date: 5-17-95

Time: 11:45 AM

Conditions

G V Pos	55
SBC Amps	27
TPH Production	4.2

Sample No	5-17-4	5-17-5	5-17-6	5-17-7
Sample ID	Solid Bowl Effluent	Screen Effluent	SBC Product	Filter Cake
Duration	12 sec. Grabs	30 sec. Grabs	Simultaneous	Simultaneous
Flow Rates				
Water (GPM)	31.23	2.28	3.02	N/A
Coal (Dry TPH)	0.114	0.329	3.44	N/A
Dry Ash	26.76	12.67	11.6	12.1
Size Distribution				
+16M	0.00	0.00	0.23	0.08
16M x 28M	0.00	0.46	8.43	3.46
28M x 0	100.00	99.54	91.34	96.45
+16M	0.00	0.00	0.23	0.08
16M x 28M	0.00	0.46	8.43	3.46
28M x 100M	0.00	36.83	57.74	39.44
100M x 200M	0.00	18.46	13.58	16.46
200M x 325M	1.60	12.10	7.14	10.95
325M x 0	98.40	32.15	12.88	29.61
	100.00	100.00	100.00	100.00

Product Loss Through Centrifuge

To Solid Bowl Drain	2.95%
To Screen Drain	8.46%

Combined Effluents & Product

Total Water (GPM)	36.53
Total Coal (Dry TPH)	3.88
Total Wet Feed (TPH)	13.02
Total Wet Product (TPH)	4.20
% Solids In Feed	29.82
Cum. Dry Ash	12.14

Figure 78

Screen Bowl Centrifuge Product Analyses

Date	4/28/95	4/28/95	5/1/95	5/4/95	5/8/95	5/17/95
Sample No.	4-28-1	4-28-2	5-1-2	5-4-1	5-8-1	5-17-6
Time	8:30 AM	2:35 PM	1:20 PM	2:30 PM	12:30 PM	11:45 AM
Conditions						
Feed Source	Mary Lee	Blend	Blend*	Blend	Mary Lee	Blend
G V Pos.	48.00	52	53	57	54	55
SBC Amps	27.00	28	27	27	25	27
Prod. (TPH)	3.44	3.51	3.74	2.27	1.86	4.20
Test Results						
Ash (Dry)	12.40	12.20	12.83	12.80	12.11	11.60
Moisture	26.00	19.00	17.40	19.00	19.00	18.00
Size Dist.						
+16M	0.12	0.43	0.31	0.35	0.31	0.23
16M x 28M	8.07	10.63	8.97	9.33	10.92	8.43
28M x 0	91.81	88.94	90.72	90.32	88.77	91.34
+16M	0.12	0.43	0.31	0.35	0.31	0.08
16M x 28M	8.07	10.63	8.97	9.33	10.92	3.46
28M x 100M	50.02	53.19	53.57	45.85	61.54	39.44
100M x 200M	13.11	12.82	15.10	17.41	12.29	16.46
200M x 325M	8.02	8.34	7.90	11.33	6.60	10.95
325M x 0	20.66	14.59	14.15	15.73	8.34	29.61
	100.00	100.00	100.00	100.00	100.00	100.00

One possible explanation is that we were getting some particle size stratification in the pipe line running from the flotation cells to the vacuum filter, and from time to time the slipstream was not receiving a full cut of froth concentrate. The slipstream take-off was tapped into the bottom side of a 50 ft pipe line which ran from the flotation cells to the vacuum filter. The pipe line was 14" in diameter and had a drop of only about 12" from the froth cells to the filter. Froth concentrate only filled the pipe about half way, and because of the short drop, velocity in the pipe line was low. Froth concentrate moved gently through the pipe line for a distance of about 40 feet before the slipstream take-off point. It is possible that, in this distance, smaller particles could work their way toward the top of the slurry stream.

Since the slipstream take-off was tapped from the bottom of the pipe line, and it was taking only about 10% of the flow, it is possible that the slipstream was biased with larger size particles. Figure 79 is a schematic representation of what may have been happening if stratification was taking place. We could not verify that there was stratification in the main pipe line without going to a great deal of time and expense. If stratification was taking place, sample results indicate that the extent of it changed from day to day.

