REPORT

FINAL QUARTERLY TECHNICAL

PROGRESS REPORT NO. 6

**PELLETIZING/
RESLURRYING AS A
MEANS OF
DISTRIBUTING AND
FIRING CLEAN COAL**

To

PITTSBURGH ENERGY TECHNOLOGY CENTER

U.S. DEPARTMENT OF ENERGY

PROJECT MANAGER: ANTHONY E. MAYNE

MARCH 17, 1992

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

**PELLETIZING/RESLURRYING AS A MEANS OF
DISTRIBUTING AND FIRING CLEAN COAL**

Contract No. DE-AC22-90PC90166

Contract Period: August 3, 1990 to August 2, 1992

Final Quarterly Technical Progress Report No.6

Period Covered by Report: October 1, 1991 to December 31, 1991

**Battelle
505 King Avenue
Columbus, Ohio 43201-2693**

Principal Investigator: H. Nicholas Conkle Phone No. (614) 424-5616

Date Submitted: March 17, 1992

Prepared for

PETC Project Manager: Anthony E. Mayne

**Pittsburgh Energy Technology Center
U. S. Department of Energy
P. O. Box 10940
Pittsburgh, Pennsylvania 15236**

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.

TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY	1
OBJECTIVE	2
PROJECT DESCRIPTION	2
PROJECT STATUS	3
Task 3 - Prepare Pilot Scale Pellets	6
Pellet Production	6
Binder Optimization	6
Roller-and-Die Pelletization	7
Extrusion Pelletization	11
Disk Pelletization	14
Slurry Production	22
Tasks 4, 5, and 6--Evaluate Storage, Handling, and Transportation Characteristics	24
Vibration Tests	24
Humidity Test	24
Heat-Cycle Test	25
Outdoor Storage Test	25
Exposed, Covered Storage Tests	32
Silo Storage Tests	32
Packing Test	37
Pellet Uniformity	48
Task 7 Reslurry Pellets and Evaluate CWF	49
Task 8 Utilization/Commercialization	55
Task 9 Prepare Additional Filter Cake	59
PLANNED FUTURE ACTIVITIES	59
SUMMARY	60
RESLURRYING AMENABILITY TEST PROCEDURE	63

LIST OF TABLES

	<u>Page</u>
Table 1. Optimized Binder Dosage for Each Coal and Pelletization Process	6
Table 2. Daily Temperature and Weather Recording During Pellet Storage	28
Table 3. Outdoor - Exposed Storage Effects on Pellets After Two Weeks	30
Table 4. Outdoor - Exposed Storage Effects on Pellets After Four Weeks	31
Table 5. Outdoor - Covered Storage Effects on Pellets After Two Weeks	34
Table 6. Outdoor - Covered Storage Effects on Pellets After Four Weeks	35
Table 7. Silo-Column Storage Effects on Pellets After Two Weeks	38
Table 8. Silo-Column Storage Effects on Pellets After Four Weeks	39
Table 9. Super-Sack Nylon Bag Storage Effects on Pellets After Two Weeks	42
Table 10. Super-Sack Nylon Bag Storage Effects on Pellets After Four Weeks	43
Table 11. Elkhorn Roller and Die Pilot Scale Production Pellet Uniformity	50
Table 12. Utah Extrusion Pilot Scale Production Pellet Uniformity	51
Table 13. Reslurrying Amenability Tests on Illinois No. 6 CPM Pellets (2.6 Liter Scale)	52
Table 14. Complete Results of Reslurrying Amenability Tests on Illinois No. 6 CPM Pellets	53
Table 15. Flotation of Micronized Upper Elkhorn No. 3 Coal (October - November 1991)	61
Table 16. Particle Size Distribution of Upper Elkhorn No. 3 Clean Coal in Filter Cake	62

LIST OF FIGURES

	<u>Page</u>
Figure 1. Project Concept	3
Figure 2. Schedule	4
Figure 3. Effect of Corn Starch Dosage with Elkhorn Coal on Pellet Strength for Pellets Produced By (a) Roller and Die, and (b) Disk Pelletization	8
Figure 4. Effect of Corn Starch Dosage with Utah Coal on Pellet Strength for Pellets Produced By Extrusion.	9
Figure 5. Effect of Secondary Binder (Corn Starch) Dosage with Lignin Binder on Cured Strength of Utah Coal Pellets.	10
Figure 6. Elkhorn Coal Roller and Die Pellets made with Corn Starch	12
Figure 7. (A) 4 in. Extruder from The Bonnet Company, Leased for Pilot Scale Pellet Production, and (B) The Die of the Extruder.	13
Figure 8. Corn Starch Bound Utah Coal Extrusion Pellets.	15
Figure 9. Lignin Bound Utah Coal Extrusion Pellets.	16
Figure 10. Pilot Scale Disk Pelletization Process Configuration.	17
Figure 11. Green Disk Pellets Stored in Racks, Ready for the Thermal Drying Process	19
Figure 12. Disk Pelleting Operation Illustrating the Three Regions in Pellet Production.	20
Figure 13. Illinois No.6 Coal with Corn Starch Disk Pellets After Thermal Drying	21
Figure 14. Pellet Storage in a Specially Designed Cubical for Outdoor-Exposed Storage	27
Figure 15. Utah Coal Pellets with Corn Starch from (A) Extrusion and (B) Roller and Die Process, Stored Outdoor-Exposed After 2 Weeks.	29
Figure 16. (A) Layout of Pellets Cubical for Outdoor-Covered Storage (B) Pilot-Scale Pellets After 4 Week Storage	33
Figure 17. Columns Constructed to Simulate Pellets Storage in Silos	36
Figure 18. Pellet Storage in "Super-Sack" Nylon Bags	40
Figure 19. Illinois No. 6 Coal Pellet Strength Variations in Different Storage Modes After 2 Weeks	41
Figure 20. Illinois NO. 6 Coal Pellet Strength Variations in Different Storage Modes After 4 Weeks	44
Figure 21. Comparison of Utah Coal with Corn starch Pellet Strength Variation After 4 Week for Pellets Produced via Roller and Die and Extrusion	46
Figure 22. Effect of Coal Type on Pellet Strength during Storage	47
Figure 23. Weight Percent of Residual Plus 48-mesh Pellet Fragments Remaining After 8 Minutes Disintegration Time Versus Average Crushing Strength of Roller and Die Pellets Made with Three Binders.	54

LIST OF FIGURES

	<u>Page</u>
Figure 24. Weight Percent of Residual Plus 48-mesh Pellet Fragments Remaining After 8 Minutes Disintegration Time Versus Average Moisture Content of Roller and Die Pellets Made with Three Binders.	54
Figure 25. Disintegration of Roller and Die Pilot Scale Pellets Made with Corn Starch Binder.	56
Figure 26. Disintegration of Roller and Die Pilot Scale Pellets Made with Shur Bond Binder (first set).	56
Figure 27. Disintegration of Roller and Die Pilot Scale Pellets Made with Shur Bond Binder (second set).	57
Figure 28. Disintegration of Roller and Die Pilot Scale Pellets Made with Lignin Binder.	57
Figure 29. Comparison of Averaged Data for Disintegration of Roller and Die Pilot Scale Pellets Containing Corn Starch, Shur Bond, and Lignin Binders.	58

Final Quarterly Technical Progress Report No.6

Contract No. DE-AC22-90PC90166

on

PELLETIZING/RESLURRYING AS A MEANS OF
DISTRIBUTING AND FIRING CLEAN COAL

by

H.N. Conkle, J.K. Raghavan, F.J. Smit, and M.C. Jha

EXECUTIVE SUMMARY

Work in this quarter focused on: preparation of large batches of pilot-scale pellets; storage and handling testing; pellet reslurrying studies; and clean-coal production. All the planned roller-and-die- and extrusion-pelletization work was successfully completed. (Pilot-scale disk pelletization will be completed in January, 1992.) Two- and four-week storage and handling test results indicate a strong, durable pellet can be prepared from the Illinois No. 6 and Utah coals which can withstand outdoor, exposed storage. Pellets in unexposed storage (either in covered buildings, silos, or in 1-ton storage bags) show no deterioration in pellet properties. Reslurrying test results indicate that the pellets can be readily formulated into 55-percent-solids slurries with viscosities below 500 cP (at 100 sec⁻¹).

