DOE/PC/90166--T6

CONTRACT NO. DE-AC22-90PC90166

# REPORT

FINAL QUARTERLY TECHNICAL

PROGRESS REPORT NO. 5

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

To

U.S. DEPARTMENT OF ENERGY

PITTSBURGH ENERGY TECHNOLOGY CENTER

NOVEMBER 21, 1991



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

Contract No. DE-AC22-90PC90166

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Battelle
505 King Avenue
Columbus, Ohio 43201-2693

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

Date Submitted: November 21, 1991

Prepared for

PETC Project Manager: Anthony E. Mayne

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

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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

During this quarter, we have:

- Completed pilot scale pellet production of Illnois No. 6 coal via roller and die technique at California pellet mill. Pilot scale pelletization of Utah coal is currently underway.
- Determined binder dosages for pilot scale pelletization, through a series of laboratory scale binder dosage optimization work.
- Decreased cornstarch dosage for pilot scale pellet production from 3 percent to 2 percent (~ 33 percent decrease).

In addition, plans for leasing a pilot scale extruder and a pilot scale disk pelletization have been completed. Appropriate production units have been identified and lease agreements with equipment suppliers are in place. Both the extruder and disk pelletizer should be in operation in the early part of the next quarter. Work is proceeding as scheduled and all pilot scale pelletization should be completed by early December.

Future work will concentrate on completing pilot scale pelletization of clean coal via roller-and-die, extrusion, and disk and to obtain initial evaluation of their storage, handling, transportation, and slurrability properties.

## 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 formulated into coal water fuels (CWFs) 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 slurried into a CWF that can be suitably atomized and fired at the user site. The wet cakes studied are being prepared from ultra-fine (95 % -325 mesh) coal beneficiated by advanced froth-flotation techniques. The coals studied include one eastern bituminous coal from Virginia (Elkhorn), one midwestern coal from Illinois (Illinois No. 6), and one western bituminous coal from Utah (Sky Line coal).

The Battelle/AMAX team is emphasizing two approaches to 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 pelletized, to form a "coal capsule," or pellet, that can be readily stored, handled, and transported under specialized (i.e., less severe) conditions. 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.**

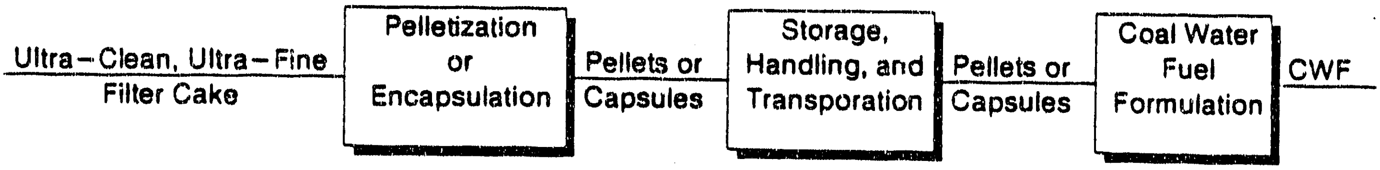


FIGURE 1. PROJECT CONCEPT

More specifically the project activities include the following 10 tasks:

- Task 0 - Acquire Coal (Completed)
- Task 1 - Identify Technology (Completed)
- Task 2 - Prepare and Test Small Batches (Completed)
- 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 is shown in **Figure 2.** Details of the work breakdown structure and the planned duration of the various project activities are included in the figure. Work in this quarter covered Tasks 3 and 9. This status section summarizes activities and accomplishments for these tasks plus planned activities for the associated tasks.

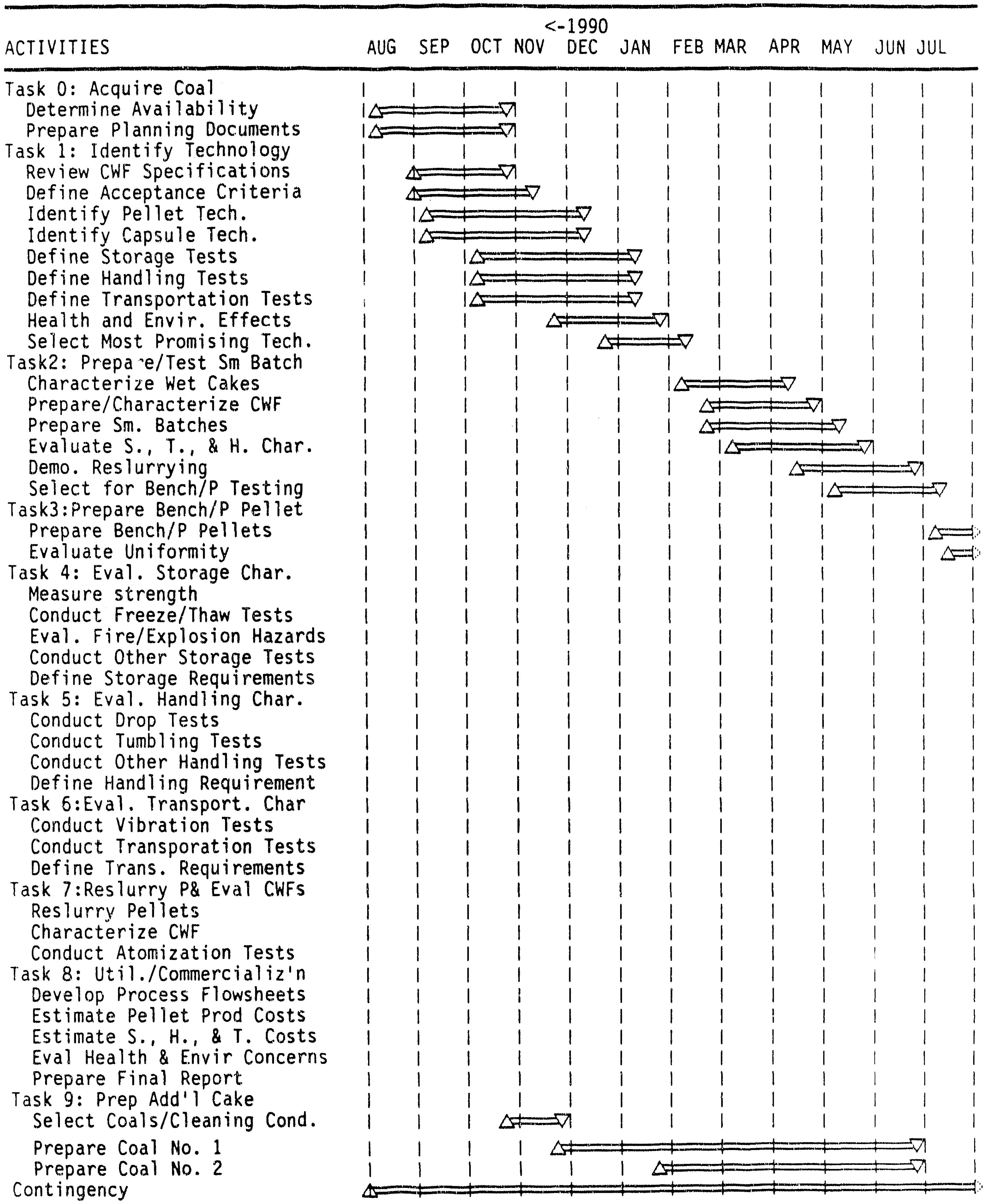


FIGURE 2. SCHEDULE FOR S. T. & H. OF COALS

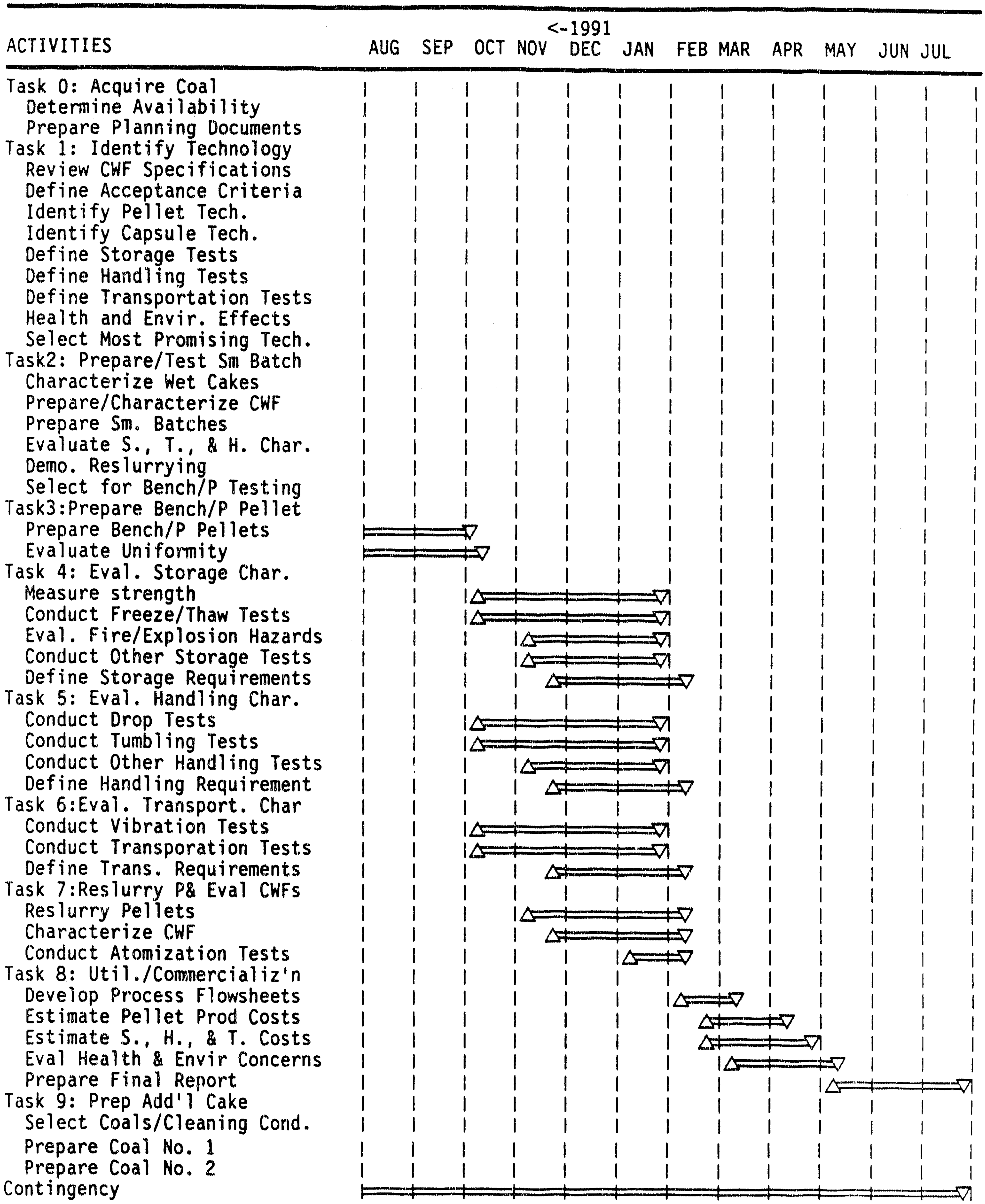


FIGURE 2. SCHEDULE FOR S. T. & H. OF COALS
(Continued)

## Task 3 - Prepare Pilot-Scale Pellets

### Pellet Production

During this quarter, activities emphasized (1) binder dosages optimization and (2) pilot scale pellet production. Pilot scale roller and die pellets were made with Illinois No. 6 and Utah coals. Limited tests were also conducted to evaluate spray coating as a means of low cost encapsulation.

**Binder Optimization**. Bench scale roller and die, disk, and extrusion techniques, pelletization tests showed that pellet properties like set strength and durability were greater than the acceptance criteria. These pellets typically had either 3-percent cornstarch, 5-percent Shur-bond, or 3-percent lignin sulfonate binders. Therefore, prior to pilot scale pellet production, the pellet binder dosage levels were optimized to minimize binder usage while still meeting the acceptance criteria. This optimization evaluation was conducted with Illinois No. 6 and coal cornstarch binder. Table 1 lists the results of this study.

This study determined the minimum acceptance dosage level based on the set strength and durability measurements. Although other pellet properties are important to determine the quality of the pellets, the set strength and durability measurements are considered the most important, as they most directly affect the pellet's storage, handling, transportation characteristics. A cornstarch binder dosage between 1.75 - 2.00 percent was found to be sufficient to meet the minimum acceptance criteria.

All pilot scale roller and die pellet production tests were made at the following recommended binder dosage levels:

| | |
|---|---|
| Cornstarch | 2 percent |
| Shur-Bond | 4.5 percent |
| Lignin-Sulfonate | 3 percent. |

TABLE 1. CORNSTARCH BINDER OPTIMIZATION STUDY WITH ROLLER AND DIE PELLETIZATION

| Coal | Binder and Dosage | Set Strength, $lbs/in^3$ | | Durability, % DI | | Ro Tap Durability, % | |
|---|---|---|---|---|---|---|---|
| | | M.A.C.[1] | Actual | M.A.C. | Actual | M.A.C. | Actual |
| Illinois No. 6 | Corn Starch 1.0 % | 100 | 120 | 28 | 20 | 90 | 85 |
| | Corn Starch 1.5 % | 100 | 149 | 28 | 32 | 90 | 87 |
| | Corn Starch 1.75 % | 100 | 147 | 28 | 33 | 90 | 90 |
| | Corn Starch 2.0 % | 100 | 175 | 28 | 39 | 90 | 91 |

(1) M.A.C.: Minimum Acceptance Criteria, established at the beginning of the program.

The lignin sulfonate and Shur-Bond dosages recommended, do not reflect an optimized dosage level, but were based on the results of bench scale tests conducted during the second and third quarters. Optimization tests for these binders are scheduled for early next quarter.

Encapsulation. Encapsulation of clean coal into capsules is a possible low cost method of reconstitution. Pellets are coated with a protective medium. Work during this quarter was initiated to identify technique of encapsulation and encapsulating medium. Tests were conducted with Utah coal. Three, low to average costing coating mediums were tested. They included

- Cornstarch emulsion
- Commercial hairspray
- Shur-Bond emulsion.