We were not able to precisely define product losses, but whatever they may have been, they did not have any effect on overall project objectives. Centrifuge effluents were recycled, so there actually was no product loss. The process consistently converted a feed which was missing about 15% of the 325M x 0 size fraction into an excellent quality of Mulled Coal. We know that Mulled Coal quality improves as the mean particle size of the wet cake diminishes. If there were no 325M x 0 losses to centrifuge effluent, Mulled Coal quality would probably have improved.

11.9.2 Air Drying Effect

Another major surprise in this project was the rapid rate of air drying which took place during the period in which Mulled Coal was in open ground storage. We knew from some early lab work that Mulled Coal air dried at a more rapid rate than unmulled Coal of the same quality. But we were totally unprepared for what happened in this project. Mulled Coal went onto the ground at just under 23% moisture. By the time it was shipped, moisture had decreased to 8%, and the majority of the moisture loss occurred within three weeks.

The Mulled Coal stockpile was started on April 5, 1995, and by June 16th, there were 966 tons of coal on the ground. Trucks were dumped along the base of the pile, and coal was stacked with a front end loader on a daily basis. We attempted to maintain the shape of the pile as a triangular prism with a height of 18 feet and a width of 40 feet. By the end of the production phase, the pile was just over 50 feet long.

Coal was shipped on August 30th. Between April 5th and August 30th there were 14" of recorded rainfall, and mean temperatures increased from 51°F in April to 85°F in August. Although we did not keep statistics on humidity it seemed relatively high during the period. There was nothing about weather conditions which would have promoted air drying. In fact almost 11" of the 14" of

PARTICLE SIZE STRATIFICATION IN FROTH CONCENTRATE LINE

14" Concentrate Pipeline From Froth Cells To Vacuum Filter

rainfall came in April, May and June while we were building the pile and constantly exposing new surfaces with the coal stacking operation. And it was during this same wet period that most of the air drying took place.

It would not have been practical to do a comparative study of air drying for unmulled coal and Mulled Coal for this project. The figures for unmulled coal would have been meaningless unless there was a stockpile of unmulled coal which was built at the same rate and in the same shape as the Mulled Coal stockpile. We do know that, in normal weather conditions, unmulled filter cake will air dry down to the 18%-20% moisture range at a fairly rapid rate. In dry weather the outer shell of a filter cake pile will become crusty and dry to below 10% moisture. But down in the pile a few feet, the moisture will not get below 18%, and the outer shell of the pile will rewet in heavy rains.

We took composite stockpile samples from time to time to keep track of changes in quality. Figure 80 is a graphic representation of moisture losses over a four month period. The time line on this graph is a bit misleading. The figure of 20% moisture on day one actually represents the weighted average of all Mulled Coal produced between April 15th and May 18th. The data points at days 21, 27, and 125 are composite stockpile samples taken on the dates indicated. Not all of the coal had been on the stockpile for 21, 27, or 125 days. Only the coal produced on the first day of the project would have been on the stockpile that long. The composite samples represented most of the coal produced between day one and the date of the sample, but we did try to avoid sampling Mulled Coal which had been on the stockpile for less than one week.

When it became apparent that Mulled Coal was air drying at an unusually rapid rate, a special test was set up where we kept a small pile of known moisture Mulled Coal separated from the main stockpile and took moisture samples on four occasions over the course of one month. We could not precisely age the Mulled Coal for the composite samples from the main stockpile. Freshly produced Mulled Coal was deposited on and stacked into the main stockpile each day. We attempted to avoid sampling coal which had been on the stockpile for less than one week, but there was no way to assign an accurate age to the coal which was sampled.

On May 11th, we produced about 10 tons of Mulled Coal at 28% moisture. This coal was dumped and stacked into a separate small stockpile. The test stockpile was sampled two weeks, three weeks, then four weeks after the date it was produced. Moisture went from 27.8% on the day it was produced, to 12.76%, to 9.20% and finally to 7.86%. After four weeks moisture was about the same as the main stockpile, so the test pile was comingled with the main stockpile.

The air drying phenomenon was, to say the least, very intriguing. However, we cannot use data from this one test condition to jump to any universal conclusions about the air drying characteristics of all Mulled Coal under all commercial circumstances.