OBJECTIVE

The objective of this study is to develop technology that permits the practical and economic preparation, storage, handling, and transportation of coal pellets, which can be reslurried into Coal water fuels (CWF) suitable for firing in small- and medium-size commercial and industrial boilers, furnaces, and engines.

PROJECT DESCRIPTION

The project includes preparing coal pellets and capsules from wet filter cake that can be economically stored, handled, transported, and reslurried into a CWF that can be suitably atomized and fired at the user site. The wet cakes studied were prepared from ultra-fine (95 % -325 mesh) coal beneficiated by advanced froth-flotation techniques. The coals studied included two eastern bituminous coals, one from Virginia (Elkhorn) and one from Illinois (Illinois No. 6) and one western bituminous coal from Utah (Sky Line coal).

The Battelle/AMAX team is emphasizing two approaches in preparing coal pellets. The first approach is the use of an internal binder to prepare pellets having sufficient strength to be stored, handled, and transported in a manner similar to raw coal. The second approach is to prepare lower-strength pellets that are coated, encapsulated, or prepared, to form a "coal capsule," or pellet, that can be readily stored, handled, and transported. In both cases, preference is being given to binders or encapsulation materials that will be desirable components of the additive package used in producing a suitable slurry.

Research activities fall into three major areas:

- Reconstitution
- Storage, Handling, and Transportation
- Coal Water Fuel Formulation.

The project concept, incorporating these three main activities is shown in Figure 1.

FIGURE 1. PROJECT CONCEPT

More specifically the project activities includes the following 10 tasks:

- Task 0 - Acquire Coal
- Task 1 - Identify Technology
- Task 2 - Prepare and Test Small Batches
- Task 3 - Prepare Bench/Pilot-scale Pellets
- Task 4 - Evaluate Storage Characteristics
- Task 5 - Evaluate Handling Characteristics
- Task 6 - Evaluate Transportation Characteristics
- Task 7 - Reslurry Pellets and Evaluate CWF
- Task 8 - Utilization/Commercialization
- Task 9 - Prepare Additional Cake.

PROJECT STATUS

The project's schedule, subdivided by task and subtask, is shown in Figure 2. Work in this quarter covered Tasks 3, 4, 5, 6, and 9. This status section summarizes activities and accomplishments on these tasks. Considerable data has been generated and this information is supplied in the tasks and subtask descriptions presented below.

FIGURE 2. SCHEDULE FOR S. T. & H. OF COALS

FIGURE 2. SCHEDULE FOR S. T. & H. OF COALS

Task 3 - Prepare Pilot Scale Pellets

Pellet Production

All extrusion- and roller-and-die pelletization tests were completed during this quarter. The disk-pelletization method of pilot scale pellet production was partially completed. Binder dosages, specific to the method of pelletization and coal type, were optimized prior to large-scale pellet production. (Specific testing, to develop the lowest cost encapsulation approach, will be completed next quarter.)

Binder Optimization. Binder dosages for the three coals were optimized through a series of bench scale pelletization tests. Table 1 shows the minimum binder levels found necessary to meet the pellet acceptance criteria.

Table 1. Optimized Binder Dosage for Each Coal and Pelletization Process

Coal	Binder	Optimized Binder Dosages, % Dry Basis		
		Roller & Die	Extrusion	Disk
Elkhorn	Corn Starch	2.0	---	4.0
	Shur Bond	4.5	---	N/D
	Lignin	---	---	N/D
Illinois No.6	Corn Starch	2.0	---	4.0
	Shur Bond	4.5	---	N/D
	Lignin	4.0	---	---
Utah	Corn Starch	2.0	2.75	---
	Shur Bond	4.5*	4.5*	---
	Lignin	---	4.0*	---

* : Required 0.50% corn starch as secondary binder for pelleting

N/D : No optimization test has been conducted

--- : No pilot scale pellet production planned

The roller-and-die pelletization technique required the lowest amount of binder dosage among the three pelletization techniques for the three coals. The compaction forces and the operating conditions in the roller-and-die pelletizer are sufficient to produce strong, durable pellets with such low binder levels. Figure 3 shows the effect of corn starch binder dosage on cured pellet strength with Elkhorn coal, pelletized via roller and die and disk pelletization techniques. With both techniques, the compressive strength of the pellets showed a trend of increased strength with increased binder dosage. For the pellets to meet the acceptance criterion, i.e. 100 lb./cu.in, the roller and die pellets require only 2% corn starch, while the disk pellets require at least 4% corn starch.

In the extrusion pelletization process, for tests conducted with Utah coal, a minimum dosage of 2.75% corn starch was required. Figure 4 shows the optimization-test data. When liquid binders such as Shur Bond and lignin sulfonate were used for pelletization, a small fraction of corn starch was always required as a secondary binder for successful extrusion. The need for corn starch was consistent with our earlier evaluation conducted in the bench scale experiments. Figure 5 shows the effect of secondary binder (corn starch) dosage on pelletizing Utah coal with 4% (dry basis) lignin sulfonate.

Roller-and-Die Pelletization. All pilot scale roller-and-die pelletization work scheduled for this project has been completed. The pellet production was conducted at the California Pellet Mill Company's facilities in Crawfordsville, Indiana. During this quarter, Elkhorn coal and Utah coal pellets were made.

Elkhorn Coal Pelletization Elkhorn coal pellets with corn starch and Shur Bond binders were produced at pilot scale capacities (1000 dry lbs each). The following general pelletization procedure was adopted:

- Blend the clean Elkhorn filter cake coal, binder, and water in a mixer and adjust the moisture level to 26 percent
- Feed the mix into the pelletizer

Figure 3. Effect of Corn Starch Dosage with Elkhorn Coal on Pellet Strength for Pellets Produced By (a) Roller and Die, and (b) Disk Pelletization

Figure 4. Effect of Corn Starch Dosage with Utah Coal on Pellet Strength for Pellets Produced By Extrusion.

Figure 5. Effect of Secondary Binder (Corn Starch) Dosage with Lignin Binder on Cured Strength of Utah Coal Pellets.

- Produce pellets (3/4-in. diameter x at least 1 in. long) that have sufficient green strength and drop resilience to pass the acceptance criteria.
- Cool the hot pellets from the pelletizer to 80-90 F, and
- Store the pellets in 55 gallon containers for transportation via truck to Battelle.

Figure 6, shows samples of cured Elkhorn coal pellets with corn starch binder. Pelletization of Elkhorn coal was quite similar to the Illinois No. 6 coal. No specific operating problems were evident for pellets made with corn starch or Shur Bond binders.

Utah Skyline Coal Pelletization. Pilot scale production of Utah coal with Shur Bond was conducted during this quarter. After the unsuccessful pilot scale production test conducted during the last quarter, binder optimization testing was conducted in a bench scale roller-and-die pelletizer. It was determined from the test, that an additional 0.75% corn starch as a secondary binder was necessary for Utah coal to make quality roller-and-die pellets. Therefore, pilot scale roller-and-die pellets with Shur Bond were made with 0.75% corn starch. This combination of binder and coal mix also gave sufficient green and cured strength to pass the acceptance criteria. Note, as previously discussed, the two other coals (Illinois No.6 and Elkhorn) required no such secondary binder additive to pelletize with Shur Bond. In addition, Utah coal also required stringent control on feed moisture in the roller and die pelletizer. It is therefore clear, that the Utah coal requires special needs to meet commercial pellet production with Shur Bond binder.