The testing method, basically involved preparing 1/2- to 1-in. disk spheres in a disk pelletizer (Voller mixer) without any binder mixed with the raw feed coal. The spheres were then sprayed with one of the above three coating media; one set with a single coating, and another set with double coating. The capsules were then thermally dried. Figures 3 and 4 show photographs of the capsules prepared with cornstarch and with commercial hairspray.

The cornstarch coated capsules show structural deformation of the coating. The capsular layer (starch) peeled-off, and did not adhere to the fine coal. This was evident with both the single and double spray coatings. With hairspray (Figure 4) the capsules stayed intact without structural deformation; but, they had low set strength ($\sim$ 5 lbs/in$^3$) and most of them failed the 1-feet drop test. Shur-Bond also proved to be a poor coating medium. During the thermal drying process, the Shur-Bond coating physically melted and formed a sticky substance.

FIGURE 3: CORNSTARCH ENCAPSULATED UTAH COAL

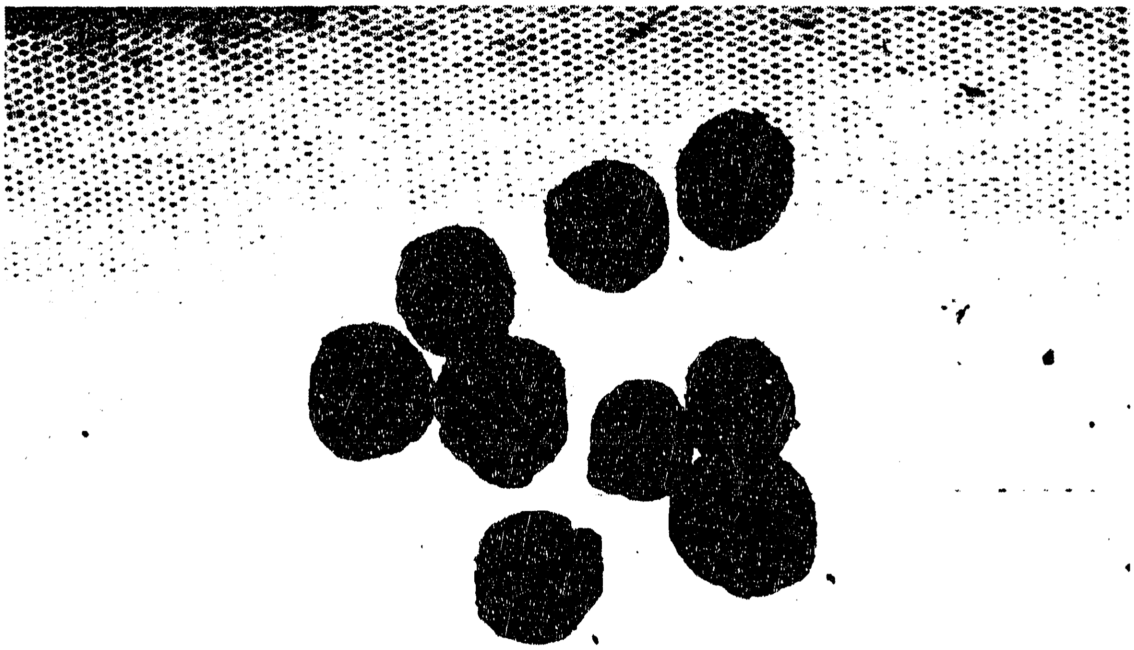

FIGURE 4. HAIRSPRAY ENCAPSULATED UTAH COAL

No acceptable encapsulating mediums were identified. Work will continue through the next quarter at a low level to explore other options.

**Roller and Die Pelletization**. Pilot scale roller and die pelletization was started during this quarter. Work was initiated at California Pellet Mill (CPM) in Crawfordsville, Indiana. The pilot scale pelletizer differed in two areas from the bench scale unit used in Task 2; (1) larger pellet size (3/4-inch diameter versus 1/2-inch diameter) and (2) higher pellet discharge temperature (180 F versus 120 F). The objective was to prepare 2500 lbs of pellets from each coal. The following table outlines the combination of coal and binder pellets that are targeted to be made at CPM via roller and die technique.

TABLE 2. R&D PILOT-SCALE PELLET PRODUCTION-TESTS

| Coal | Corn Starch | Shur-Bond | Lignin Sulfonate |
|---|---|---|---|
| Illinois No. 6 | X | X | X |
| Utah | X | X | |
| Elkhorn | X | X | |

In this quarter, tests were conducted with the Illinois No. 6 coal series, and the Utah coal pellets with cornstarch binder. Other pelletization tests are scheduled in November when the remaining clean coal supply is received.

**Illinois No. 6 Coal Pelletization**. All pelletization via roller and die technique was done in CPM's large-scale pelletizer. The pelletizer can produce pellets at rates of approximately 300 lbs/hr. The production scheme is shown in Figure 5.

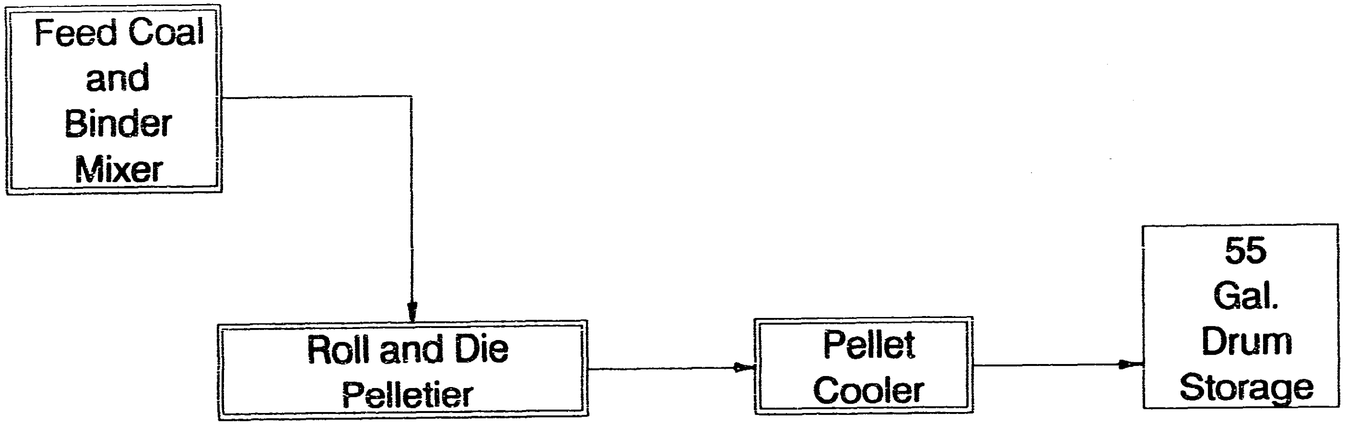


FIGURE 5. ROLLER & DIE PELLETIZATION SCHEME AT CPM

The pelletizer, shown in Figure 6, was fitted with a 3/4-in. die. The pelletizer's shear knife inside the pelletizer was set to make 1- to 2-in. long cylindrical pellets. Figure 7, shows the pelletizer producing Illinois No. 6-cornstarch pellets. The general pelletization procedure involved:

- Blending the clean coal and binder in a mixer and adjusting the moisture level
- Feeding the mix into the pelletizer
- Producing pellets that have sufficient green strength and pass the drop test
- Cooling the hot pellets from the pelletizer, and
- Storing the pellets in 55 gallon containers for transport back to Battelle.

**Utah Skyline Coal Pelletization**. Similar to the pelletizing operation of Illinois No. 6 coal, the pilot scale pelletization of Utah coal with cornstarch binder was conducted and completed during this quarter. Figure 8, shows the pellets sampled from the production stream.

Using the selected coals and binder combinations, this production process has been successful. Cornstarch produced pellets with the greatest green strength and drop resistance. Lignin sulfonate and Shur-Bond bound Illinois No. 6 coal pellets were also acceptable. However, Shur-Bond bound Utah pellets could not be prepared. Several possible explanations were identified and are listed below:

- The Shur-Bond thermally degraded in the pelletizer
- Binder not adequately mixed
- Shur-Bond binder properties were inconsistent
- Utah coal has significantly different properties than other eastern coals.

The cause of failure will be investigated during the next quarter.