Air Drying Effect

Main Stockpile

Date Produced/Sample Date	4/27/95	5/18/95	5/24/95	8/30/95
Sample No.	N/A	5-18-1	5-24-1	N/A
Type Of Sample	Wt. Ave. Moist.	Stockpile Comp.	Stockpile Comp.	Gorgas Analysis
Days Following Production	1	21	27	125
Moisture	19.95	9.20	7.57	7.86

12.0 DECOMMISSIONING OPERATIONS

After producing one final load of Mulled Coal on Friday morning, June 16, 1995, we began at 9:00 AM to dismantle the Mulled Coal plant addition. We fell 34 tons short of the 1000 ton production target, but we had an extremely tight schedule, and we were concerned that we would miss an important commitment to one of our equipment suppliers if we continued producing.

We had committed to having the screen bowl centrifuge out of the plant and ready to ship by the end of the work day on June 20th. The mechanical contractor, who had installed the heavy equipment back in February and March, was scheduled to move back on to the job with a crane on the morning of June 20th. The schedule allowed only 1-1/2 days for project personnel to disconnect, clean up and have all heavy equipment ready to be lowered down out of the plant.

This early part of the decommissioning plan went like clockwork. The contractor moved in as scheduled on June 20th. By the end of the day, all heavy equipment had been moved out of the plant and hauled to a staging yard, and early the following day, the screen bowl centrifuge was returned to the manufacturer. The contractor spent two more days on the job during which he dismantled chutes; lowered the remaining reagent drums down out of the plant; and patched holes in the floor decks at elevations of 458', 467' and 476'.

EI personnel did all of the other dismantling work including:

- Packing and shipping via UPS all computer, monitoring, and laboratory equipment, and the reagent spray system and miscellaneous control room equipment and supplies.
- Removed all valves, fittings, etc. and hauled them to the staging yard.
- Disconnected all electrical switches, E-Stops, etc. and hauled them to the staging yard.
- Cut out and scrapped all light steel framework and fabrications.
- Pulled and scrapped all control wire, lead lines, and bent conduit.
- Removed all usable conduit and fittings and hauled them to the staging yard.
- Plugged off the slipstream take-off point and the place where we tapped the centrifuge effluents into the vacuum filter drain.

With permission of the owner of the Host Site, we left in place the control room shell, the new steps, the hoist doors, the additional structural steel floor supports, and the electrical leads running from the Chetopa motor control center to the project control room. Upon removal, these items would only have been worth scrap value, and removal cost would have exceeded scrap value.

By June 28th all project equipment had been removed from the plant. It had either been shipped back to Pittsburgh via UPS or it was stacked in the staging yard awaiting shipment. The project bays were all in equal or better condition than they were prior to the project.

We had employed a local specialty company to assist us with palletizing and packing heavy equipment, and making other insurance and shipping arrangements for the equipment being held in the Chetopa staging yard. The equipment was shipped on July 7th. It completely filled a full size flat bed trailer. On this shipment the pug mill was dropped off at the lessor's plant in Georgia, and the balance of the load was dropped off a few days later at EI.

All of the project equipment arrived in Pittsburgh undamaged. From Pittsburgh, leased equipment was forwarded on to lessors. All other equipment was cataloged and is in storage at EI.

All scrap metal, wood products and miscellaneous waste products were disposed of in the Chetopa waste disposal system. The waste products were separated and placed in appropriate dumpsters which were hauled away by a commercial waste disposal company.

Waste products from Chetopa coal samples which were analyzed in Energy International's Pittsburgh laboratories were placed in sealed drums. The waste drums either were or will be disposed of by a commercial disposal company.

In the field, all coal sampling was done on clean fine coal. Waste from the sampling was included in the clean coal product if dewatered, or it was returned to the fine coal sump if it was in slurry form.

13.0 SHIPMENT DEMONSTRATION

13.1 Background

Alabama Power, a subsidiary of The Southern Company, operates a coal fired power plant which is located about 25 miles from the project site. The power plant is a 1200 MW station which burns about 3,400,000 tons of coal per year. This particular plant was considering a proposal to burn a rewash fine coal product which was to be recovered from a nearby slurry impoundment. It was felt that experience with our Mulled Coal product would give them an indication of how reprocessed pond fines might behave in their truck receiving and fuel handling system. Arrangements were made to ship 12 truckloads, or about 300 tons, on the morning of August 30, 1995.