Extrusion Pelletization. Pilot scale extrusion pellet production, planned for Utah coal only, was completed in this quarter. Three binders, i.e. corn starch, Shur Bond, and lignin sulfonate was used to produce at least 800 lbs (dry basis) of pellets in each case. The extrusion pelleting operation was conducted in a 4-in. extruder, at approximately 250 lb/hr. Photographs of the extruder and the extruder die leased from The Bonnet Company are

Figure 6. Elkhorn Coal Roller and Die Pellets Made with Corn Starch

Figure 7. (A) 4 in. Extruder from The Bonnet Company, Leased for Pilot Scale Pellet Production, and (B) The Die of the Extruder

shown in Figure 7A & 7B. The following general extrusion-pelletization procedure was adopted:

- Blend clean Utah filter cake with binder(s) in a mixer; adjust moisture as desired. Typically 35-40% moisture level was appropriate.
- Feed the mix gradually through the extrusion press.
- Shear the extruded pellets at about 1-1.5 in. length as it is produced.
- Thermal dry the pellets in a gas fired batch oven at ~180 F for about 2 hours.
- Store the dried pellets in 55 gallon drums.

Pelletization of Utah coal with corn starch binder was achieved without any technical problems. The pellets prepared at the optimized dosage level (2.75%, dry basis) showed excellent green and cured strength. A photograph of the corn starch bound pellets is shown in Figure 8. The pellets were thermally dried in the batch oven and air-cooled.

Pelletizing Elkhorn coal with Shur Bond and lignin binder was also successfully completed. With both these liquid binders, about 0.75% corn starch was co-added as a secondary binder to increase the compressive strength of the pellets. Thermally cured pellets made with 4.0% lignin sulfonate as the primary binder are shown in Figure 9.

Disk Pelletization Disk pellets at pilot scale quantities, ~1000 lb (dry basis) was planned for production with Illinois No. 6 and Elkhorn coals. The Andritz Sprout Bauer disk pelletizer was received and installed this quarter. Pilot scale pellets were made with Illinois No.6 coal with corn starch binder. The 5-ft. diameter, Model 1000 disk pelletizer along with coal feed mix feeding system used in the pilot scale production is shown in Figure 10. The following general disk pelletization procedure was adopted:

Figure 8. Corn Starch Bound Utah Coal Extrusion Pellets

Figure 9. Lignin Bound Utah Coal Extrusion Pellets

Figure 10. Pilot Scale Disk Pelletization Process Configuration

- Blend clean coal filter cake (at 25-30% moisture) with binder in a mixer
- Feed the mix gradually at desired feed rates (~70-100 lb/hr), through a screw feeder
- Adjust the disk-pan angle (40-42°), pan rotation speed, and water spray locations.
- When pellets are formed (nucleation), adjust feed rate and water spray levels to allow for pellet growth
- When the pellets are about 5/8-3/4-in. diameter, collect the pellets rolled over from the pan.
- Thermal dry the green pellets in the batch oven at ~180 F for about 2 hours
- Store the dried, cooled pellets in 55 gallon drums.

Figure 11, shows freshly produced disk pellets stored in racks, ready for thermal drying. The batch thermal dryer is also shown in the figure.

Illinois No. 6 Disk Pelletization. Pelletization with corn starch binder was accomplished during this quarter. The disk pellets were produced with 4.0% corn starch. Figure 12, shows the pelleting operation as seen on the pan of the pelletizer. Clearly, three regions of pellet production can be seen. Regions I and II show pellet nucleation and growth, respectively. Fully grown pellets at about 5/8-3/4-in. diameter are discharged from Region III of the pan.

Photograph of the Illinois No. 6 coal with corn starch disk pellets, after the thermal drying process are shown in Figure 13. The pellets show excellent structural integrity and meet the acceptance criteria. Production of other disk pellets are currently underway.

Disk pelletization method was observed to require more binder than the roller and die and extrusion pelletization technique. This method may therefore be economically unattractive at least from the perspective of binder utilization. However, the process is fairly simple and requires very little process control.

Figure 11. Green Disk Pellets Stored in Racks, Ready for the Thermal Drying Process

Figure 12. Disk Pelleting Operation Illustrating the Three Regions in Pellet Production

Figure 13. Illinois No. 6 Coal with Corn Starch Disk Pellets
After Thermal Drying

Slurry Production

The objective of this effort is to demonstrate that the pilot-scale pellets produced via roller-and-die, disk- and extrusion-techniques can be converted into good quality slurry. In this quarter, AMAX R&D started the reslurrying amenability tests with Illinois No. 6 and Utah coal pellets from roller and die pelletization. A summary of the amenability testing procedure which was developed while working on the first batch of pellets (CPM 1-1 to 1-6) is given in Appendix A. Basically, the procedure involves disintegrating the pellets in a Cowles dissolver with the appropriate amount of water and dispersant and sampling the slurry periodically to determine its viscosity and the amount of plus 48 mesh (300 micrometer) pellet fragments remaining in the mixture. The amount of moisture in each lot of pellets is determined first in order to calculate the water addition needed to provide a 55-percent coal slurry. The amount of dispersant added at the start of each test is based upon previous experience and is selected to provide a target viscosity of 500 centipoise (cP) at 100 Sec⁻¹.

Development of a continuous "pellet-to-slurry" system is also currently in process at Amax R&D. Design of the system included consideration of the scale and slurry specifications of some of the existing DOE combustion programs. For this purpose, three DOE contractors were contacted to determine their fuel consumptions and specifications. Their responses were as follows:

- Bruce Miller, Pennsylvania State University. The program is past the point where fuel comparisons are being made, although they have a 2 MM Btu/hr combustor for such work. They prefer a high loading, nominally minus 48-mesh PC-grind fuel. They use a 0.164-inch (4 mm) opening strainer in their fuel system and rarely have problems with oversize material. They have not operated for more than 8 hours at a time.
- John Balsavitch, TECOGEN. The residential combustor program will be completed in March. The system is for 125,000 Btu/hr and can accept PC grind slurry. (We did not inquire about strainers in the system.)
- Tony Litka, TECOGEN. The industrial and commercial combustor burns up to 350 pounds of dry coal per hour as slurry. The burner will handle 1-mm particles (presumably at low concen-

trations). They could schedule fuel comparison burns at Waltham next fall.

- David Arnold, University of Alabama. They plan to begin the program with 80 HP (3.6 MM Btu/hr) boiler which will burn 260 pounds of dry coal as slurry per hour. They hope to do some fuel comparisons. The atomizer that they have now is intended for minus 48-mesh fuel.

It appears from the conversations with the above individuals that a pellet reslurrying system would need to process several hundred pounds of pellets per hour if used with one of the existing systems. Fuels with minimal amounts of plus 48-mesh fragments are preferred, although the TECOGEN system may be able to accept particles up to 14 mesh in size.

Present plans, therefore, call for a two-stage system. Initial disintegration would be in a high-speed mixer, and top-size control would be obtained by either having a stone mill in series with the mixer or else having a vibrating screen in a closed circuit with the mixer. Methods for feeding the pellets to the mixer are currently being investigated. A general system configuration for reslurrying has been designed. Summary of the design basis is as follows.

Capacity	Match University of Alabama atomizer rig = 10 gallons per hour or Match 0.5 million Btu/hr combustor at PETC = 36 pounds dry coal per hour = 7 gallons per hour
Particle Size	Boiler Grind - 100 percent passing 1 MM (about 14 mesh), 98 percent passing 0.3 mm (48 mesh)
Loading	54 to 55 percent coal
Viscosity	200 to 800 cP at 100 s-1
Reslurrying Retention Time	8 Minutes

A belt feeder available at Amax R&D appears to be suitable for the system. It is a fixed-speed unit, but the actual feed rate will depend upon the material. During a recent trial, a 1,000-gram batch of roller-and-die

pellets was quite evenly fed at a rate of 240 grams per minute. For pellets containing 18 percent moisture, this is equivalent to 42 pounds dry coal or 7.9 gallons of slurry per hour, which is quite close to the nominal consumption of the University of Alabama atomization rig and the PETC combustor. The slight mismatch can be handled by installing a small surge tank in the system so that the reslurrying module may be operated for longer or shorter periods than the atomizer or combustor.