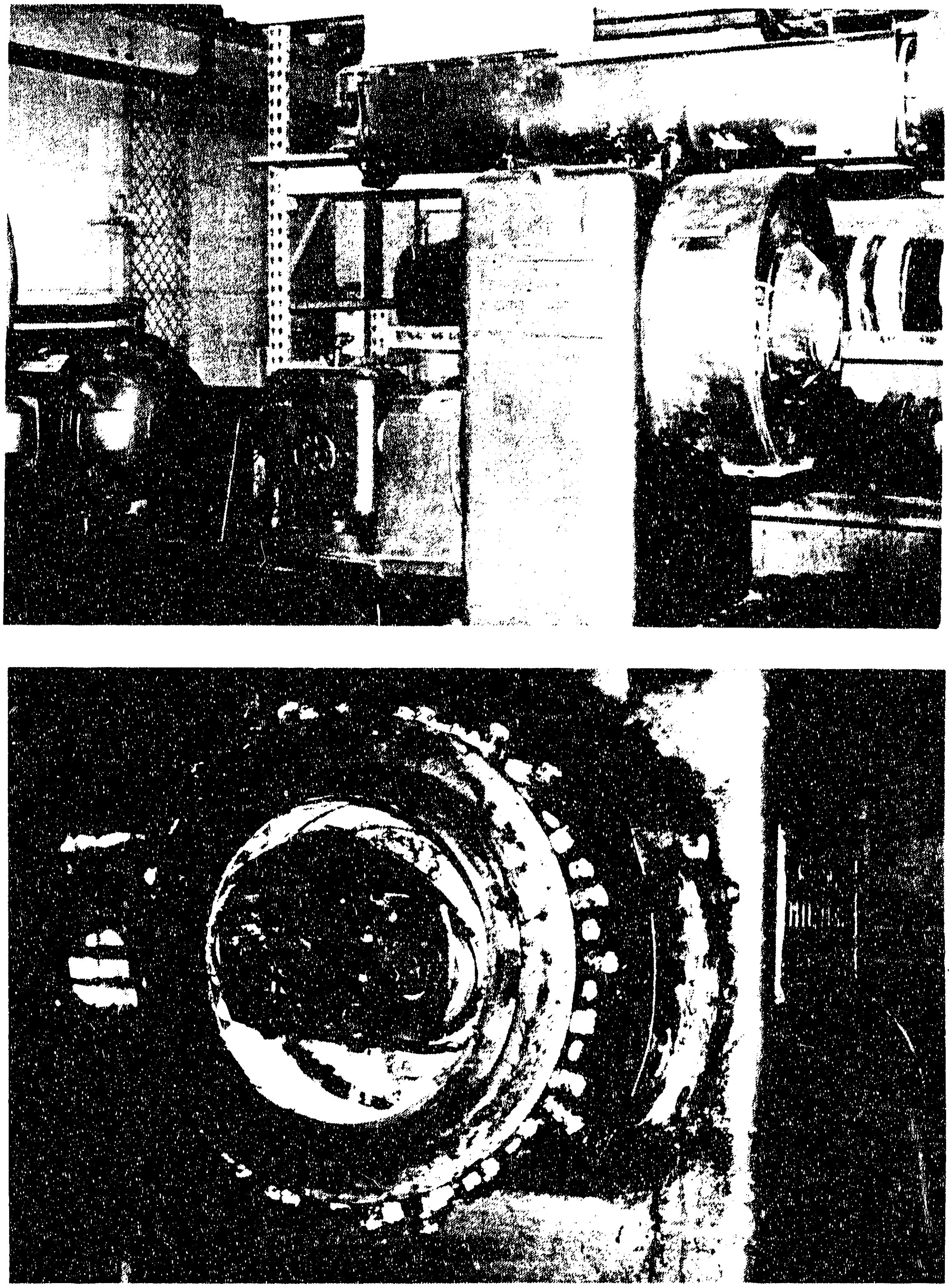

FIGURE 6. PHOTOGRAPH OF CPM's COMMERCIAL PELLETIZER AND A VIEW OF THE PELLETIZER'S ROLLER AND DIE

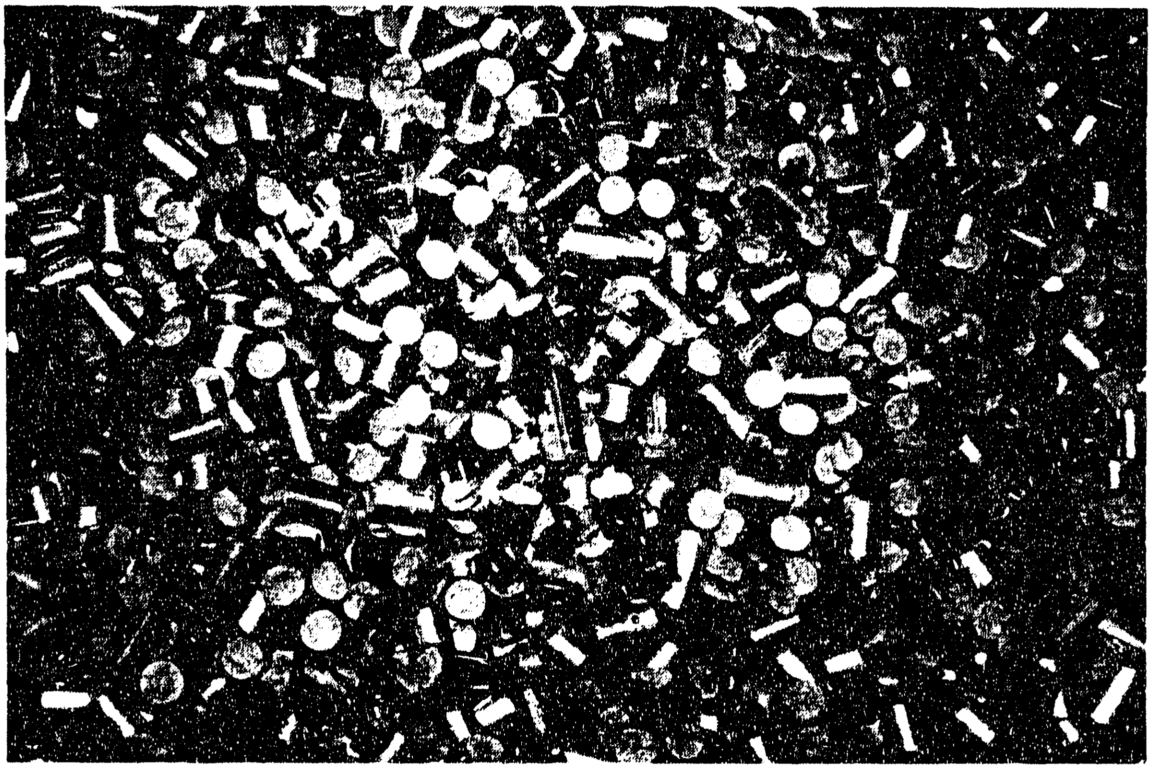

FIGURE 7. ILLINOIS NO. 6 CORNSTARCH PILOT-SCALE PRODUCTION PELLET

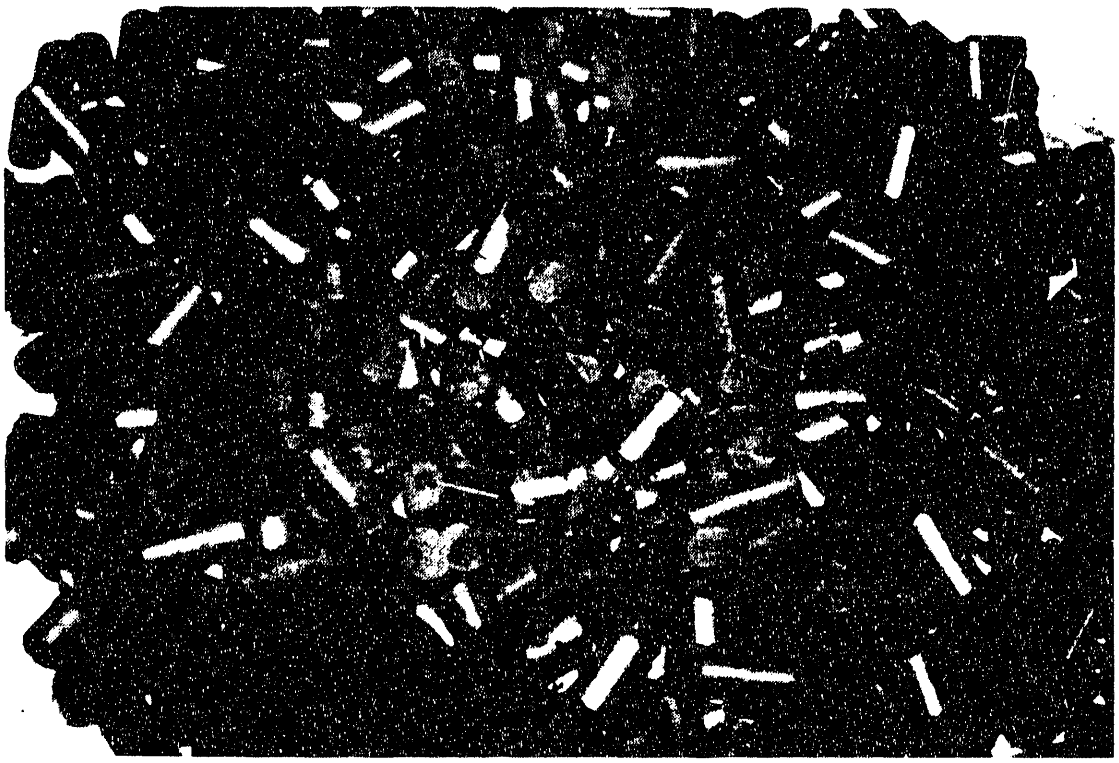

FIGURE 8. UTAH SKYLINE COAL AND CORNSTARCH PILOT-SCALE PRODUCTION PELLETS

**Disk Pelletization**. During this quarter, Andritz Sprout-Bauer (ASB) was identified to be a potential pilot scale disk-pellet producer. A feasibility evaluation was conducted at ASB using their small, 100 lbs batch unit. Strong, durable Illinois No. 6 coal pellets with cornstarch binder were made.

Figure 9 is a photograph of the disk pelletizer. Figure 10 shows the disk pelletization process. Samples of Illinois No. 6 coal pellets with cornstarch made in the small unit is shown in Figure 11. The pellets were made relatively quickly and required a moisture level of approximately 40 percent for nucleation and growth. The spherical disk pellets were typically between 3/8- to 3/4-in. in diameter.

Table 3, presents the results on the set strength and durability of these disk pellets.

TABLE 3. DISK PELLETIZATION-FEASIBILITY TEST RESULTS

| Coal | Binder | Strength, lbs/in$^3$ | Durability, % | |
|---|---|---|---|---|
| | | | DI | Ro Tap |
| Illinois No. 6 | Corn Starch @ 3 % | 92 | 46 | 81 |

The one-week set strength of the disk pellets approached the desired level (100 lbs/in$^3$). Based on the positive results of the small unit tests, a 5-ft diameter Model 1000 disk pelletizer was leased from ASB for pilot scale pellet production at Battelle. The pelletizer is expected to arrive in the first week of November. The planned coals and binders to be evaluated are shown in Table 4.

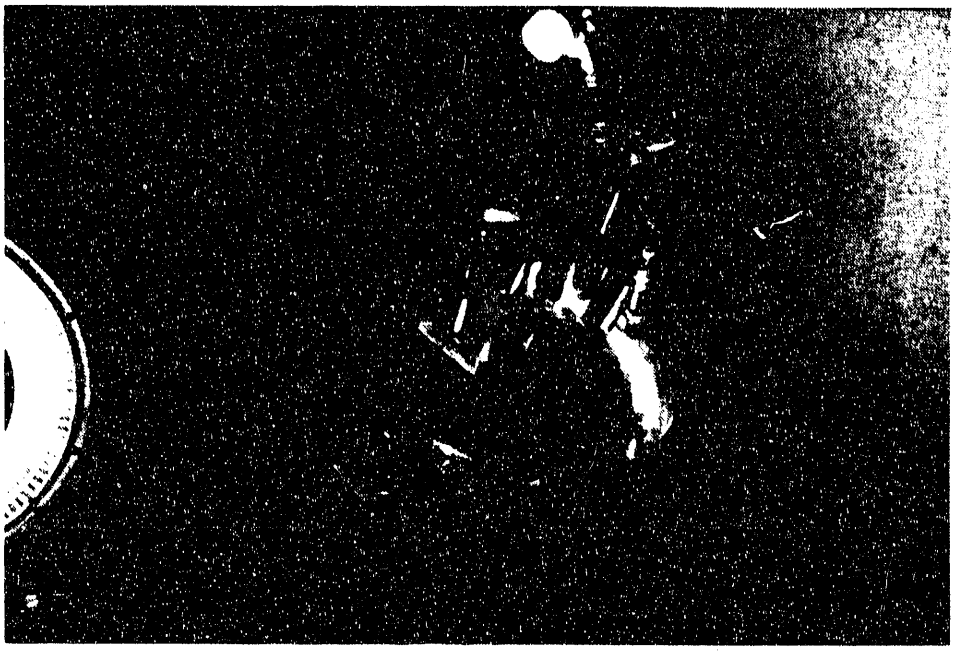

FIGURE 9. ANDRITZ SPROUT-BAUER'S DISK PELLETIZER

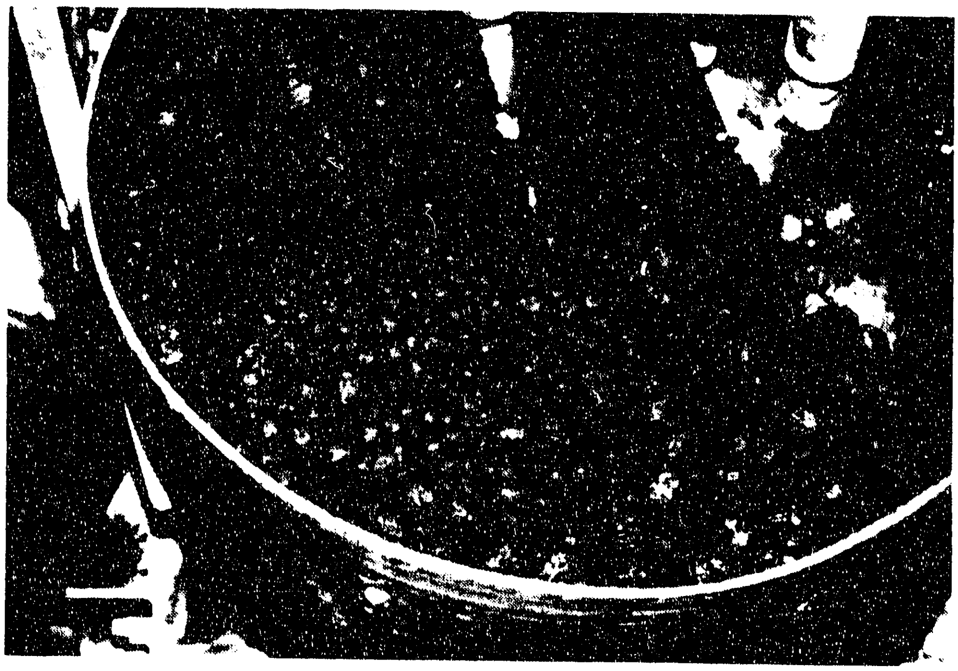

FIGURE 10. DISK PELLETS PRODUCTION AT ASB

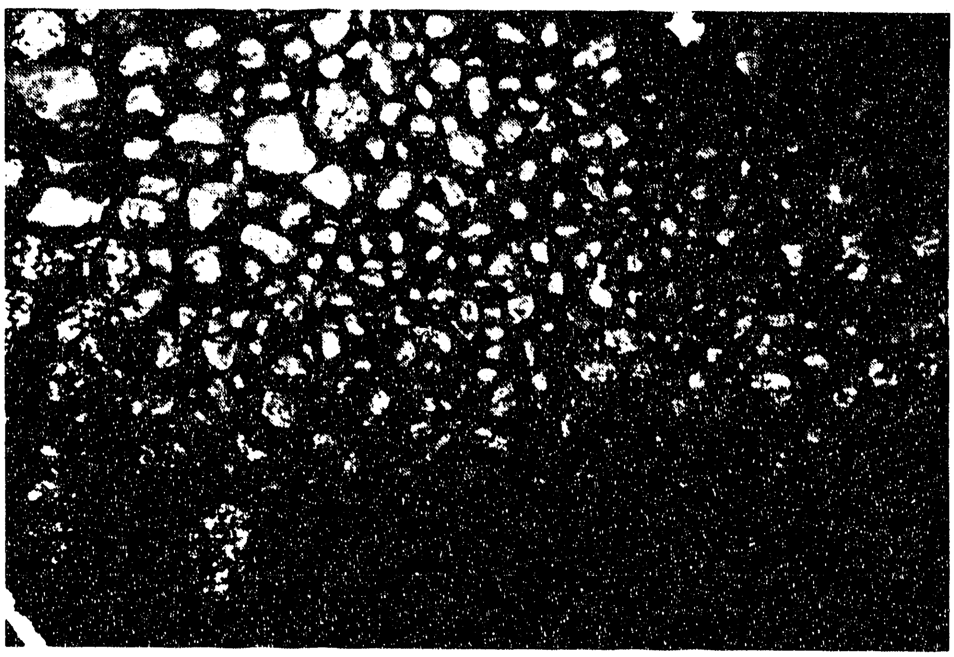

FIGURE 11. ILLINOIS NO. 6 WITH CORNSTARCH DISK PELLETS SAMPLE

TABLE 4. PILOT SCALE DISK PELLETIZATION TESTS

| Coal | Cornstarch | Shur-Bond | Lignin Sulfonate |
|---|---|---|---|
| Illinois | X | X | |
| Elkhorn | X | X | X |

Thermal drying of disk pellets is required for commercial disk pelletization. A natural gas fired drying unit has been installed at Battelle for this service.

**Extrusion Pelletization**. A 4-in. extruder has been leased from the Bonnet Company for extrusion at Battelle. The unit, along with a dryer, is ready for production. Pilot scale extrusion tests with Utah coal will be conducted with cornstarch and Shur-Bond binders in late October.

## Slurry Production

The objective of this effort is to demonstrate that the pellets can be successfully converted into good quality slurry. In this quarter we have focussed to improve the technique of reformulating coal pellets to coal-water-slurry. In addition, Amax is also developing a continuous "pellet-to-slurry" reformation circuit. It is expected that this effort will involve developing a low cost reslurrying apparatus that could be used in future slurry evaluation test at University of Alabama. Amax has completed several reformulation tests to understand the slurry production method. Reslurring tests were made with cornstarch bound Utah disk pellets (from bench scale pellet production). Two tests were made using a Cowles dissolver to determine the mixing time required to make usable slurry starting with as-received pellets and calculated amounts of water and dispersant. The first test was at 1500 rpm and the second was at 3200 rpm using a 5-inch diameter container. Slurry samples were collected after 2, 4, 8, and 16 minutes of mixing. To determine the percentage of coarse pellet fragments (i.e., material too large to be included with the slurry) the samples were washed on a 48-mesh sieve. Slurry viscosities were measured at the end of each test. The results are summarized in Table 5. Copies of the rheograms are attached in Appendix A.

As shown in Table 5 and the rheograms, dispersion at 1500 rpm required considerable time (at least 16 minutes), and the initial product was thixotropic. The thixotropic character was reduced by diluting the slurry with water which also lowered the slurry viscosity. For this reason, the amount of A-23 dispersant used in the follow-up test at 3200 rpm was reduced to 1.3 percent of the dry coal weight and the amount of water added was increased slightly. The resulting slurry was less dilatant and less thixotropic. The higher speed also reduced the amount of residual pellet fragments in the slurry.

On the basis of the recommendation from the Cowles dissolver's manufacturer, a slightly larger sample container (7-in. ID) was tried. A dispersion test was made on 1600 grams (dry weight) of a bench scale pellet sample of 3 percent starch Illinois No. 6 roller and die pellets. Dispersion was accomplished in about the same length of time as before despite the fact that the sample size had almost quadrupled. The results are given in Table 6 and the rheogram in Appendix A. The slurry after 16 minutes had a lower viscosity than the target of 500 cP and it appeared to be very stable and not thixotropic.