13.2 Stockpile Coal Temperature

There was some concern at the power station that, after ground storage of about three months, a medium sulfur fine coal stockpile would develop hot spots. Based on laboratory testing, we feel that the Mulled Coal process would inhibit oxidation and spontaneous combustion, but to be on the safe side, we decided to test the stockpile temperature prior to shipment.

A thermocouple with a remote readout device was mounted on the end of a 12' section of 1/2" diameter pipe. On August 29th (the day before the Alabama Power shipment), coal temperatures were taken around the perimeter and at the center of the stockpile. Temperatures around the perimeter (in about 4') were in the 123-126°F range, and temperatures at the center were in the 120-122°F range. Air temperature at the time of the test was 95°F, and for the previous 30 days, high temperature ranged from 89-103°.

13.3 Stockpile Condition Prior to Shipment

There were some obvious signs of sheet erosion prior to shipment. There were a number of small (a few inches wide and a few inches deep) erosion "gullies" scattered around the perimeter of the stockpile. It is thought that this type of erosion occurs only when coal on the outside of the stockpile air dries to the point where it is almost bone dry and begins to slump slightly from its own weight. When this happens, the dry coal is almost fluid. Even a slight rain can cause small erosion gullies down to a depth where the coal has not lost all of its surface moisture.

This type of sheet erosion never occurred when the Mulled Coal on the outside of the stockpile was freshly produced (in the 18% to 30% moisture range). With fresh Mulled Coal on the outside of the pile, there was no sheet erosion -- even during heavy downpour conditions.

13.4 Hauling Arrangements

The coal was to be hauled by a local truck contractor who had experience in hauling from Drummond sites into the Gorgas station. Six tractor trailers making two rounds each were used for the shipment. The six loads for each round were bunched up so that the trucks could be dumped one right after the other. Because the Mulled Coal was so dry, it was decided to tarp each load.

13.5 Loading

Coal trailers for the shipment measured 8' wide x 34' long x 5 1/2' high and were rated at about 1500 cu ft capacity at level full. Since the Mulled Coal had a relatively shallow angle of repose, and since it had a lower bulk density than coarser clean coal, we attempted to completely load each truck to level full capacity. Trucks were loaded in three passes with a front end loader which was equipped with a 20 cu yd bucket. Truck loads averaged 27 1/2 tons -- indicating an average bulk density for Mulled Coal of about 37 lbs per cu ft. This compares favorably with laboratory bulk density tests run on the Mulled Coal product.

13.6 Dumping and Handling at the Gorgas Station

There was no problem whatsoever with trucks dumping or the coal passing through the fuel handling system at the Gorgas Station. Figure 81 is a schematic representation of the truck coal receiving system. EI representatives were permitted to observe and videotape the Mulled Coal loads as they were dumping, and we were stationed so that we could follow the movement of the coal from the truck dump through two bins and onto the stockpile.

There were two small differences between the behavior of Mulled Coal and the behavior of the regular baseline 1 1/4" x 0" coals as they dumped and moved through the system. The trailer beds for some of the Mulled Coal loads had to be tilted at a slightly sharper angle before the load began to dump. But as soon as the load started to move, it dumped quickly and completely. It is thought that this may have resulted from our efforts to get "level full equivalent" loads. In some cases the front end loader operator actually tamped down the load with the bottom of the loading bucket. The loads which were tamped down had to be tilted at a sharper angle to dump. There was no coal under the belt head of the stacking belt, so the coal dropped a distance of about 30' from the belt head to the ground. As would be expected, when the Mulled Coal dropped this distance, it caused more dust than the coarser baseline coals.