A mixing tank design was sketched and submitted to the Amax R&D shop for fabrication. The tank will be 7.5 inches in diameter and 12 inches tall and will provide 8 minutes of retention at the expected capacity of the belt feeder. Several overflow outlets are provided so that the working volume may be changed to investigate other retention times. The slurry will leave the tank through louvers cut in the sidewall so that oversize pellet fragments will be retained in the mixing zone. The first trials will be to see whether these louvers will hold back all of the plus 1-mm fragments. If not, a 35-mesh Sweco screen will be installed to receive the slurry and return the oversize fragments to the mixing chamber. In the event the Sweco screen is not satisfactory, a stone mill will be leased for use in the module for controlling the amount of oversize in the product.

Tasks 4, 5, and 6--Evaluate Storage, Handling, and Transportation Characteristics

Storage, handling, and transportation controlling tests were initiated in this quarter. Pellet evaluation after 2 and 4 week of production and storage has been completed.

Vibration Tests. No new results are available in this quarter. Testing to simulate transportation of pellets will be conducted in the next quarter.

Humidity Test. No tests were conducted during this quarter. Tests to understand the effect of humidity on pellets will be initiated in the next quarter.

Heat-Cycle Test. No new tests results are available in this quarter. Simplified testing approach is being planned. The new approach is targeted to test the coal pellets with Shur-bond binder only.

Outdoor Storage Test. The emphasis of this test is to evaluate the effect of the following storage conditions on the pellet characteristics:

- Exposed, outdoor storage
- Covered, outdoor storage
- Silo storage.

Among the several pilot scale production samples, the following pellets were select for 2, 4, and 12 week storage evaluation in this quarter.

- Utah coal with corn starch pellets made via. roller and die technique at California Pellet Mill (CPM)
- Utah coal with corn starch pellets made via. extrusion technique at Battelle
- Illinois #6 coal with corn starch pellets made via. roller and die technique at CPM
- Illinois No. 6 coal with Shur-bond pellets made via. roller and die technique at CPM
- Illinois No. 6 coal with lignin sulfonate pellets made via. roller and die technique at CPM

Evaluation with other pilot-scale production samples, including Elkhorn coal pellets, will be continued in the next quarter.

Exposed, Outdoor Storage Test. The pilot scale production pellets were stored in cubicles, and exposed to outdoor weather and temperature conditions. The cubicles were constructed in such a way, that water would drain through the bottom surface, thus preventing any water stagnation effect on the pellet. A photograph of the pellets, stored in the cubicles is shown in Figure 14. The pellets as seen in the figure are stacked up towards one of

the walls of the cubicles. This has been intentionally done to achieve maximum loading effect on the pellets, for a given quantity of pellets. In each case, about 100 lb of pellets were used for the evaluation. The weather and temperature conditions recorded during the two and four week period of storage are presented in Table 2.

The information presented in the table indicates that the outdoor pellets were exposed to severe rain and low temperature conditions. At the end of the second and fourth week of pellet storage, 20 pounds of pellet was sampled from the storage lot for pellet and reslurryability evaluation. At the end of week 2, very little obvious physical destruction was noticed with corn starch and Shur-bond bound pellets of Utah and Illinois coals. Photographs of the Utah coal pellets after 2 weeks of storage are shown in Figure 15. Lignin based Illinois No. 6 pellets showed a greater extent of physical destruction. At the end of week 4, most of the corn starch bound pellets continued to show good physical integrity. Lignin bound pellets showed medium to high levels of deterioration.

The physical integrity of the pellets after storage were determined by measuring the dried compressive strength and the Ro-tap durability of the pellets. Tables 3 and 4 present the results of strength and durability after 2 and 4 weeks of storage. The strength measured, one week after production, is also presented in the tables for comparison.

Corn starch bound pellets show a mixed trend of strength and durability variations. The storage effect appears to be strongly influenced by the type of coal and pelleting technique. Under exposed, outdoor storage, initial assessment after 2 and 4 week with the pellets studied so far, presents the following general information:

Figure 14. Pellet Storage in a Specially Designed Cubical for Outdoor-Exposed Storage

Table 2. Daily Temperature and Weather Recording
During Pellet Storage

Date	Weather Conditions	Recorded Daily Temperatures	
		High, F	Low, F
19 Nov. 91	Showers	57	50
20 Nov. 91	Partly Sunny	57	51
21 Nov. 91	Rain	54	50
22 Nov. 91	Drizzle	56	37
23 Nov. 91	Rain	40	29
24 Nov. 91	Partly Sunny	55	34
25 Nov. 91	Rain	58	34
26 Nov. 91	Drizzle	49	32
27 Nov. 91	Rain	40	25
28 Nov. 91	Showers	48	28
29 Nov. 91	Partly Sunny	65	50
30 Nov. 91	Rain	64	44
1 Dec. 91	Drizzle	42	33
2 Dec. 91	Rain	40	29
2 Week Average		52	37
3 Dec. 91	Drizzle	47	22
4 Dec. 91	Rain	22	10
5 Dec. 91	Drizzle	29	23
6 Dec. 91	Rain	39	32
7 Dec. 91	Drizzle	54	35
8 Dec. 91	Rain	63	39
9 Dec. 91	Drizzle	51	29
10 Dec. 91	Rain	46	31
11 Dec. 91	Drizzle	48	33
12 Dec. 91	Rain	56	38
13 Dec. 91	Drizzle	55	37
14 Dec. 91	Rain	41	19
15 Dec. 91	Drizzle	28	15
16 Dec. 91	Drizzle	36	19
4 Week Average		47	32

Figure 15. Utah Coal Pellets with Cornstarch from (A) Extrusion and (B) Roller and Die Process, Stored Outdoor-Exposed After 2 Weeks

Table 3. Outdoor - Exposed Storage Effects on Pellets After Two Weeks

No.	Sample Description	Moisture From Storage %	Avg. Compressive Strength (lb _f /cu.in)		Avg. Ro-Tap Durability RDI	
			Production	Storage	Production	Storage
1	Illinois No.6 with Corn Starch - Roller & Die	17	82	134	92	93
2	Illinois No.6 with Shur Bond - Roller & Die	17	47	56	77	73
3	Illinois No.6 with Lignin - Roller & Die	14	61	48	82	66
4	Utah with Corn Starch - Roller & Die	15	82	62	91	74
5	Utah with Corn Starch - Extrusion	16	97	133	83	93

Table 4. Outdoor - Exposed Storage Effects on Pellets After Four Weeks

No.	Sample Description	Moisture From Storage %	Avg. Compressive Strength (lb _f /cu.in)		Avg. Ro-Tap Durability RDI	
			Production	Storage	Production	Storage
1	Illinois No.6 with Corn Starch - Roller & Die	5	82	144	92	95
2	Illinois No.6 with Shur Bond - Roller & Die	8	47	62	77	80
3	Illinois No.6 with Lignin - Roller & Die	10	61	84	82	73
4	Utah with Corn Starch - Roller & Die	12	82	76	91	76
5	Utah with Corn Starch - Extrusion	10	97	131	83	96

- Pellets made with corn starch show excellent potential for survival even after 4 week storage.
- Lignin sulfonate bound pellets show extremely low resistance to survive.
- Shur Bond pellets show excellent resistance to water penetration, but are inferior in strength.

Exposed, Covered Storage Tests. Under conditions similar to outdoor storage testing, pilot scale production pellets were stored but protected from weather conditions such as rain, sun, snow, etc. However, the pellets were exposed to the effects of temperature variations. Photographs of the pellets stored in covered cubicles are shown in Figure 16 A and B. Figure 16 A shows the general layout of the cubicles and Figure 16 B shows the pellets after four week of storage. The temperature recorded during the periods of storage was given earlier in Table 2.