TABLE 5. RESLURRYING ILLINOIS No. 6 SPHERICAL PELLETS CONTAINING 1.5 % STARCH BINDER (PILOT-SCALE PRODUCTION PELLETS)

| | First Run | Second Run |
|---|---|---|
| Pellet Weight, grams | 500 | 573 |
| Pellet Moisture, % | 21.7 | 21.7 |
| Water, ml | 212 | 246 |
| A-23, % of Dry Pellet | 1.5 | 1.3 |
| Slurry Volume, liters | 3 | 3 |
| Mixer Blade, type | Serrated | Serrated |
| Mixer Speed, rpm | 1200 | 3200 |
| PLUS 48-MESH FRAGMENTS IN SLURRY, DRY WEIGHT % | | |
| 2 Minutes | 12.2 | 9.8 |
| 4 Minutes | 10.4 | 3.8 |
| 8 Minutes | 6.3 | 1.9 |
| 16 Minutes | 4.2 | |

| | ORIGINAL | 1st DILUTION | 2nd DILUTION | 3rd DILUTION | ORIGINAL |
|---|---|---|---|---|---|
| FINAL SLURRY | | | | | |
| Coal Plus Binder, % | 56.2 | 54.5 | 53.3 | 52.4 | 55.9 |
| Mixing, Minutes/Liter | 32 | 32 | 32 | 32 | 13 |
| Viscosity, cP | | | | | |
| 100 $s^{-1}$ | 400 | 200 | 125 | 85 | 430 |
| 500 $s^{-1}$ | 715 | 345 | 215 | 140 | 655 |
| 1,000 $s^{-1}$ | 795 | 405 | 257 | 168 | 720 |
| Rheology | Dilatant Thixotropic | Dilatant Thixotropic | Dilatant Slightly Thixotropic | Dilatant Slightly Thixotropic | Dilatant Thixotropic |

TABLE 6. RESLURRYING ILLINOIS No. 6 ROLLER AND DIE PELLETS CONTAINING 3 PERCENT CORNSTARCH BINDER

| Reslurrying Conditions | |
|---|---|
| Pellet Weight, grams | 1835 |
| Pellet Moisture, % | 12.79 |
| Water, ml | 1006 |
| A-23, % of Dry Pellet | 1.3 |
| Slurry Volume, liters | 2.5 |
| Mixer Blade, type | Serrated |
| Mixer Speed, rpm | 4500 |
| PLUS 48-MESH FRAGMENTS IN SLURRY, DRY WEIGHT % | |
| 2 Minutes | 13.2 |
| 8 Minutes | 7.3 |
| 16 Minutes | 3.5 |
| Slurry Properties | |
| Coal Plus Binder, % | 55.5 |
| Mixing, Minutes/Liter | 6.4 |
| Viscosity, cP | |
| 100 $s^{-1}$ | 200 |
| 500 $s^{-1}$ | 200 |
| 1,000 $s^{-1}$ | 210 |
| Rheology | Near Newtonian<br>Not Thixotropic |

When compared with the earlier reslurrying test at lower rpm (3200 rpm), higher speed was not shown to improve reslurrying, see below:

| | At 3,200 rpm | At 4,500 rpm |
|---|---|---|
| Pellets, % Cornstarch | 1.5 | 30 |
| Volume, Liters | 0.6 | 2.5 |
| Dispersion, Minutes/Liter | 5.7 | 6.4 |
| Plus 48-Mesh Fragments, % | 3.8 | 3.5 |

The comparison shows that at about the same mixing time per unit volume, the amount of pellet fragments remaining in the slurries was about the same despite the difference in impeller speeds.

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

Table 7 summarizes the test plan for evaluating the pilot scale pellets. Most of the tests are linked closely with each other in the evaluation procedure, and have a direct impact on storage, handling, and/or transportation. Therefore, the tests and results will be reported together. Separate recommendations will, however, be provided at the completion of Tasks 4, 5, and 6 on the storage, handling, and transportation characteristics.

**Vibration Test**. The purpose of this test is to understand the survivability characteristics of the pellets when subjected to the forces and movements the pellets experience during transportation and handling. Since it is impractical to produce hundred ton quantities of pellets to directly measure these effects, small scale tests have been devised.

TABLE 7. TASK 4-7 TEST PLAN

| | TYPE OF TEST | TEST DESCRIPTION/REMARKS | PURPOSE |
|---|---|---|---|
| 1 | Vibration | - Test unit built<br>- Established a reference data base with Illinois No. 6 raw coal<br>- Quantify the fines generated from pellets and its raw coal | Simulation of handling and transportation characteristics |
| 2 | Humidity | - 5 tests for each coal/binder combination | Simulation of transportation and storage characteristics |
| 3 | Heat-cycle | - Test for the temperature spontaneous combustion | Simulation of transportation and storage characteristics |
| 4 | Outdoor and silo storage | - Sample 8 lbs after 1, 2, 4, 12, and 25 week<br>- Evaluate pellet strength and slurry quality | Storage Characteristics |
| 5 | Packing | - 3 bags made of various types of materials<br>- 50 lbs of pellets required for each bag | Storage evaluation |
| 6 | Pellet uniformity | - Sample 3 lbs of pellets from every 150 lbs of pellet production<br>- Check for strength, durability, weatherability, and other routine data | Pellet quality evaluation |
| 7 | Slurry uniformity | - Sample 5 lbs of pellets from every 150 lbs of pellet production<br>- Check for consistency of slurry preparation in terms of dosage, viscosity, etc.<br>- Simplified reslurrying procedure may be employed | Evaluation of slurry quality |

The following testing is planned:

- Design a vibration simulation test unit to handle ~ 75 lbs of pellets.
- Obtain baseline data on fines (-1/4 in.) that are generated when the pellets are subjected to
  a) low, medium, and high vibration intensity and
  b) vibrating period ranging between 30 min. to 5 hrs.
- Generate test data on fines produced from an actual transportation test in a truck
- Correlate the results of the actual transportation test and simulation tests to establish a test condition
- Evaluate the pilot-scale production pellets under appropriate test condition.

In this quarter, we have completed designing, fabricating, testing, and generating baseline data under medium vibration with the simulation test unit. We have also obtained data from an actual truck-transportation tests.

Table 8 shows fines generation versus test conditions. Fines are generated gradually over several hours of vibration. Figure 12 shows these vibration data and the results of an actual transportation test conducted with 1/2-in. (bench scale) and 3/4-in. (pilot scale) pellets. The vibration simulation test appears to reasonably simulate the forces and movements that the pellets experience during transportation in a truck. Additional simulation tests at higher intensities of vibration are planned in the next quarter.

TABLE 8. VIBRATION SIMULATION TEST RESULTS AT MEDIUM VIBRATION INTENSITY

| Coal Pellet | | Vibration, hrs | | | |
|---|---|---|---|---|---|
| | | 0.5 | 1 | 3 | 5 |
| Illinois No. 6 Coal with 1.5 % Cornstarch | Initial wt (lbs) | 66.59 | 66.2 | 68.40 | 71.53 |
| | Final wt (lbs) | 64.85 | 64.58 | 66.2 | 68.4 |
| | % Fines generated | 2.6 | 2.45 | 3.22 | 4.38 |

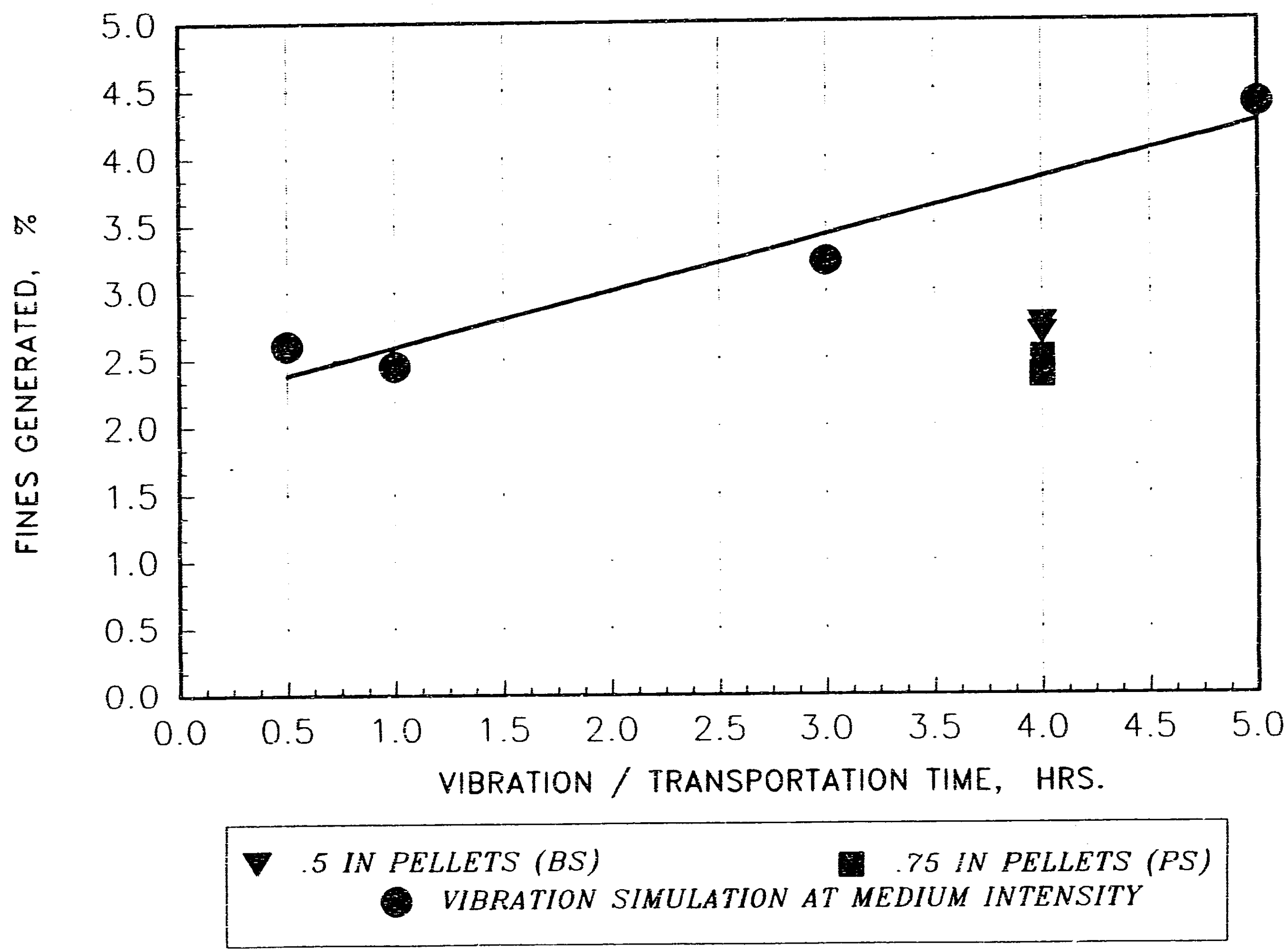


FIGURE 12. VIBRATION SIMULATION TEST AND ACTUAL TRANSPORTATION TEST CORRELATION

**Humidity Test**. The purpose of this test is to understand the effects of humidity levels on the pellets. The pellets are expected to be exposed to varying humidity conditions during storage and transportation. This may affect pellet strength, durability, and reslurrying behavior. The humidity test will be designed to evaluate these effects. No work was initiated on this test in this quarter. Tests are scheduled in the next quarter.

**Heat-Cycle Test**. During storage and transportation pellets are expected to be exposed to environments conducive for spontaneous combustion. The heat-cycle test have been designed to simulate this environment, and measure the temperature at which spontaneous combustion would occur. Amax is investigating the potential for spontaneous combustion in their reactivity test apparatus shown in Figure 13.

During this quarter, the reactivity test system has been tested and "trial" reactivity data have been obtained with disk pellets. Two 3x14-mesh samples of the crushed Illinois No. 6-Shur-Bond spheres were preheated to 75 and 120 C, respectively, under nitrogen and transferred to the adiabatic chamber. Humidified oxygen was passed through the samples while the temperatures were being monitored. The first test at 75 C was continued for 5 hours. There was an initial temperature rise which could be attributed to absorption of water on the coal, but no further indication of any exothermic oxidation of the coal was observed.

The second test at 120 C behaved differently. The initial rise continued to 262 C. This was followed by a decline in the temperature and later a continuous rise until the final temperature was near 300 C after 6 hours. Temperature traces for the two tests are shown in Figure 14 and 15. Thus this pellet sample was self heating at 120 C but not at 75 C. Coals with self-heating temperatures below 70 C are considered to have a high spontaneous combustion potential; 70 to 100 C, a medium potential; and above 100 C a low potential. These pellets are therefore rated as having a low spontaneous combustion potential.

Work will continue to perfect the testing procedure and generate data with pilot-scale production pellets.