13.7 Conclusion

Mulled Coal was produced at the 23% moisture level for the shipment demonstration, but, by the time we were ready to ship, moisture was only 8%. A total of 300 tons of the 8% moisture material was successfully shipped by truck, unloaded, and handled with the conventional equipment available at the electric utility. The fact that the Mulled Coal process promoted very rapid air drying was unexpected and is now considered to be potentially one of the most advantageous features of the process. Unmulled fine coal at 8% moisture would be extremely dusty; however, this did not translate into a problem for the mulled product at 8% moisture level used in the 12 truckload shipment. Also, we know from lab testing that there was very little difference in the handling characteristics of Mulled Coal at 23% moisture and Mulled Coal after it air dried to 8% moisture, and we know that Mulled Coal would easily have passed through this system right after it was produced (while it was still high in moisture). Additionally, we know that unmulled wet cake at 23% moisture would never have passed through this system, and it never would have air dried to a point where it could be handled at the Gorgas Station.

Figure 81

POWER STATION
COAL RECEIVING SETUP

TANDEM TRUCK DUMP

SURGE BIN

CONSOLIDATING BIN

STACKING CONVEYOR

LIVE STOCKPILE

14.0 COMMERCIAL CONSIDERATIONS

The Mulled Coal process was developed as a means of converting ultra clean Coal Water Fuel into a granular, free flowing intermediate fuel form that is inexpensively stabilized for storage and shipment. The process works extremely well in this application, but the use of Coal Water Fuel has not gained widespread acceptance, and it does not appear that there will be many near-term commercial opportunities to apply the process in this manner.

The purpose of this project was to evaluate the application of the Mulled Coal technology to the types of every day wet fine coal problems which have plagued the coal industry ever since the introduction of wet processes for cleaning fine coal. We achieved all of the major project objectives. Starting with a 28Mx 0 clean coal product with ash up to 13% and moisture up to 27%, we proved the concepts that:

Excellent quality Mulled Coal could be produced consistently and continuously; at a convincing rate of production; and in the environment of a typical commercial coal preparation plant.

Mulled Coal can be stored, handled, and shipped without causing any of the problems normally associated with wet fine coal.

Equipment designs and circuit controls, which were based on laboratory and pilot scale test work, were appropriate for full scale commercial operations.

From experience gained in the proof of concept project, we can identify a number of areas where the Mulled Coal technology can be used on a commercial basis to economically alleviate handling problems or broaden markets. We established major equipment specifications for various levels of production, and we can accurately project key capital and operating costs.

14.1 Commercial Applications

14.1.1 Slurry Pond Recovery Projects

There is in excess of 100 million tons of fine size, higher rank bituminous coal (28M x 0 or 150M x 0, low vol, mid vol and high vol A) stored in accessible slurry impoundments throughout the U.S. coal fields. This represents a very significant source of low cost fuel, and the inventory figure is growing every day. There are currently over 100 preparation plants with completely wet circuits which have not been provided with fine coal preparation or recovery circuits. Collectively, these plants have an installed capacity of about 50,000 tons per hour. They process about 190 million tons per year of raw coal, and they probably bleed off between 10 and 20 million tons of fine coal each year. Not all of this coal is ending up in accessible slurry impoundments, and not all of the coal which ends up in a pond is worth recovering. However, it is safe to assume that we are putting recoverable coal into accessible slurry impoundments at least twice as fast as we are removing it.

The reason that fine coal was directed to slurry impoundments in the first place, and the reason that it is not being recovered at a faster rate (in spite of the relatively low cost), is market resistance to wet fine coal. And that market resistance is related to the plugging, fouling, bridging, storage and transportation problems which are historically associated with fine wet coal. The Mulled Coal process represents a low cost solution to all of those problems.

Commercial slurry pond recovery projects fall into three general categories:

1. Ponds where the material is low enough in ash that it can be recovered without any further separation process.
2. High ash ponds which are located adjacent to our near refuse fired cogeneration plants. In these cases the slurry pond material is a desirable boiler feed source because even though it is high ash, it is generally higher in heat value than the coarse refuse which is the primary fuel source for the plant.
3. High ash ponds where a low ash product can be recovered by washing or rewashing in a flotation or combination spiral/flotation circuit.

The common thread running through all of these projects is that they end up with a very low cost wet and sticky product which is difficult to market. Previous solutions have included blending in small percentages of the recovered product with a dry coarser coal, blending larger portions in with coarser coal and thermally drying the blend, or drying the recovered material by itself with a combination thermal drying/pelletizing process. These solutions are all expensive and they partially offset the built-in cost advantage of removing material from a pond versus conventional mining methods.