Unlike the exposed outdoor storage, all pellets stored under covered conditions showed excellent structural integrity after 4 weeks. Though pellets made with lignin binder had deteriorated, the damage was far less since there was no direct contact of water under this storage conditions. At the end of 2 and 4 week periods of storage, 15 to 20 pounds of pellets were sampled from storage for pellet and reslurryability evaluation.

Compressive strength and ro-tap durability measurements obtained with the two and four week storage pellets are presented in Table 5 and Table 6, respectively. Clearly, these pellets show increased strength since production. The lignin bound pellets specially show good survivability. Shur-bond bound pellets do not show much variation in strength between storage under covered and exposed conditions.

Silo Storage Tests. The five pilot scale production pellets listed earlier, were also studied for storage effects in silos. Fifteen cylindrical columns (8 in. x 10 ft.) were constructed to simulate the silos. The columns were fitted with a manual gate at the bottom, and were loaded from the top. Figure 17 shows the arrangement of silo-simulation columns. The silo-columns

Figure 16. (A) Layout of Pellets Cubical for Outdoor-Coverage Storage
(B) Pilot-Scale Pellets After 4 Week Storage

Table 5. Outdoor - Covered Storage Effects on Pellets After Two Weeks

No.	Sample Description	Moisture From Storage %	Avg. Compressive Strength (lb/cu.in)		Avg. Ro-Tap Durability RDI	
			Production	Storage	Production	Storage
1	Illinois No.6 with Corn Starch - Roller & Die	5	82	178	92	95
2	Illinois No.6 with Shur Bond - Roller & Die	14	47	45	77	96
3	Illinois No.6 with Lignin - Roller & Die	7	61	84	82	92
4	Utah with Corn Starch - Roller & Die	9	82	75	91	90
5	Utah with Corn Starch - Extrusion	3	97	125	83	96

Table 6. Outdoor - Covered Storage Effects on Pellets After Four Weeks

No.	Sample Description	Moisture From Storage %	Avg. Compressive Strength (lb./cu.in)		Avg. Ro-Tap Durability RDI	
			Production	Storage	Production	Storage
1	Illinois No.6 with Corn Starch - Roller & Die	3	82	158	92	95
2	Illinois No.6 with Shur Bond - Roller & Die	4	47	66	77	80
3	Illinois No.6 with Lignin - Roller & Die	4	61	115	82	96
4	Utah with Corn Starch - Roller & Die	5	82	126	91	92
5	Utah with Corn Starch - Extrusion	2	97	128	83	96

Figure 17. Columns Constructed to Simulate Pellets Storage in Silos

are exposed to weather and temperature variations. The pellets, however, are protected from variations in weather, but are subjected to the temperature variations through the silo-column walls.

Prior to loading the columns, the pellets were screened and all - 1/4 in. fractions were rejected. About 150 pounds of pellets were loaded from the top of the column. After 2 and 4 weeks, 15 to 26 pounds of pellets were sampled from the bottom of the silo-column for pellet and reslurrability evaluation. The pellet samples were also measured for the 1/4-inch fines fraction that was generated during loading and storage in the silo-column.

Results of compressive strength and ro-tap durability measurements obtained with the 2 and 4 week silo-column storage are presented in Tables 7 and 8, respectively. The pellets from the silo-columns, show good strength and durability measurements after 2 and 4 weeks especially with the corn starch bound pellets. Shur-bond pellets show little variations in its strength.

Packing Test. During the quarter, we have conducted tests to evaluate the effects of bagging pellets in super-sack "nylon" bags. The five pilot-scale production pellets were investigated. One hundred pounds of pellets were packed in these nylon bags and were stored exposed to weather and temperature conditions. A photograph of the bags filled with pellets is shown in Figure 18. These bags were closed prior to storage.

Tests identical to outdoor storage tests, were conducted with the bag-stored pellets sampled after 2 and 4 weeks. Tables 9 and 10 present these results. The corn starch bound pellets stored in bags were measured for maximum pellet strength after 4 weeks. Lignin bound pellets also showed comparable survivability characteristics to pellets stored under outdoor-covered conditions.

Figures 19 and 20 compare the strength of all Illinois No. 6 pellets produced by roller and die techniques after 2 and 4 weeks. At the end of 2 and 4 weeks, corn starch-bound pellets measured much higher strengths than

Table 7. Silo-Column Storage Effects on Pellets After Two Weeks

No.	Sample Description	Moisture From Storage %	Avg. Compressive Strength (lb _f /cu.in)		Avg. Ro-Tap Durability RDI	
			Production	Storage	Production	Storage
1	Illinois No.6 with Corn Starch - Roller & Die	6	82	105	92	96
2	Illinois No.6 with Shur Bond - Roller & Die	9	47	30	77	80
3	Illinois No.6 with Lignin - Roller & Die	9	61	66	82	90
4	Utah with Corn Starch - Roller & Die	11	82	111	91	88
5	Utah with Corn Starch - Extrusion	3	97	170	83	97

Table 8. Silo-Column Storage Effects on Pellets After Four Weeks

No.	Sample Description	Moisture From Storage %	Avg. Compressive Strength (lb _f /cu.in)		Avg. Ro-Tap Durability RDI	
			Production	Storage	Production	Storage
1	Illinois No.6 with Corn Starch - Roller & Die	7	82	183	92	93
2	Illinois No.6 with Shur Bond - Roller & Die	10	47	53	77	81
3	Illinois No.6 with Lignin - Roller & Die	9	61	90	82	91
4	Utah with Corn Starch - Roller & Die	13	82	102	91	91
5	Utah with Corn Starch - Extrusion	4	97	179	83	96

Figure 18. Pellet Storage in "Super-Sack" Nylon Bags

Figure 19. Illinois No. 6 Coal Pellet Strength Variations in Different Storage Modes After 2 Weeks

Table 9. Super-Sack Nylon Bag Storage Effects on Pellets After Two Weeks

No.	Sample Description	Moisture From Storage %	Avg. Compressive Strength (lb./cu.in)		Avg. Ro-Tap Durability RDI	
			Production	Storage	Production	Storage
1	Illinois No.6 with Corn Starch - Roller & Die	11	82	116	92	95
2	Illinois No.6 with Shur Bond - Roller & Die	13	47	50	77	78
3	Illinois No.6 with Lignin - Roller & Die	14	61	97	82	88
4	Utah with Corn Starch - Roller & Die	11	82	113	91	93
5	Utah with Corn Starch - Extrusion	3	97	123	83	80

Table 10. Super-Sack Nylon Bag Storage Effects on Pellets After Four Weeks

No.	Sample Description	Moisture From Storage %	Avg. Compressive Strength (lb./cu.in)		Avg. Ro-Tap Durability RDI	
			Production	Storage	Production	Storage
1	Illinois No.6 with Corn Starch - Roller & Die	9	82	299	92	95
2	Illinois No.6 with Shur Bond - Roller & Die	9	47	79	77	78
3	Illinois No.6 with Lignin - Roller & Die	10	61	79	82	78
4	Utah with Corn Starch - Roller & Die	7	82	134	91	92
5	Utah with Corn Starch - Extrusion	2	97	142	83	97

Figure 20. Illinois No. 6 Coal Pellet Strength Variations in Different Storage Modes After 4 Weeks

pellets made with other binders. The corn starch pellets also show continued increase in strength in silos and bags after 2 weeks. Within the first 2 weeks, the curing and setting process is more effective with the pellets that are stored outdoor-covered.

Lignin bound pellets were observed to be well protected when stored outdoors and covered. With bags and silo, the pellets strength and durability showed little change. In the case of Shur-bond bound pellets, the pellets show very little variations in strength after 2 and 4 weeks, for any given storage mode. Although the Shur-bond provides excellent protection of moisture penetration, it definitely lacks strength.