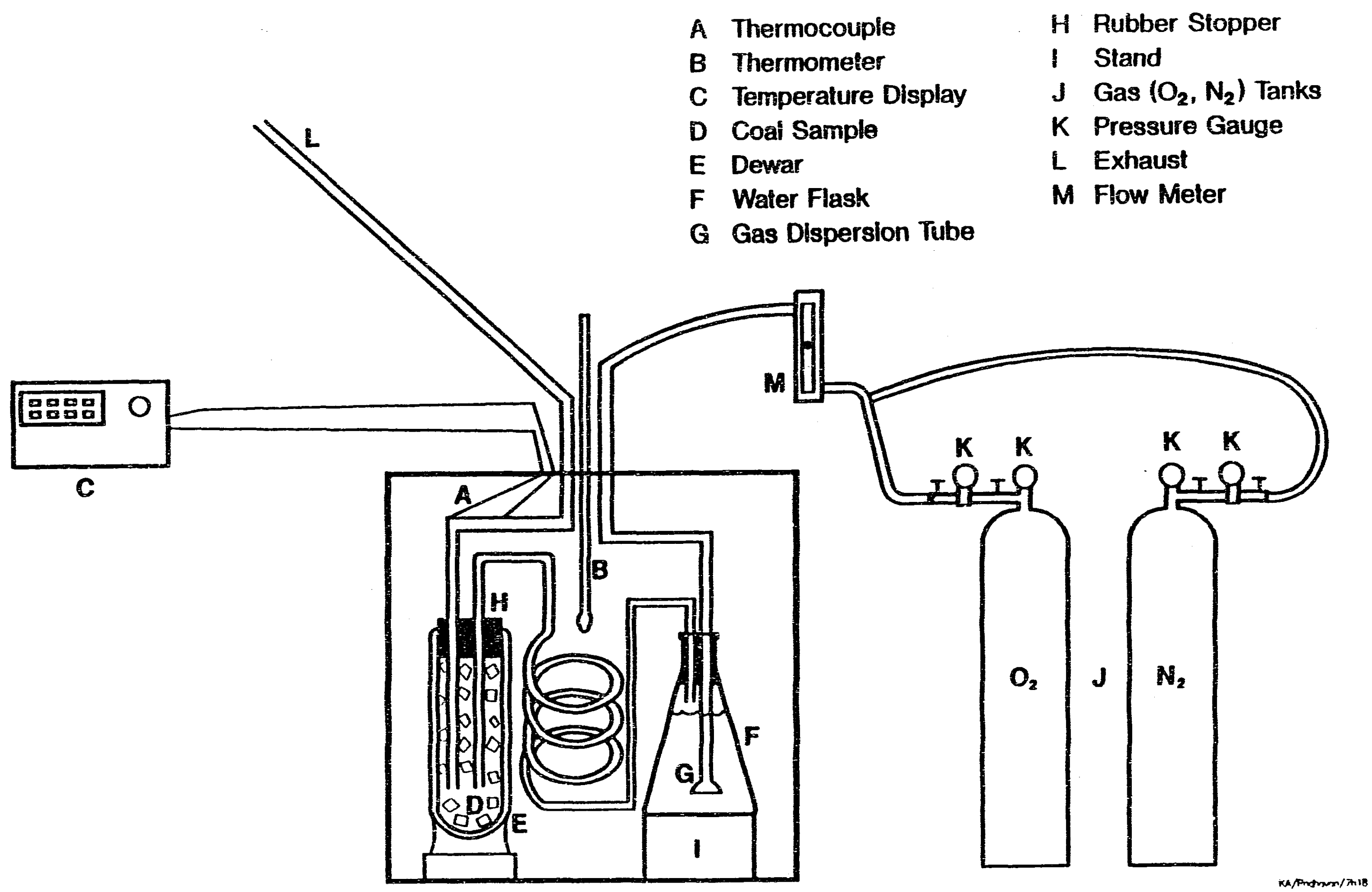


FIGURE 13. REACTIVITY TEST APPARATUS, USED FOR MEASURING THE TEMPERATURE FOR SPONTANEOUS COMBUSTION

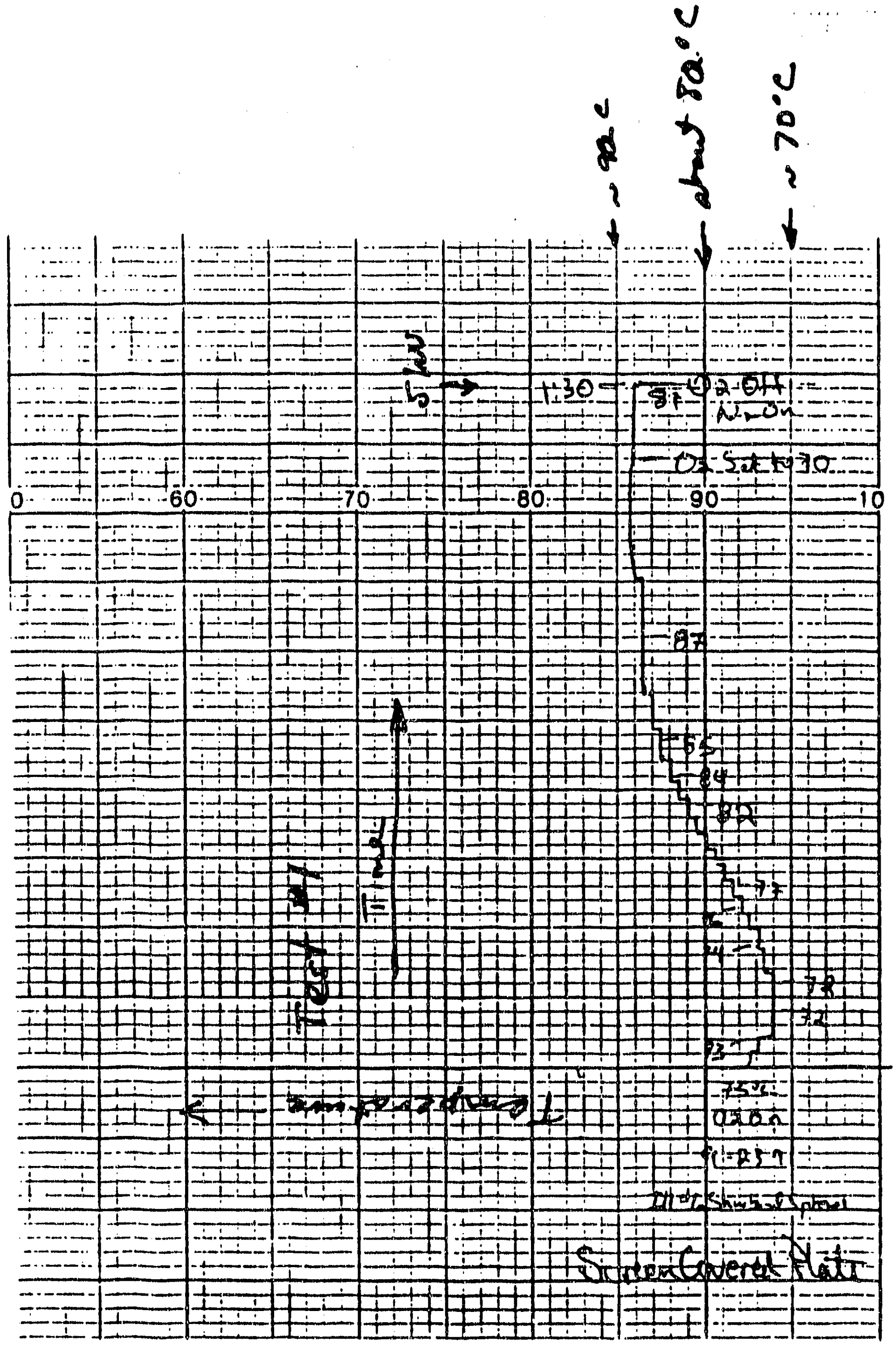


FIGURE 14. TEMPERATURE TRACE FOR TEST CONDUCTED AT 75°C

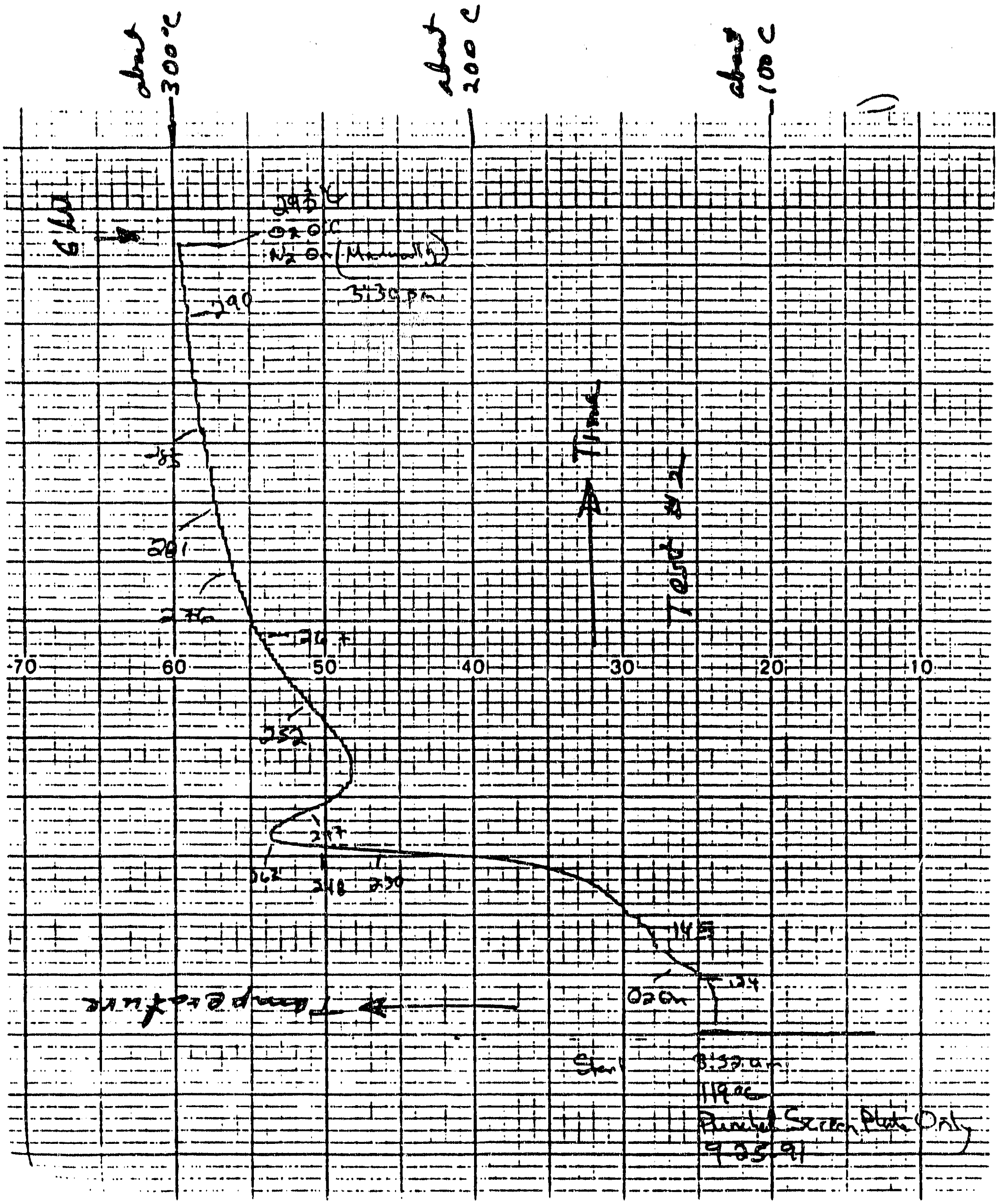


FIGURE 15. TEMPERATURE TRACE FOR TEST CONDUCTED AT 120°C

<u>Outdoor Storage Test</u>. The emphasis of the test is to evaluate the effects of storage conditions on pellets. It is planned to study the following storage situations:

(a) Exposed, outdoor storage

(b) Covered, outdoor storage

(c) Silo storage.

In this quarter, design of silo storage simulation unit has been initiated. The pellet testing and simulated-silo storage fabrication are scheduled to commence in the next quarter.

<u>Packing Test</u>. The purpose of this test, is to understand the effects of storage on pellets prepacked in bags. The following packing bags have been identified:

(1) Super-sack "nylon" bags

(2) Polyethylene bags and

(3) Multilayered paper bags.

Indoor and outdoor bag storage tests are planned for next quarter. Pellets from these bags will be sampled at intervals of 2, 4, and 12 weeks to study the effect of storage time on strength, durability, and reslurrability.

<u>Pellet Uniformity</u>. 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 is to examine the effect of operational variations on the uniformity of the pellets.

The testing procedure involves:

- Sample 15 lbs of pellet at varying time intervals of production, from the three production techniques for each of the coals
- Measure the pellet'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 roller and die pelletization for Illinois No. 6 coal with cornstarch, Shur-Bond, and lignin sulfonate binders and for Utah coal with cornstarch binder.

Tables 9 and 10 present these data along with the acceptance criteria. The cornstarch pellets marginally meet the acceptance levels over the entire period of large scale production. It is also observed that the pilot scale pellets with 3/4-inch diameter measure lower cured strength than the bench scale pellets with 1/2-inch diameter. This observation is logical, since with the same binder dosages and with identical forces of compaction, coal particles are less tightly bound with the binder in the larger diameter pellets.

With Shur-Bond binder, the pellet quality was observed to deteriorate with production time as noted by the durability data. It is suspected that the thermal effects during pelletizing has a detrimental effect on the binder and thus on the pellet strength and durability. In the next quarter this aspect will be investigated.

Figures 16 and 17 show the variation of pellet set strength over production time for Illinois No. 6 and Utah coal pellets measured after one and two weeks of production. The strengths after one week are close to the minimum acceptance levels. After two weeks, especially with cornstarch bound pellets, the strengths exceed the minimum acceptable strength.

## Task 7 - Reslurry Pellets and Evaluate CWF

The objective of these tests is to evaluate the effect of pellet production on slurry formulation and slurry characteristics. No work has been initiated in this quarter. Amax is scheduled to begin evaluation in the next quarter.