In each case, instead of blending, or thermal drying, or pelletizing, the Mulled Coal process could have been used as a low cost final conditioning step to prepare a boiler grade fuel with vastly improved handling characteristics.

14.1.2 Integration into Multi-Circuit Preparation Plants

As previously discussed, there are over 100 completely wet preparation plants which are not equipped with fine coal separation or recovery equipment. These plants simply bleed off fine coal in a slurry form.

There are plants which wash to 0, but the handling characteristics of the 1-1/4" x 0 clean coal product are so heavily influenced by the wet, sticky fine coal that markets for the overall product are limited. This is especially true with higher grind deep mine coals where larger percentages of the total product consist of the finer size fractions. Some customers may accept the full 1-1/4" x 0 product, but others, who are more sensitive to wet coal handling problems, will insist that the finest size fractions be excluded from shipments, or they will impose moisture restrictions which will prohibit the inclusion of the finest size fraction.

Many of these plants will install a separate fine coal belt which will divert the finest size fraction away from the regular clean coal collecting belt when shipping to certain customers. The fine coal ends up in a separate stockpile. From there it is either blended in with a much drier coal (perhaps raw strip coal), or it is metered in very small quantities back into the regular clean coal product for shipment on less restrictive orders. In either case the fine coal ends up on a lower price market, and the additional handling cost to divert it to ground storage and back into a blend is significant.

In these cases the Mulled Coal process is simply inserted at the tail end of the fine coal preparation circuit. The mechanically dried fine coal product discharges to a surge feeder, which in turn feeds the pug mill where reagent is added in and mixed with the wet coal. The Mulled Coal is discharged from the pug mill to the regular clean coal collecting belt, and the process eliminates the adverse handling characteristics which were caused by the untreated wet coal.

14.1.3 Alternative to Thermal Drying

There is no substitute for thermal drying when the primary objective is to avoid the cost of shipping water to a distant market, or where a customer has an inflexible requirement for fuel with a very high as-received heat value.

On the other hand there are situations where coal buyers set maximum moisture limits which are based on previous handling problems with coal which exceed the arbitrary limits. When maximum limits are set in the 6% to 8% moisture range, many deep mine producers, who wash to 0, cannot produce a 1-1/4" x 0" clean coal product which meets the low moisture specification.

The options for placing the clean coal product in the low moisture market are thermal drying or diverting or discarding enough fine wet coal until the coarser product meets the designed moisture specification. The Mulled Coal process can be used to make high moisture coal handle like 6% moisture coal. It will usually be less expensive than thermal drying, and there will be none of the environmental and safety hazards normally associated with drying fine coal.

The following table shows a hypothetical comparison of preparing a 10% moisture clean coal product for a 7% maximum moisture market by either thermal drying or using the Mulled Coal process. This illustration could be indicative of a deep mine operator in a high grind seam, who is washing to 0, and preparing coal for the compliance or near compliance market. Figures used for size distribution, heat value, price and cost may not be entirely appropriate. They are used here only to illustrate the type of analysis needed to compare mulling to thermal drying.

MULLING VERSUS THERMAL DRYING

	<u>Mulled</u>	<u>Thermally Dried</u>
Size Distribution (% of total)		
1-1/4" x 28M	75	75
28M x 0	25	25
Ash (Dry)	8.0	8.0
Moisture	9.0	6.0
Btu (A/R)	12,699	13,158
Btu (MAF)	15,300	15,300
FOB Mine Price (@ 1.15/MM Btu)	29.21	30.26
Less:		
Cost of Thermal Drying	-	2.50
Cost of Mulling ⁽¹⁾	<u>.38</u>	<u>-</u>
Net Realization	28.83	27.76

(1) Mulling cost is included at \$1.50/ton for the 28M x 0 size fraction. The 28M x 0 size fraction was considered to have been at 18% moisture.

14.1.4 Freeze-Proofing

When washed coal freezes and hangs up in rail cars, the freezing problem can always be traced to the 28M x 0 size fraction. In cold producing regions, and when coal is shipped into cold regions, it is sometimes necessary to apply freeze-proofing chemicals to the entire shipment in order to insure that cars will dump properly. Depending on the moisture and size consistency of the coal, freeze-proofing can cost as much as \$1.00 per ton.