Storage tests conducted with Utah coal show some effect of pelletization method on pellet strength. Figure 21 compares and illustrates the variation. The extruded pellets show higher strength in silos and bags than pellets made via roller and die. Of course, the production strength (cured strength after 1 week) may be a factor. The additional storage test data will allow further evaluation to determine if pellet production method is a significant factor on pellet survivability during storage. But, among the two coals studied in the quarter, there is definite effect of type of coal on pellet storage. Figure 22 compares the four week pellet strength of Illinois No. 6 and Utah coal produced by the roller and die techniques. For the same initial green strength, the Illinois No. 6 coal shows a much greater potential to survive storage in each of the storage modes than Utah coal.

In conclusion, storage is strongly influenced by:

- Binder type
- Coal type
- Method of pelletization.

Figure 21. Comparison of Utah Coal with Cornstarch Pellet Strength Variation After 4 Week for Pellets Produced via Roller-and-Die and Extrusion

Figure 22. Effect of Coal Type on Pellet Strength during Storage

In the next quarter, these storage tests will be continued and pellets will be sampled after 12 week for evaluation. In addition, other pilot-scale pellets will also be investigated. Reference storage data with one raw coal will be generated to compare the deterioration experience with pellets against actual raw-lump coal.

Other packing bags, such as polyethylene and multilayered bags may be studied in the next quarter.

Pellet Uniformity. During pilot scale pellet production the pellets will see varying roller and die temperatures, loading, extruder heat-up rates, feed material variations, etc. Therefore, the purpose of this test was to examine the effect of operational variations on the uniformity of the pellets.

The testing procedure involves:

- Sample 15 pounds of pellet at varying time intervals of production, from the three production techniques for each of the coals
- Measure the pellets's
 - Strength (set)
 - Durability (Ro-tap and tumble)
 - Weatherability
- Evaluate the pellet uniformity with respect to pellet production.

In this quarter, testing has been completed for pilot-scale pellets of the following cases:

- Utah coal extrusion pellets; prepared with cornstarch, lignin, and Shur-bond
- Elkhorn coal roller and die pellets prepared with cornstarch.

Tables 11 and 12 present the pellet uniformity data for the Elkhorn and Utah coal, respectively. The set strength measured after 1 week of pellet production, show good strength with corn starch pellets of both Elkhorn and Utah coals (Tables 11 and 12). Lignin and Shur-bond Utah coal extrusion pellets show inferior set strength characteristics. The durability numbers (DI and RDI) reflect the same trend observed with the strength data. The pilot scale pellets, subjected to freeze and thaw (Weatherability Index) tests show the corn starch-bound pellets to have good WI properties. Lignin bounds pellets disintegrate under WI test conditions. Pellets sampled from production indicate good uniform pellet production with both the pelleting techniques (roller and die and extrusion). In particular in the roller-and-die technique, poor quality in feed mix and processing is usually seen to result immediately in bad pellets with inferior green strength.

Task 7 Reslurry Pellets and Evaluate CWF

The objective of this task is to evaluate the effect of pellet production on slurry formulation and slurry characteristics. The reslurrying amenability tests were completed on 22 Illinois No. 6 roller and die production pellet samples furnished by Battelle. The amenability test provides information concerning the ease and rate at which pellets disintegrate in water and the viscosity of the resulting slurry.

A comparison of the reslurrying results for the Illinois No. 6 roller and die pellets after 8 minutes of dispersion is presented in Table 13. Table 14 is a complete compilation of the test data. The residual amounts of plus 48-mesh fragments in the slurries are also plotted against the moisture contents and crushing strengths of the pellets in Figures 23 and 24, respectively.

The test data show that roller-and-die pellets formed with a water-soluble lignin binder disintegrate more readily than pellets formed with either corn starch or Shur-bond binders. It does not appear from the plotted results that the differences in the rates of disintegration can be attributed

Table 11. Elkhorn Roller and Die Pilot Scale Production Pellet Uniformity

Sample I.D.	Binder, Conc. %	Design-ation	Sampling Time, min	Set Strength, lb _f /in ³		Durability, DI		Ro-Tap Durability RDI		Weather Index WI	
				A.C	Actual	A.C	Actual	A.C	Actual	A.C	Actual
CPM 8-1	Corn Starch 2.75%	AllBond 200	15	100	122	28	25	90	72	60	75
CPM 8-2	Corn Starch 2.75%	AllBond 200	30	100	124	28	23	90	78	60	82
CPM 8-3	Corn Starch 2.75%	AllBond 200	45	100	117	28	23	90	74	60	79
CPM 8-4	Corn Starch 2.75%	AllBond 200	60	100	99	28	21	90	70	60	80
CPM 8-5	Corn Starch 2.75%	AllBond 200	75	100	102	28	17	90	74	60	79
CPM 8-6	Corn Starch 2.75%	AllBond 200	90	100	116	28	27	90	74	60	74
CPM 8-7	Corn Starch 2.75%	AllBond 200	125	100	119	28	24	90	74	60	79
CPM 8-8	Corn Starch 2.75%	AllBond 200	150	100	120	28	13	90	76	60	79

AC: Acceptance Criteria

Table 12. Utah Extrusion Pilot Scale Production Pellet Uniformity

Sample I.D.	Binder, Conc. %	Designation	Sampling Time, min	Set Strength, lb _f /in ³		Durability, DI		Ro-Tap Durability RDI		Weather Index WI	
				A.C	Actual	A.C	Actual	A.C	Actual	A.C	Actual
BE-1	Corn Starch 2.75%	AllBond 200	30	100	110	28	76	90	84	60	81
BE-2	Corn Starch 2.75%	AllBond 200	60	100	93	28	74	90	82	60	78
BE-3	Corn Starch 2.75%	AllBond 200	90	100	120	28	71	90	84	60	82
BE-4	Corn Starch 2.75%	AllBond 200	120	100	124	28	81	90	84	60	80
BE-5	Corn Starch 2.75%	AllBond 200	150	100	22	28	76	90	83	60	72
BE-6	Lignin[1] 2.75%		45	100	73	28	62	90	82	60	0
BE-7	Lignin[1] 2.75%		90	100	70	28	66	90	81	60	0
BE-8	Shur Bond[1] 2.75%		45	100	45	28	42	90	75	60	NA
BE-9	Shur Bond[1] 2.75%		90	100	50	28	46	90	74	60	NA
BE-10	Shur Bond[1] 2.75%		120	100	55	28	48	90	78	60	NA

[1] : Pellet Production Achieved with 0.5-0.7% Corn Starch Additional Binder

Table 13. Reslurrying Amenability Tests on Illinois No. 6 CPM Pellets (2.6 Liter Scale)