## Task 8 - Utilization/Commercialization

**Economic Evaluation Criteria**. During this quarter, guidelines for process/production cost estimation were drafted for DOE-PETC review. It is believed that a common method of economic comparison would be beneficial for

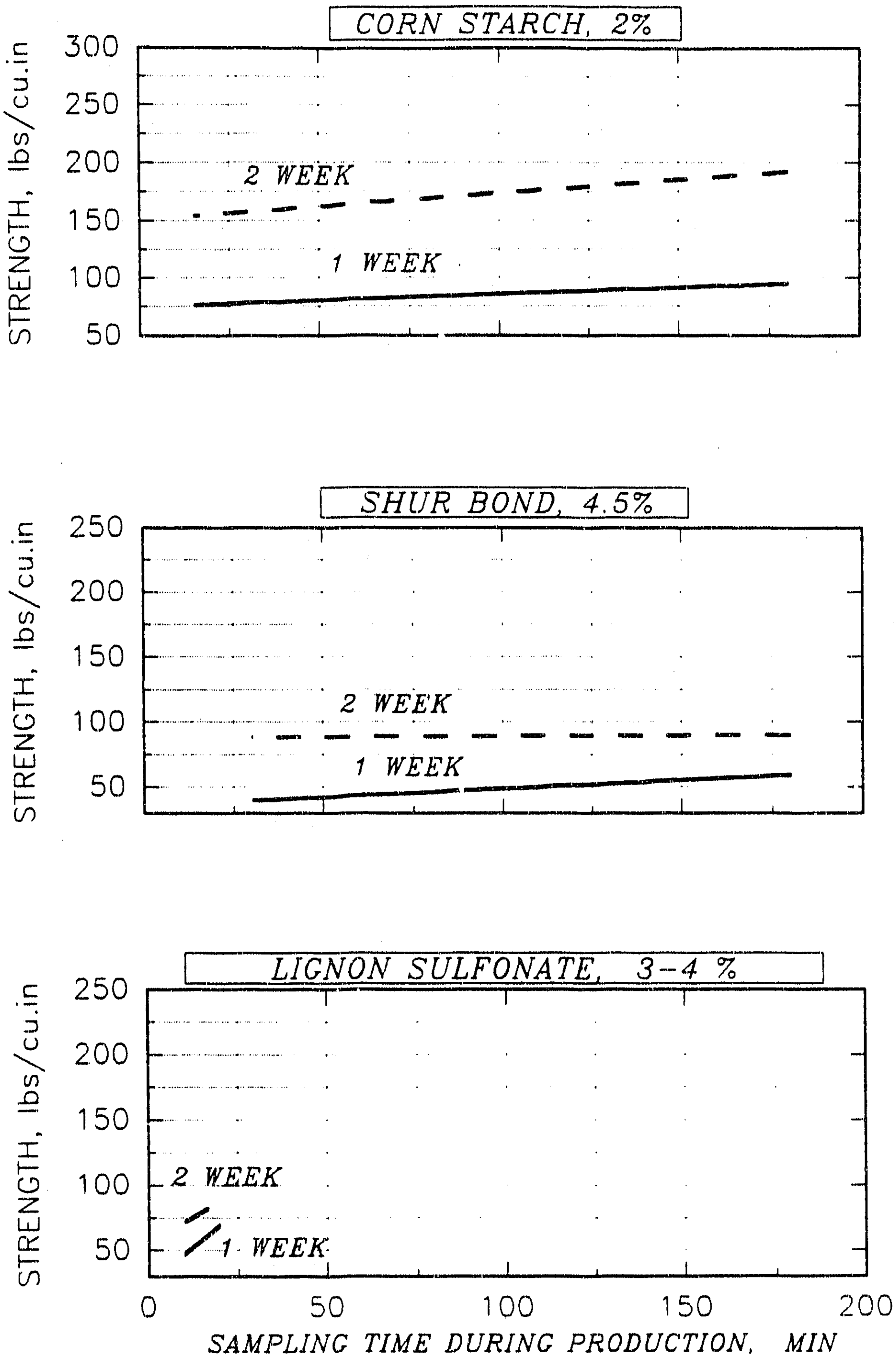


FIGURE 16. SET STRENGTH VARIATIONS OF ROLLER AND DIE PELLETS FOR ILLINOIS NO. 6 COAL

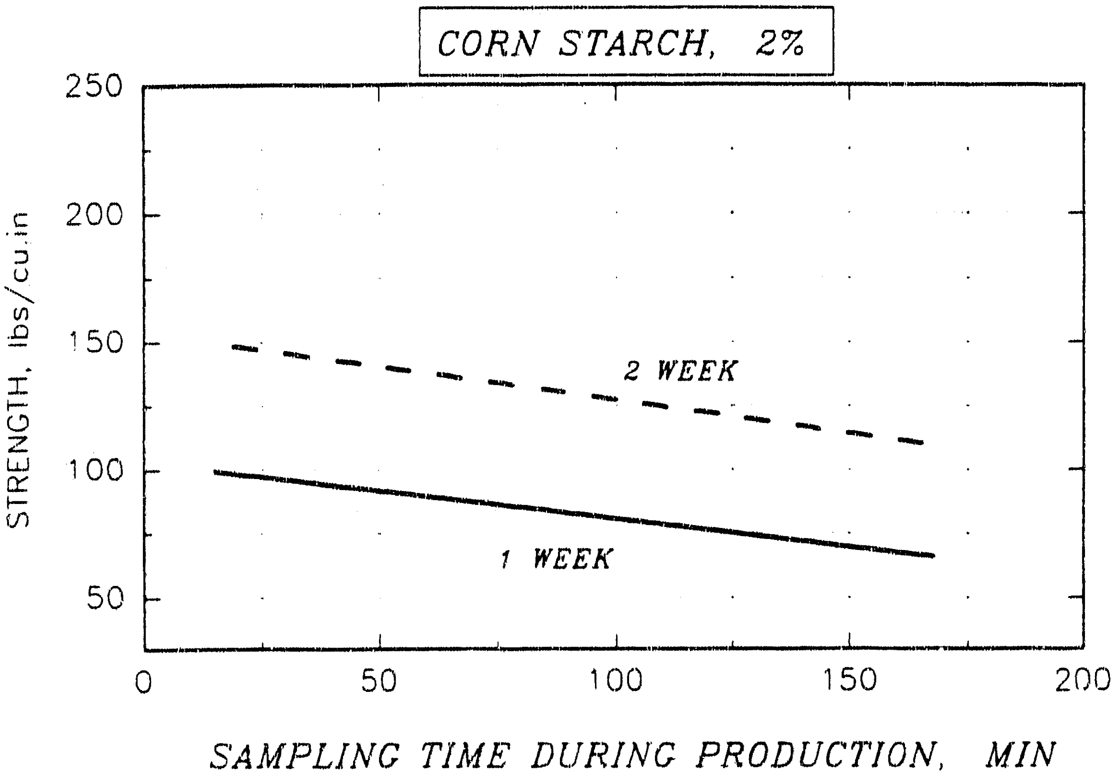


FIGURE 17. SET STRENGTH VARIATION OF ROLLER AND DIE PELLETS FOR UTAH COAL

Table 9. Illinois No.6 Coal Pilot Scale Production via. Roller & Die Pelletization

| Sample I.D. | Binder, Concent. % | Designation | Sampling Time, min | Set Strength, lbs/in$^3$ | | Durability, DI | | | | Weather. Index W.I | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | DI | | Ro Tap | | | |
| | | | | A.C | Actual | A.C | Actual | A.C | Actual | A.C | Actual |
| CPM 1-1 | Corn Starch, 2% | AllBond 200 | 15 | 100 | 84 | 28 | 27 | 90 | 94 | 60 | 84 |
| CPM 1-2 | Corn Starch, 2% | AllBond 200 | 30 | 100 | 84 | 28 | 29 | 90 | 91 | 60 | 91 |
| CPM 1-3 | Corn Starch, 2% | AllBond 200 | 60 | 100 | 71 | 28 | 34 | 90 | 91 | 60 | 86 |
| CPM 1-4 | Corn Starch, 2% | AllBond 200 | 90 | 100 | 75 | 28 | 36 | 90 | 91 | 60 | 84 |
| CPM 1-5 | Corn Starch, 2% | AllBond 200 | 120 | 100 | 84 | 28 | 34 | 90 | 92 | 60 | 93 |
| CPM 1-6 | Corn Starch, 2% | AllBond 200 | 150 | 100 | 108 | 28 | 50 | 90 | 94 | 60 | 84 |
| CPM 7-1 | Corn Starch, 2% | AllBond 200 | 15 | 100 | 91 | 28 | 36 | 90 | 92 | 60 | 87 |
| CPM 7-2 | Corn Starch, 2% | AllBond 200 | 25 | 100 | 76 | 28 | 33 | 90 | 94 | 60 | 90 |
| CPM 2-1 | Shur Bond, 4.5% | Sherax | 30 | 100 | 39 | 28 | 31 | 90 | 73 | 60 | 84 |
| CPM 2-2 | Shur Bond, 4.5% | Sherax | 45 | 100 | 38 | 28 | 16 | 90 | 69 | 60 | 84 |
| CPM 2-3 | Shur Bond, 4.5% | Sherax | 60 | 100 | 35 | 28 | 16 | 90 | 77 | 60 | 85 |
| CPM 2-4 | Shur Bond, 4.5% | Sherax | 90 | 100 | 45 | 28 | 15 | 90 | 81 | 60 | 85 |
| CPM 3-1 | Shur Bond, 4.5% | Sherax | 45 | 100 | 48 | 28 | 20 | 90 | 81 | 60 | 80 |
| CPM 3-2 | Shur Bond, 4.5% | Sherax | 90 | 100 | 53 | 28 | 21 | 90 | 80 | 60 | 83 |
| CPM 3-3 | Shur Bond, 4.5% | Sherax | 120 | 100 | 62 | 28 | 15 | 90 | 80 | 60 | 85 |
| CPM 3-4 | Shur Bond, 4.5% | Sherax | 150 | 100 | 55 | 28 | 16 | 90 | 75 | 60 | 70 |
| CPM 3-5 | Shur Bond, 4.5% | Sherax | 180 | 100 | 54 | 28 | 15 | 90 | 80 | 60 | 86 |
| CPM 5-1 | Lignin Sulfonate, 3% | | 15 | 100 | 56 | 28 | 16 | 90 | 85 | 60 | 0 |
| CPM 5-2 | Lignin Sulfonate, 3% | | 20 | 100 | 65 | 28 | 11 | 90 | 86 | 60 | 0 |
| CPM 6-1 | Lignin Sulfonate, 3% | | 10 | 100 | 50 | 28 | 19 | 90 | 82 | 60 | 0 |
| CPM 6 3 | Lignin Sulfonate, 3% | | 15 | 100 | 56 | 28 | 17 | 90 | 78 | 60 | 0 |
| CPM 6-3 | Lignin Sulfonate, 3% | | 20 | 100 | 76 | 28 | 18 | 90 | 79 | 60 | 0 |

A.C. represents the Acceptace Criteria established

Table 10. Utah Coal Pilot Scale Production via. Roller & Die Pelletization

| Sample I.D. | Binder, Concent. % | Design-ation | Sampling Time, min | Set Strength, lbs/in$^3$ | | Durability, DI | | | | Weather. Index W.I | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | DI | | Ro-Tap | | | |
| | | | | M.A.C | Actual | A.C | Actual | A.C | Actual | A.C | Actual |
| CPM 4-1 | Corn Starch 2% | AllBond 200 | 10 | 100 | 101 | 28 | 51 | 90 | 92 | 60 | 100 |
| CPM 4-2 | Corn Starch 2% | AllBond 200 | 20 | 100 | 85 | 28 | 41 | 90 | 92 | 60 | 100 |
| CPM 4-3 | Corn Starch 2% | AllBond 200 | 85 | 100 | 77 | 28 | 43 | 90 | 93 | 60 | 100 |
| CPM 4-4 | Corn Starch 2% | AllBond 200 | 93 | 100 | 114 | 28 | 39 | 90 | 93 | 60 | 100 |
| CPM 4-5 | Corn Starch 2% | AllBond 200 | 160 | 100 | 54 | 28 | 26 | 90 | 87 | 60 | 100 |
| CPM 4-6 | Corn Starch 2% | AllBond 200 | 168 | 100 | 66 | 28 | 23 | 90 | 88 | 60 | 100 |

A.C. represents the Acceptace Criteria established assessing the relative merits of the four DOE logistic programs. Guidelines are outlined below.

Plant capacities of 50, 250, and 1000 ton per day were suggested. These capacities are approximately equivalent to 0.5, 2.5, and 10 railroad car loads per day. A plant capacity smaller than 50 tons per day might not be economically practical and it is difficult to imagine early plants with capacities over 1,000 per day. The process evaluation starting point should be the clean coal at the preparation plant delivered to the on-site processing facility. The end point is prepared fuel (either CWF, or dry coal) delivered to the users storage unit.

Develop Process Flowsheet. As a first step, process flowsheets detailing the transformation of coal filter cake to its final product, i.e., CWF or dry coal, should be developed for the following three plant capacities and transportation distances:

- 50 ton/day - 10, 50, and 100 miles
- 250 ton/day - 10, 50, and 100 miles
- 1000 ton/day - 50, 100, and 300 miles.

The purpose of these flowsheets is to provide a sound basis for estimating the production cost. All major equipment such as crushers, pumps, agitator tanks, conveyors, screw feeders, cyclones, etc., should be identified and included for accurate estimation.

Flowsheets should also include the type and size of equipment required at each stage of the producer's operation and at the user's site, as well as proposed transportation modes and containers. All support systems required for proper control of storage, handling, and transportation should be recommended including ventilation, climate control, and any others as necessary. Key process areas that should be included are:

- Clean coal handling (Clean coal processing operations like conveying, drying, blending, screening, etc.)
- Additives Preparation (Reconstitution additives like gels, binders, dispersant, stabilizers, etc.).

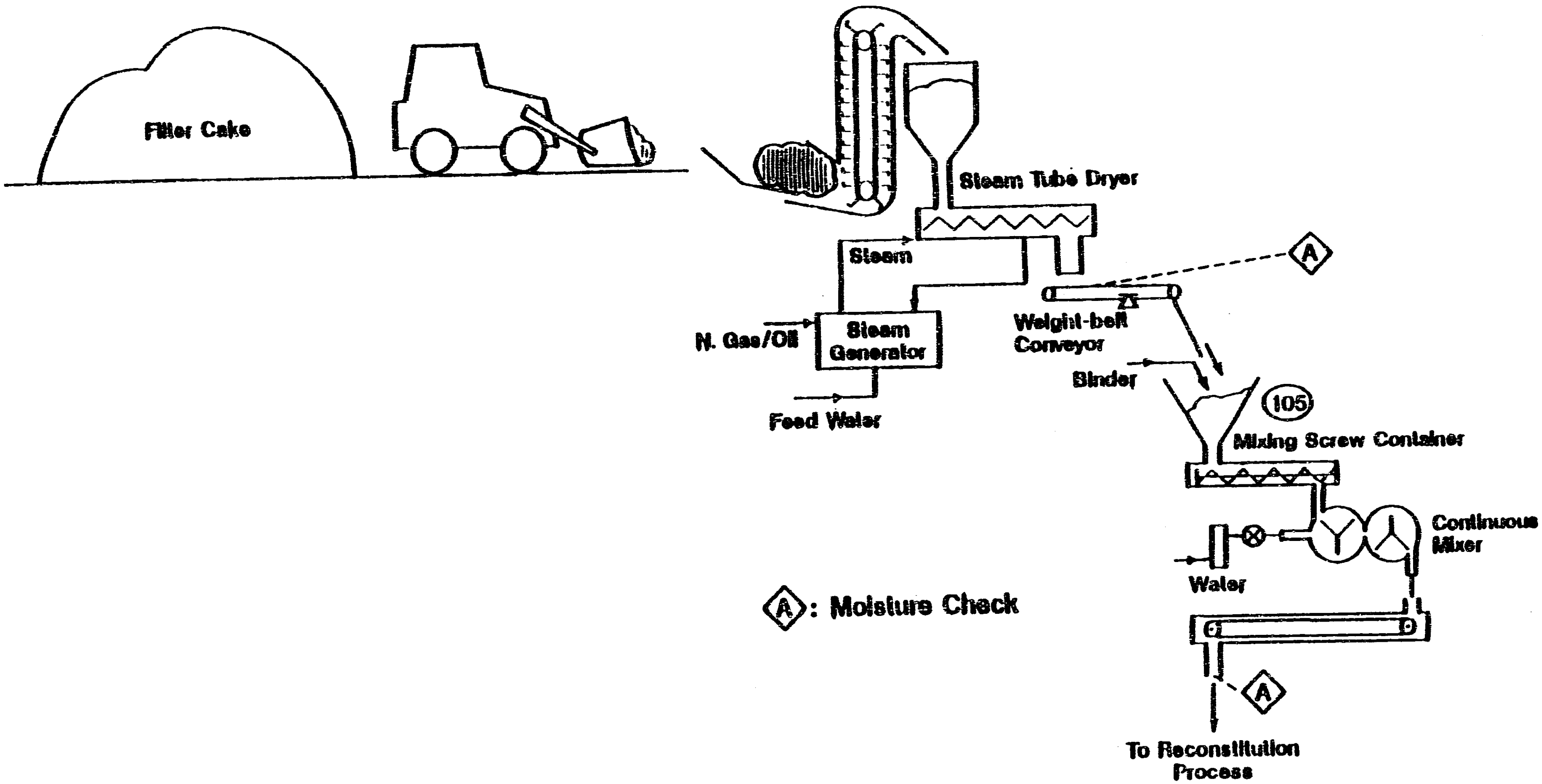


FIGURE 18. TYPICAL FEED PREPARATION PROCESS

- Reconstitution/reformulation processes (Pelletizing, drying, gelling, etc., operations).
- Product handling, storage, and transportation
- Slurrying (if used).