The Mulled Coal process is not a freeze-proofing process. The water enveloped in and attached to individual agglomerates can freeze, but the reagent coating prevents individual agglomerates from freezing to each other, to other pieces of coal or to the steel sides and hoppers of rail cars. When the Mulled Coal process is used to prevent cold weather handling and car dumping problems, only the 28M x 0 size fraction is treated. Cost can run as high as \$1.50 per ton for the 28M x 0 coal treated, but costs per overall clean ton (1-1/4" x 0") will only be in the \$0.30 to \$0.40 per ton range depending on the size distribution of the clean coal product.

14.2 Major Equipment

The major pieces of equipment used in a Mulled Coal circuit are a pug mill (double paddle mixer) and a surge feeder. The design considerations for these two pieces of equipment (and all other component parts of the circuit) are described in Sections 6.3 through 6.11.

The double paddle mixer will be used in every commercial installation. There may be instances where the use of a surge feeder is not required. Mechanical fine coal dewatering equipment often discharges dry coal with periodic short duration surges. This is especially true in the case of vacuum filters. The surge feeder levels out momentary surges and delivers an even and consistent flow of wet cake to the pug mill. The surge feeder can also be used (as it was in this project) as a means of presenting wet cake to on-line monitors in an ideal configuration and density for accurate measurement. If the flow of wet cake off the dewatering equipment is even, and if on-line monitoring is not required, then the use of a surge feeder is not absolutely necessary. The guiding principle in deciding whether or not to use a surge feeder is that there must be an even flow of material to the pug mill for a precise and efficient application of reagent. Reagent cost accounts for over 80% of the total cost of operating a Mulled Coal circuit; while the cost of using a surge feeder is less than 5%.

In the project we used scale models of commercial size equipment. Throughout the shakedown and production operations, we ran numerous controlled tests to establish capacities and load factors for the scale model equipment. Nominal capacity for the project equipment was established at 5 TPH; with a maximum capacity of 7 TPH or 40% over nominal capacity. Information gathered in the project was used to project dimensions and load factors for commercial size equipment at nominal capacities of 25, 50 and 75 TPH.

75 TPH is considered to be the maximum nominal capacity rating for a single Mulled Coal circuit. Pug mill mixing shafts are about 12 ft long, and they cannot be supported at any place other than the ends. Horsepower requirements at capacities in excess of 75 TPH could cause shaft flexing problems. Capacities in excess of 75 TPH would require dual circuits, but generally, the capacity of individual Mulled Coal circuits can be set to match the capacity of the centrifuges or filters which provide the wet cake feed to the circuit.

Figures 82 and 83 show the scale up dimensions for the pug mill and surge feeder.

Pug mills in the 25 to 75 ton capacity range are used extensively in commercial minerals processing applications. The 50 TPH and 75 TPH surge feeders are not in common use. They would be special order machines, but that should not present a problem. This type of equipment is not mass produced. Each new machine is manufactured to specifications set out in individual orders. There is absolutely no doubt that this type of surge feeder would perform successfully at 75 TPH.

The reagent delivery system for commercial installations retains the essential design elements of the project system (described in detail in Section 6.5). Commercial systems will not be supplied with compressed air (it was found to be unnecessary) and the manual valves used to control the system will not be located in a control room.

Figure 82

PUG MILL

	PROJECT MACHINE			
	5 TPH	25 TPH	50 TPH	75 TPH
A" MIXING CHAMBER LENGTH	120"	120"	120"	120"
B" MIXING CHAMBER WIDTH	18"	39"	56"	66"
C" MIXING CHAMBER DEPTH	15"	28"	38"	42"
WORKING CAPACITY (Cu. Ft.)	10	50	100	150
RETENTION TIME (Minutes)	2.28	2.28	2.28	2.28
HORSEPOWER	10	17 1/2	30	50

Figure 83
SURGE FEEDER

	PROJECT MACHINE			
	5 TPH	25 TPH	50 TPH	75 TPH
1" HOPPER DEPTH	16"	27"	35"	40"
3" HOPPER WIDTH	16"	27"	35"	40"
2" HOPPER LENGTH	29"	50"	63"	73"
3" DISCHARGE TUBE DIA.	8"	17"	24"	29"
IVE HOPPER CAPACITY (Cu. Ft.)	3.9	19.6	39.1	58.7
ETENTION TIME (Seconds)	54	54	54	54
ORSEPOWER	3	10	15	20