Pellet Sample	Binder	Pellet Properties		Dispersion at 8 Minutes						
		Moisture, %	Crush lbf ^a	+48 Mesh, %	Coal, %	A-23, % ^b	Viscosity, cP			
							100 s ⁻¹	500 s ⁻¹	1,000 s ⁻¹	
CPM 1-2	Starch	16.46	84	4.8	55.4	1.10	1,100	700	605	
CPM 1-3	Starch	16.48	71	3.3	53.7	1.20	260	280	295	
CPM 1-1	Starch	15.66	84	3.5	54.1	1.20	300	370	387	
CPM 1-4	Starch	16.45	75	4.0	54.6	1.20	380	380	390	
CPM 1-5	Starch	18.40	84	6.2	56.7	1.20	880	780	750	
CPM 1-6	Starch	12.91	108	6.3	54.1	1.20	325	415	430	
CPM 7-1	Starch	10.09	91	6.8	53.5	1.20	320	335	340	
CPM 7-2	Starch	13.55	76	7.0	55.8	1.20	880	750	690	
CPM 2-1	ShurBond	17.29	39	5.9	54.7	0.74	125	160	185	
CPM 2-2	ShurBond	18.26	38	6.4	56.0	0.74	325	285	310	
CPM 2-3	ShurBond	15.01	35	7.1	55.7	0.74	150	190	225	
CPM 2-4	ShurBond	16.10	45	5.5	54.3	0.74	100	140	160	
CPM 3-1	ShurBond	21.62	48	5.8	56.3	0.74	390	415	430	
CPM 3-2	ShurBond	22.59	53	5.8	55.0	0.74	280	300	320	
CPM 3-3	ShurBond	22.63	62	4.2	56.2	0.74	500	340	325	
CPM 3-4	ShurBond	20.69	55	5.8	55.2	0.74	200	225	240	
CPM 3-5	ShurBond	19.16	54	4.3	53.6	0.74	115	160	175	
CPM 5-1	Lignosite	16.22	56	0.58	55.7	0.70	295	300	320	
CPM 5-2	Lignosite	17.50	65	0.58	57.1	0.68	800	550	540	
CPM 6-1	Lignosite	15.00	50	1.73	55.1	0.70	300	335	350	
CPM 6-2	Lignosite	11.63	56	1.61	54.5	0.70	180	200	235	
CPM 6-3	Lignosite	11.00	76	1.76	55.1	0.70	200	235	250	

^a Fifth quarterly report to DOE.^b Weight percent of coal in slurry.

Table 14. Complete Results of Reslurrying Amenability Tests on Illinois No. 6 CPM Pellets

Pellet Sample	Binder	Mixing Time, Minutes	+48 Mesh, % ^a	Coal, %	A-23, % ^a	Viscosity, cP		
						100 s ⁻¹	500 s ⁻¹	1,000 s ⁻¹
CPM 1-1	Corn Starch	4	6.0	54.1	1.20			
		8	3.5	54.1	1.20	300	370	387
		16	1.6	53.8	1.20	260	290	300
CPM 1-2	Corn Starch (Diluted) (Refined ^b)	8	4.8	55.4	1.10	1,100	700	605
		8	4.8	54.8	1.10	1,325	540	440
			<0.1	-55.0	1.10	High		
CPM 1-3	Corn Starch	8	3.3	53.7	1.20	260	280	295
CPM 1-4	Corn Starch	4	7.2	54.5	1.20			
		8	4.0	54.6	1.20	380	380	390
CPM 1-5	Corn Starch	4	9.6	56.6	1.20			
		8	6.2	56.7	1.20	880	780	750
		8	6.2	55.3	1.20	500	500	495
CPM 1-6	Corn Starch	4	10.0	54.0	1.20			
		8	6.3	54.1	1.20	325	415	430
		16	3.7	54.0	1.20	260	300	312
CPM 2-1	ShurBond	4	10.1	54.9	0.74			
		8	5.9	54.7	0.74	125	160	185
		16	3.4	54.7	0.74	180	150	165
CPM 2-2	ShurBond	4	10.8	56.1	0.74			
		8	6.4	56.0	0.74	325	285	310
		16	3.6	56.0	0.74	510	315	300
CPM 2-3	ShurBond	4	11.2	55.8	0.74			
		8	7.1	55.7	0.74	150	190	225
		16	4.0	55.9	0.74	200	185	205
CPM 2-4	ShurBond	4	9.8	54.4	0.74			
		8	5.5	54.3	0.74	100	140	160
		16	3.1	54.2	0.74	125	125	135
CPM 3-1	ShurBond	4	9.0	56.2	0.74			
		8	5.8	56.3	0.74	390	415	430
		16	3.1	56.3	0.74	480	385	380
CPM 3-2	ShurBond	4	8.6	54.9	0.74			
		8	5.8	55.0	0.74	280	300	320
		16	3.4	54.9	0.74	495	315	295
CPM 3-3	ShurBond	4	7.4	55.2	0.74			
		8	4.2	56.2	0.74	500	340	325
CPM 3-4	ShurBond	4	8.6	54.9	0.74			
		8	5.8	55.2	0.74	200	225	240
		16	3.2	54.9	0.74	325	250	240
CPM 3-5	ShurBond	4	6.7	53.6	0.74			
		8	4.3	53.6	0.74	115	160	175
		16	2.8	53.6	0.74	125	140	150
CPM 5-1	Lignosite	4	1.13	55.6	0.70			
		8	0.58	55.7	0.70	295	300	320
		16	0.12	55.9	0.70	490	310	295
CPM 5-2	Lignosite	4	1.31	57.0	0.68	680	595	600
		8	0.58	57.1	0.68	800	550	540
		8	0.58	55.7	0.68	400	330	332
CPM 6-1	Lignosite	4	3.67	55.1	0.70			
		8	1.73	55.1	0.70	300	335	350
		16	0.61	55.0	0.70	300	265	268
CPM 6-2	Lignosite	4	2.80	54.3	0.70	200	240	260
		8	1.61	54.5	0.70	180	200	235
CPM 6-3	Lignosite	4	3.16	55.1	0.70	220	280	300
		8	1.76	55.1	0.70	200	235	250
CPM 7-1	Corn Starch	4	9.7	53.3	1.20			
		8	6.8	53.5	1.20	320	335	340
		16	3.7	53.2	1.20	290	275	270
CPM 7-2	Corn Starch	4	11.1	55.6	1.20			
		8	7.0	55.8	1.20	380	750	690
		16	3.5	55.4	1.20	1,275	795	670
		16	3.5	54.4	1.20	800	575	515
		16	3.5	54.2	1.20	600	480	435

^a Plus 48 mesh and A-23 reported as weight percent of dry coal in slurry.

^b Refined by passing slurry through a Bico-Braun disc pulverizer. High viscosity of product may have been due to air entrainment.

Figure 23. Weight Percent of Residual Plus 48-Mesh Pellet Fragments Remaining After 8 Minutes Disintegration Time Versus Average Crushing Strength of CPM Pellets Made with Three Binders

Figure 24. Weight Percent of Residual Plus 48-Mesh Pellet Fragments Remaining After 8 Minutes Disintegration Time Versus Average Moisture Content of Pellets Made with Three Binders

to differences in the strengths of the various pellets or to their differing moisture contents.

Figures 25, 26, 27, and 28 are plots of the weight of plus 48-mesh pellet fragments remaining in the slurry versus mixing time when reslurrying CPM pellets made with corn starch, Shur-bond (2 sets), and Lignin binders, respectively. In each case, the plots show that very rapid disintegration of the pellets occurs during the first 4 minutes of mixing in the Cowles dissolver, followed by a relatively constant, but slower, rate thereafter. Averages of the disintegration kinetic data for pellets made with each binder are plotted in Figure 29. Figure 29 illustrates the faster disintegration of Lignin binder pellets in comparison to the disintegration of pellets containing the other two binders.

The amount of A-23 dispersant added during each amenability test was based upon prior experience reslurrying similar pellets. As noted before, larger A-23 additions were required to produce similar viscosities when reslurrying pellets containing the corn starch binder than when reslurrying pellets containing Shur-bond or Lignin binders. An inspection of the viscosity data in Table 14 suggests that longer mixing times usually result in slightly lower viscosities at the 1,000 s⁻¹ shear rate. Results were mixed at the 100 s⁻¹ shear rate. The viscosity often appeared to increase at 100 s⁻¹ with longer mixing time, but that effect may be an indication of air entrainment.

These evaluations and future amenability test results will be incorporated into the pilot scale reslurrying and atomization work scheduled to be conducted in the next quarter.

Task 8 Utilization/Commercialization

No specific effort was undertaken during this quarter. In next quarter, we plan to meet with Pyro Mining, KY, to discuss their experiences in commercial pellet production. In addition, economic assessment of several process operations will be combined in the next quarter.