Health and safety monitor points and transport-accident considerations should also be recommended. Duration of storage should be indicated at each stage. A typical process flow-sheet is shown in Figure 18.

**Estimate Processing Production Costs**. Economic projections, which include capital and operating costs to process the clean coal filter cake and produce the CWF, will be estimated for the three plant capacities. These estimates will include the broad areas outlined earlier.

While developing the cost model, several factors and assumptions control the reconstitution/reformulation and slurrying stages. Therefore, the cost models developed for the four programs of approach should share the same common assumptions to allow meaningful comparison between the programs. Table 11 summarizes suggested values for many common raw material and utility costs and estimating factors. Based on these assumptions, the following cost items will be included in Battelle's estimate for the three plant capacities:

- Capital investment
- Annual operating cost.

Contributions from individual process areas outlined earlier and the total processing/production cost will also be provided.

Finally the product cost, in $/ton feed filter cake or $/MM Btu slurry, will be estimated. This is a combination of the operating cost plus a fraction of the capital costs prorated over the annual clean coal pellets, slurry, dry coal, etc. produced. The fraction of the capital costs to be added to the operating costs depends on many economic factors such as interest rate, debt/equity ratio, tax rates, plant life, profit levels desired, etc. A common way of including the capital cost contribution is the use of a "capitalization factor." A factor of 23.8 percent of Fixed Capital Investment (FCI) will be applied. It is based on a 15 percent after tax return based

TABLE 11. COST ESTIMATE--PROCESS ASSUMPTIONS

**PROCESS RELATED:**

| | |
|---|---|
| HOURS OF OPERATION | 16 HRS/DAY |
| NO. OF OPERATING DAYS | 200 DAYS/YR |

**OPERATING COST RELATED:**

| | |
|---|---|
| FINE-CLEAN COAL COST | NOT INCLUDED |
| ADDITIVES | |
| CORN STARCH | $0.10 PER LB |
| LIGNIN SULFONATE | $0.035 PER LB |
| ASPHALT EMULSION | $0.065 PER LB |
| DISPERSANT, A-23 | $0.50 PER LB |
| STABILIZER, FLOCON | $3.00 PER LB |
| LUBRICANT | $1.00 PER LB |
| UTILITIES | |
| ELECTRICITY | $0.05 PER KWH |
| STEAM | $0.004 PER LB |
| PROCESS WATER | $0.000038 PER LB |
| LABOR | |
| OPERATING | $30.00 PER MAN-HR |
| MAINTENANCE | 3.00% OF FCI |
| SUPERVISION | 15.00% OF OPERATING LABOR |
| OPERATING SUPPLIES | 15.00% OF OPERATING LABOR |
| MAINTENANCE SUPPLIES | 4.00% OF FCI |
| LABORATORY CHARGES | 15.00% OF OPERATING LABOR |
| PLANT OVERHEAD | 60.00% OF OPER AND MAINT., LABOR & SUPERVISION |
| LOCAL TAXES AND INSURANCE | 1.50% OF FCI |
| DEPRECIATION | 8.00% OF FCI |

**CAPITAL INVESTMENT RELATED:**

| | |
|---|---|
| DIRECT COST ITEMS | |
| EQUIPMENT INSTALLATION | 39.00% OF PE COST |
| INSTRUMENTATION AND CONTROLS | 13.00% OF PE COST |
| PIPING | 31.00% OF PE COST |
| ELECTRICAL | 10.00% OF PE COST |
| BUILDING | 29.00% OF PE COST |
| YARD IMPROVEMENTS | 10.00% OF PE COST |
| SERVICE FACILITIES | 55.00% OF PE COST |
| INDIRECT COST ITEMS | |
| ENGR & SUPERVISION | 32.00% OF PE COST |
| CONSTRUCTION EXPENSE | 34.00% OF PE COST |
| OTHER | |
| CONTRACTORS FEES | 5.00% OF DIRECT & INDIRECT COST |
| CONTINGENCY | 10.00% OF DIRECT & INDIRECT COST |
| WORKING CAPITAL | 74.00% OF PE COST |
| STARTUP COST | 50.00% OF PE COST |

*NOTE: PE = PURCHASED EQUIPMENT*
*FCI = FIXED CAPITAL INVESTMENT*

on FCI, and a 37 percent combined state and income tax rate [0.238 = 0.15/(1-0.37]. Product cost then becomes:

$$\text{Product Cost} = \frac{\text{(Annual Operating Cost + (0.238 • FCI)}}{\text{Annual Production}}$$

If annual production is expressed in tons, the product cost will be $/ton; if MM Btu slurry, the product cost is $/MM Btu slurry.

**Commercial Coal Pellet Producers**. We have identified the following coal-pellet plant operations producing coal pellets for commercial use:

- Pyromining, Kentucky
- Flyash Haulers, Nevada.

Both these operations are currently producing pellets via roller and die techniques at quantities between 50-300 ton/day. The data they have generated for storage, handling, and transportation is of great interest. We plan to visit one or both these plants to gather production and cost data.

## Task 9 - Prepare Additional Cake

### Need for Additional Coal

The originally planned scope of Task 9 included the production of 2,000 lbs (dry equivalent) of both Illinois No. 6 and Utah coals -- 1,000 lbs for small-scale testing and 1,000 lb for pilot scale testing. This effort has been completed. However, upon completion of the bench-scale studies, and after review of the quantity of pellets needed for the various storage, handling, transportation and slurry-preparation tests, the required quantity of clean coal was reevaluated. About 5,700 lb of dry clean coal was required, see Table 12. It became clear that the original planned clean-coal production would be inadequate to properly evaluate the many pellet properties of interest.

Therefore, with U. S. DOE approval, the quantity of clean coal requested from AMAX was increased. In addition, clean Elkhorn coal was added to the AMAX request. (Recall that the first 1,000-lb batch of Elkhorn coal was supplied by Virginia Polytechnic Institute, as they could best meet our demanding delivery schedule.)

## Delivery Schedule

The quantity and delivery schedule agreed between Battelle and AMAX is shown in Table 13 below.

TABLE 12. CLEAN COAL REQUIREMENTS

| Test Description | Quantity of Dry-Coal Required, lbs |
|---|---|
| Main production, 2 processes x 2 binders @ 1,000 lb each | 4,000 |
| Lignin Sulfonate test (Illinois No. 6 coal,roller-and-die pelletization) | 1,000 |
| Truck transportation (1 @ 200 lb) | 200 |
| Super pellet study (1 @ 500 lb) | 500 |
| Total | 5,700 dry, or at 40 % moisture, 9,500 lb filter cake |

TABLE 13. ADDITIONAL PILOT PLANT CLEAN COAL DELIVERY SCHEDULE

| Coal | Needed Filter Cake Quantity, dry lbs | Delivered Through September 30, 1991 | Balance Due 6th Quarter | Final Delivery Date |
|---|---|---|---|---|
| Illinois No. 6 | 5,700 | 4,679 | * | September 13, 1991 |
| Utah Skyline Mine | 5,700 | 2,050 | 3,650 | October 21, 1991 |
| Elkhorn No. 3 | 5,700 | 0 | 5,700 | November 22, 1991 |

* Amax cleaned all the available Illinois No. 6 coal, no additional clean Illinois No. 6 coal was requested.

Note that Amax met the initial delivery schedule provide in the last yearly plan. This extension in the production quantities necessitates the extension of the Task 9 period from July 1 through November, 1991. This is reflected in the Schedule presented previously in Figure 2.

### Clean Coal Production

As part of the delivery of cleaned coal, 4,350 lbs of Illinois No. 6 filter cake, (2,679 lb dry equivalent) was shipped on September 5, 1991. This production followed the procedures outlined in the second quarterly report. A comparison of the moisture and ash levels of the initial and recent clean coal deliveries is shown in Table 14 below.

TABLE 14. ANALYSIS OF CLEANED ILLINOIS COAL

| Characteristic | Initial Illinois No. 6 Coal | New Illinois No. 6 Coal |
|---|---|---|
| Moisture, % | 42.5 | 38.4 |
| Ash, % | 4.38 | 4.28 |

The ash levels are similar and more efficient dewatering was achieved in the new clean coal production. The clean-coal particle size distribution is shown in Table 15.

## PLANNED FUTURE ACTIVITIES

Work in the sixth quarter will involve completion of Task 3 (Prepare Bench/Pilot-scale Pellets), and work on Tasks 4 (Evaluate Storage Characteristics), 5 (Evaluate Handling Characteristics), 6 (Evaluate Transportation Characteristics), 7 (Reslurry Pellets and Evaluate CWF), and 9 (Prepare Additional Cake).

Work on Task 8 (Utilization/Commercialization) originally planned to commence in February, 1992 may be accelerated (but is still shown on the schedule as beginning in February). The information gathered will be incorporated in our assessment of the economics of the various processes and binders.

TABLE 15. PARTICLE SIZE DISTRIBUTIONS OF MICRONIZED ILLINOIS DELTA MINE FLOTATION FEED AND CLEAN COAL[a]

| Particle Size, μm | Clean Coal |
|---|---|
| 75 | 99.93 |
| 53 | 99.84 |
| 45 | 98.45 |
| 38 | 98.22 |
| 30 | 96.89 |
| 20 | 78.93 |
| 15 | 68.87 |
| 10 | 50.76 |
| 8 | 43.43 |
| 6 | 32.55 |
| 4 | 21.97 |
| 3 | 14.91 |
| 2 | 7.53 |
| 1 | 1.56 |
| Mass Mean Diameter, μm[b] | 12.2 |

(a) Combination of sieving and SediGraph determinations.
(b) Calculated from particle size distribution.

Specifically, we plan to:

- Evaluate Shur-Bond and corn-starch pellets for all three coals with the two recommended processes.
- Study Illinois No. 6 coal with lignin sulfonate binder for roller-and-die pelletization.

- Complete large-scale clean coal production.
- Test pellet properties of one pellet and one coal against its raw parent coal in an actual truck transportation test. The estimated pellet quantity required for a 55 gallon drum filled to 1/2 - 3/4 of its capacity is 200 lbs.
- Select for each coal, one pellet/binder combination for "super-pellet" production. The "super-pellet" would contain all the additives that are necessary including reslurrying. The aim of making this type of pellet would be to ensure that at the user site only minimal effort will be required for the reslurrying process, i.e., crushing and adding water. The estimated quantity required for the "super-pellet" study is 500 lbs.

## SUMMARY

Significant accomplishments achieved during the fifth quarter include:

- Preferred binder dosage was established for pilot plant roller and die Illinois No. 6 coal production.
- Pilot scale Illinois No. 6 and Utah pellet production was initiated.
- Plans for disk and extrusion pelletization were finalized and pilot-scale equipment leased; all pellet production should be completed by early December, 1991.
- Reduced-cost slurry production techniques were identified and several alternatives tested.
- Over 4,350 lb of froth-flotation cleaned Illinois No. 6 coal filter cake (2,679 lbs dry basis) was prepared for the pilot-scale reconstitution and slurry production testing in this quarter; the Utah and Elkhorn clean-coal should be delivered by the end of November.
- The project is approximately on schedule and on budget; all indications are that the overall project should be completed on or before schedule.