- * The reagent pump will be a magnetically coupled gear pump with a DC drive.
- * The flow meter will be a high grade positive displacement gear type meter.
- * Spray nozzles will deliver wide angle fan patterns.
- * Individual spray nozzles can be shut down remotely to maintain ideal system pressure over a wide range of flow rates.
- * Reagent flow will be automatically adjusted by a control loop which includes one or more on-line instruments which will monitor key process variables such as coal feed rate and surface moisture. The process control loop may be simplified or even eliminated in applications where flow rate and moisture are consistent, or where Mulled Coal quality is not critical.

The table below shows reagent system capacities for project equipment and commercial installations.

	<u>Project Equipment</u>	<u>Commercial Installations</u>		
Processing Capacity (TPH)	5	25	50	75
Reagent Flow				
Minimum (GPM)	0.09	0.37	0.75	1.12
Maximum (GPM)	0.38	1.88	3.76	5.64
Nominal Rating (GPM)	0.22	1.13	2.36	3.38
Spray Nozzles				
Number Required	3	4	6	8
Spray Pattern	Fan	Fan	Fan	Fan
Included Angle (Degrees)	120	120	120	120
Flow Rate (GPH)	5	28	39	42
Operating Pressure (PSI)	20	50	50	50
Reagent Tank Capacity				
Day Tank (Gal.)	N/A	500	1,000	1,500
Main Storage Tank (Gal.)	N/A	6,000	10,000	15,000

14.3 Capital Cost

Capital and operating costs for a commercial Mulled Coal circuit depend on the type of application, the quality of the wet cake, and the target handling characteristics for the Mulled Coal product.

For instance, if the Mulled Coal circuit is simply being added onto the tail end of a fine coal circuit in an existing plant, then capital costs will be limited to the cost of equipment components, the cost of integrating the electrical and process control circuits into the existing plant control circuits, and the cost of minor structural changes required to fit in the new equipment. However, if the Mulled

Coal circuit is to stand alone to process slurry pond material at a greenfield project, then capital costs must include the cost of a complete plant structure, plus the cost of conveyors to move the material into and out of the new plant. Capital costs will never be significant as compared to reagent costs, but the capital cost for each particular application will differ, and it will be dependent upon a host of local factors.

Wet cake surface moisture, ash, and particle size distribution have a significant impact on required reagent dose, and each project will involve a wet cake with entirely different characteristics. There are predictable relationships between reagent cost and wet cake characteristics. In general, when all other characteristics remain equal:

- * Increases in surface moisture will result in increased reagent cost.
- * Increases in ash will result in increased reagent cost.
- * Increases in mean particle size will result in increased reagent cost. (see 5.3.1)

The desired handling characteristics of the Mulled Coal product will also affect reagent cost. In an application where the Mulled Coal circuit is used to condition 28M x 0 clean coal in an integrated preparation plant, and the 28M x 0 Mulled Coal is to be blended back in with coarser clean coal products, and the objective is simply to eliminate rail car dumping or freezing problems, then reagent consumption will be relatively low. On the other hand, in a stand alone circuit where the Mulled Coal will be shipped by itself, and the objective is to prepare a fine coal product which will gravity discharge from a bin with mass flow characteristics, then reagent consumption will be relatively high.

In order to make a precise estimate of capital and operating costs for a particular project, it is necessary to know the type of application, the quality of wet cake to be treated, and the desired handling characteristics for the end product. However, there are equipment components and capital costs which will be common to all projects, and we can make general predictions of reagent costs which will cover a range of wet cake and end product quality. The following sections project capital costs, reagent costs, and other operating costs at various levels of production.

14.3.1 Major Components

Site specific capital costs such as structures, bins, conveyors, etc., cannot be estimated because they will vary significantly from project to project. However, the pug mill, surge feeder, and reagent delivery system costs will be common to all projects (the surge feeder may not be required in rare instances - see Section 14.2). Listed below are projected common component costs at various levels of production.