Figure 25. Disintegration of CPM Pilot Production Pellets Made with Corn Starch Binder

Figure 26. Disintegration of CPM Pilot Production Pellets Made with Shur Bond Binder (First Set)

Figure 27. Disintegration of CPM Pilot Production Pellets made with Shur Bond Binder (Second Set)

Figure 28. Disintegration of CPM Pilot Production Pellets made with Lignosite Binder

Figure 29. Comparison of Averaged Data for Disintegration of Roller-and-Die Pilot Scale Pellets Containing Corn Starch, Shur Bond, and Lignin Binders

Task 9 Prepare Additional Filter Cake

In this quarter, approximately 4 tons of Upper Elkhorn No. 3 coal from the Wentz preparation plant were cleaned in the Amax R&D flotation system. The 8,415 pounds of filtered clean coal was shipped to Batteile in two lots on November 6 and November 11, respectively. The combined production contained 6,149 pounds of dry coal and averaged 26.9 percent moisture. Details of the clean coal production are given in Table 15, and the particle size distribution of the filter cake is given in Table 16.

PLANNED FUTURE ACTIVITIES

Work in the seventh quarter will involve completion of Tasks 3, 4, 5, 6, and 7. (Task 9 was completed in the sixth quarter.) Work will also be initiated on Task 8 (Utilization/Commercialization). Planned are a visit to an operating commercial roller-and-die coal pelletization plant associated with a fine-coal preparation plant (Pyro Mining), and a re-assessment of the initial cost estimates for pellet production. The cost estimates will also be expanded to include the costs for storage, handling, and especially transportation, and reslurrying.

Specifically we plan to:

- Complete disk pelletization pilot-scale pellet production
- Complete storage and handling evaluations of the pilot-scale pellets produced
- Complete reslurrying evaluation, including the development of a pellet-to-slurry system
- Complete the final round of pellet-slurry production and atomization tests
- Evaluate the potential to produce a super pellet -- one containing all the ingredients so that all is need for slurry formulation is to add water
- Complete the pellet production, storage, handling, transportation, and reslurrying cost evaluation for the three processes and the three coals

- Prepare papers for the Institute of Briquetting and Agglomeration, and for the Conference on Coal Utilization & Slurry Technologies
- Prepare a video tape explaining the program, accomplishments, and remaining tasks.

SUMMARY

Significant accomplishments achieved during the sixth quarter include:

- Preferred binder dosage rates were established for the various coals and pelletization processes
- Pilot-scale roller-and-die, and extrusion Illinois No. 6 and Utah coal production were initiated and completed
- Pilot-scale disk pelletization was initiated
- Pellet reslurrying system was designed with expected assembly early in the seventh quarter
- Over 8,415 lb of froth-flotation cleaned Elkhorn coal (6,149 lb dry equivalent) and an additional 4,155 lb of Utah coal (2,915 lb dry equivalent) was prepared and delivered for pilot-scale pellet production
- The project is approximately 1 month behind schedule and on budget. The delay was due to the decision to produce larger quantities of pellets to obtain more realistic pelletization data. The delay will not affect the project budget or planned completion date.

Table 15. Flotation of Micronized Upper Elkhorn No. 3 Coal
(October - November 1991)

<u>Circuit Configuration</u> Four 1 cubic foot Hazen-Quinn subaeration cells arranged in one bank, no separate conditioner cell, four active aerated cells.	
<u>Flotation Feed</u>	
Dry Coal, lb/hr	113.9
Slurry, lb/hr	4,751
Dry Ash, %	3.03
Solids, %	2.4
<u>Reagents</u>	
Dowfroth 250, ppm slurry	9.5
Dowfroth 250, lb/t dry coal	0.93
Diesel Fuel, lb/t dry coal	0.92
<u>Nominal Retention</u>	
Time, minutes	3.2
<u>Clean Coal</u>	
Dry Ash, %	1.48
Weight Yield, %	78.8
Combustible Recovery, %	80.1
Filter Cake Moisture, %	26.9
<u>Residue</u>	
Dry Ash, %	8.08

Table 16. Particle Size Distribution of Upper Elkhorn
No. 3 Clean Coal in Filter Cake

Particle Size, Micrometers	Weight Passing, %
75	99.90
53	99.66
45	99.20
38	98.77
30	95.27
20	80.61
15	67.27
10	40.29
8	27.56
6	15.20
4	6.95
3	4.29
2	2.44
1	0.84
Mass Mean Diameter, Micrometers	13.8

APPENDIX A

RESLURRYING AMENABILITY TEST PROCEDURE

APPENDIX A

RESLURRYING AMENABILITY TEST PROCEDURE

Revised October 28, 1991

OBJECTIVE

Provide a standard procedure for preparing slurries so that the reslurrability of test pellets may be compared. The principal basis for comparison will be the ease (or rate) at which pellets can be disintegrated.

APPARATUS

1. Cowles laboratory dissolver, Model 1-VG, 0 to 4,500 rpm, 3-inch diameter Hi-Shear serrated edge impeller (0 to 3,500 fpm tip speed) set 1-1/2 inches above bottom of container or at 1/2 slurry depth whichever is less, 7-inch diameter container with baffles, usual slurry depth = 4 inches (2.5 liters - 1,600 g dry coal).
2. Three-inch diameter, 48-mesh (0.3 mm opening) test sieve and vibrator.
3. Fann viscometer and glass thermometer.
4. Coal drying oven and 3-place balance.

STEPS IN PROCEDURE

1. Determine moisture in pellets.
2. Weigh out sufficient pellets to contain 1,600 grams dry weight (wet pellet weight = $1,600 * 1000 / (100 - \text{percent moisture in pellets})$). Prorate pellet, water, and dispersant additions in the event 1,600 grams dry weight of pellets are not available.
3. Calculate total weight of 55 percent coal + binder slurry to be produced from pellets ($1,600 / 0.55 = 2,909$ grams).
4. Calculate weight of A-23 solution required for 1,600 grams of coal + binder. (A-23 solution = $1,600 * \text{addition rate percent} / 43$.)
 - a. Normally use addition rate of 1.2 percent A-23 for pellets with the starch binder.
 - b. Normally use addition rate of 0.74 percent A-23 for pellets with Shur Bond or lignin binders.
5. Calculate additional amount of water needed (additional water = $2,909 - \text{wet pellet weight} - \text{A-23 solution weight}$).

A-2

6. Clamp 7-inch diameter container into dissolver with impeller in position.
7. Place additional water (Step 5), A-23 solution (Step 6), and pellets (Step 2) into container.
8. Cover container to catch splashes during start-up. Run impeller 4 minutes at 4,500 rpm. Stop and dip out about 90 ml for sieve test. Resume mixing for another 4 minutes (8 minutes total). Stop and dip out 90 ml for viscosity and sieve test. Add 9 ml water to make-up for evaporation (14 ml for starch binder pellets). Resume mixing for another 8 minutes (16 minutes total). Stop and remove container from machine. Place slurry into capped plastic sample containers.
9. Perform viscosity test on 8-minute and 16-minute slurry samples shortly after collection. Include a temperature measurement. Also dry between 2 and 7 grams of each sample for moisture/percent solids determination. Calculate coal + binder loading from percent solids $[\text{coal} + \text{binder} = \text{percent solids} * 100 / (100 + \text{A-23 addition percent rate})]$.
10. Perform sieve tests on 4-minute, 8-minute, and 16-minute slurry samples. (Weigh slurry sample onto a tared 48-mesh sieve. Gently wash with a small stream of water from a wash bottle while vibrating the sieve. Dry and weigh residue while on sieve. Compare with the calculated dry weight of the slurry sample.)
11. Report coal loading and percent plus 48 mesh for 4-minute sample and the coal loading, percent plus 48 mesh, and viscosities at 100, 500, 1,000 s-1 for the 8- and 16-minute samples. (Viscosity measurements on 4-minute samples are erratic because of the size of the pellet fragments remaining in those samples.)

END

**DATE
FILMED**

9 / 17 / 92