# APPENDIX A

## PELLET SLURRY RHEOGRAMS

8-27-91

HOUSTON INSTRUMENT

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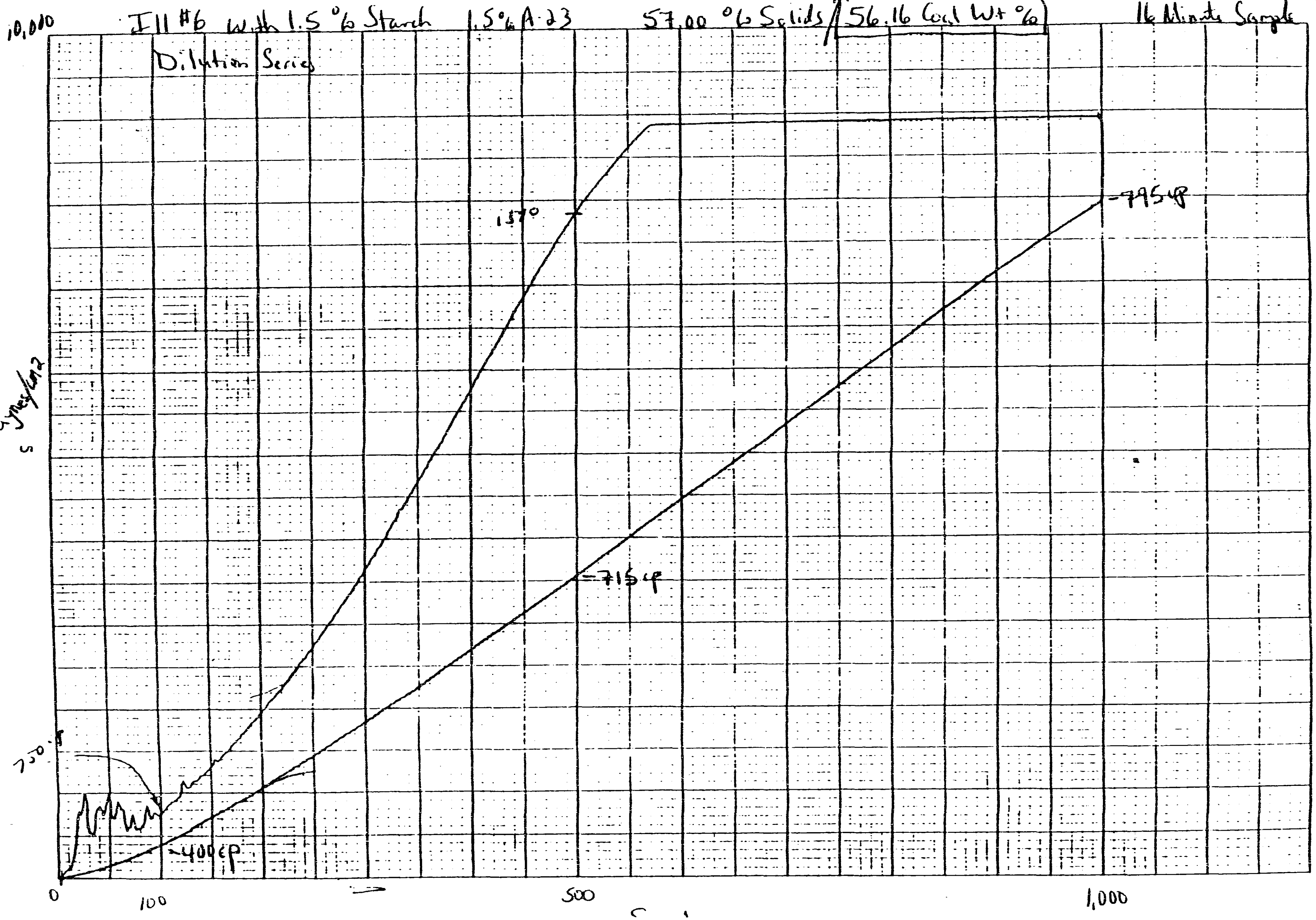
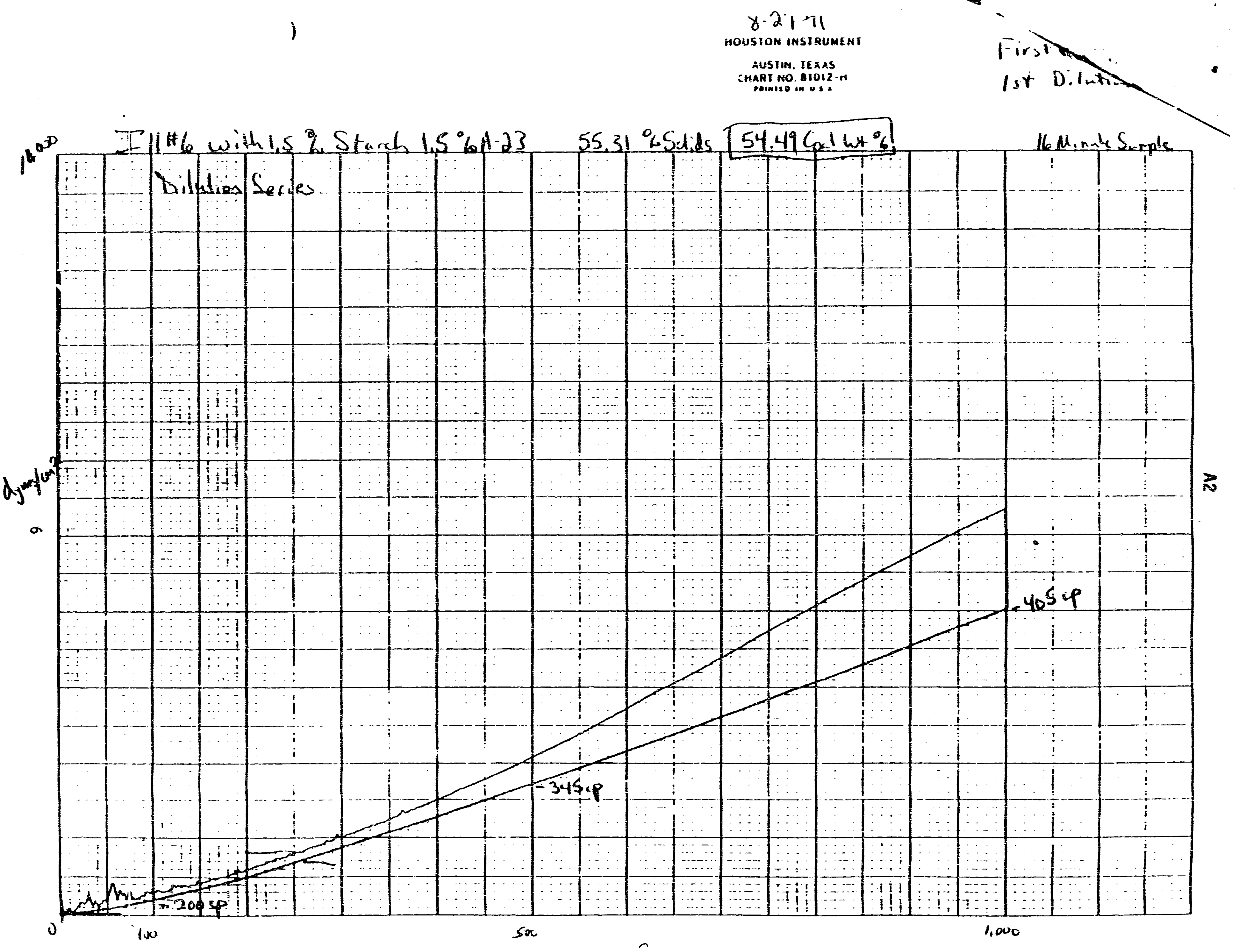
First
original




8-21-71
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AUSTIN, TEXAS
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55.31 % Solids
54.49 Coal Wt %
16 Minute Sample
Dilution Series
1000
dynes/cm²
-405 cp
-345 cp
-200 cp
0
100
500
1,000

HOUSTON INSTRUMENT

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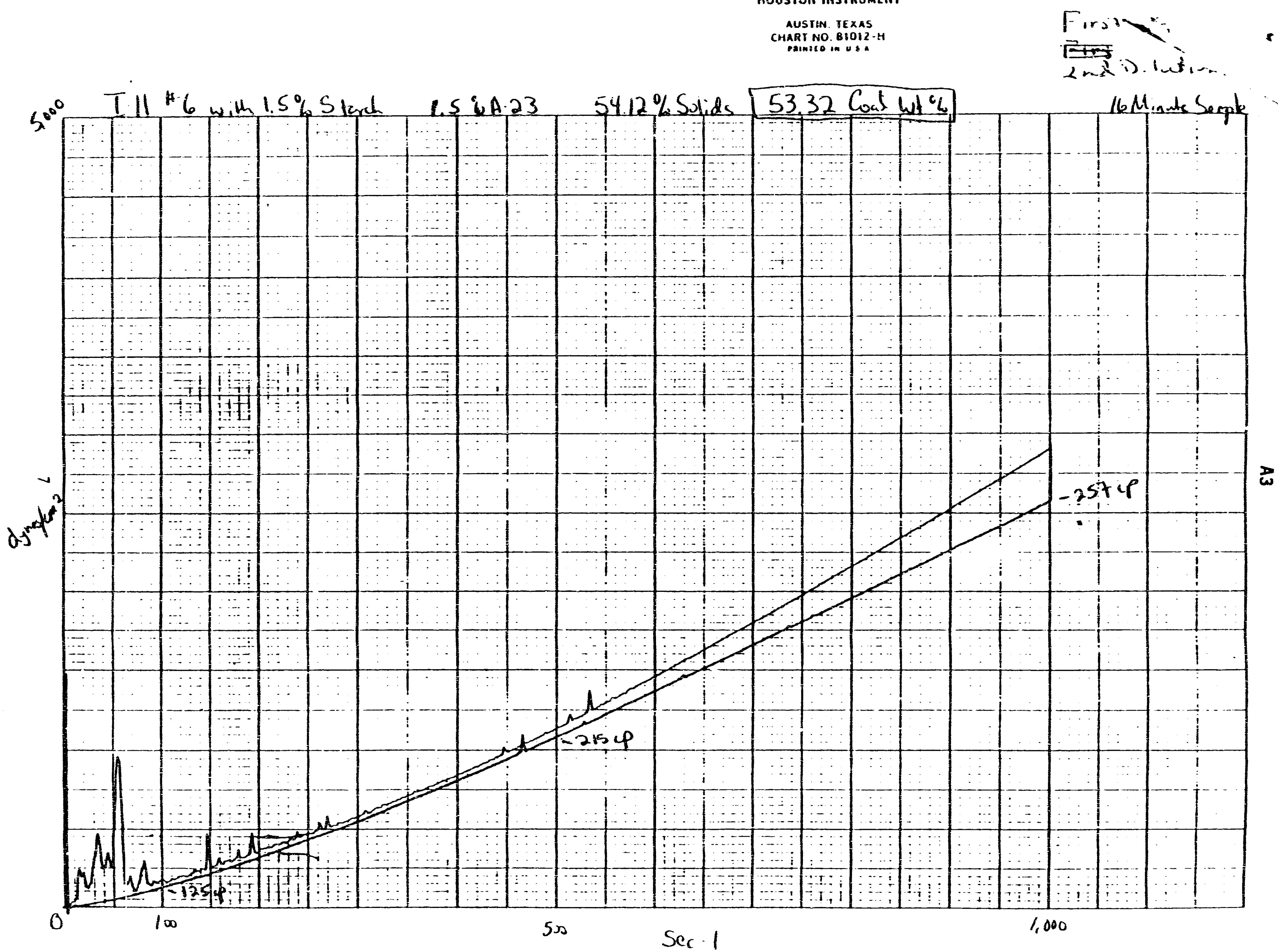

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8-27-11
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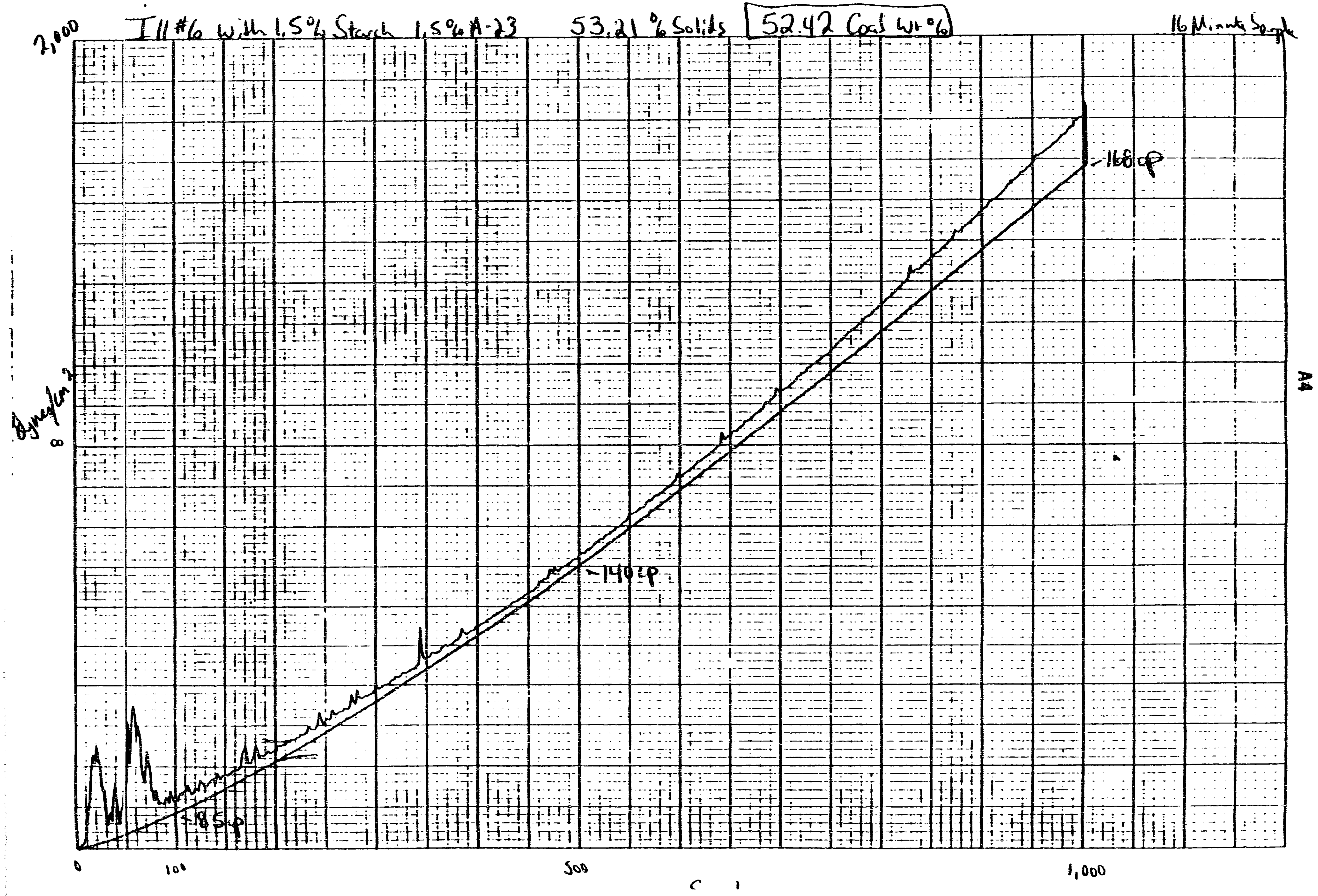

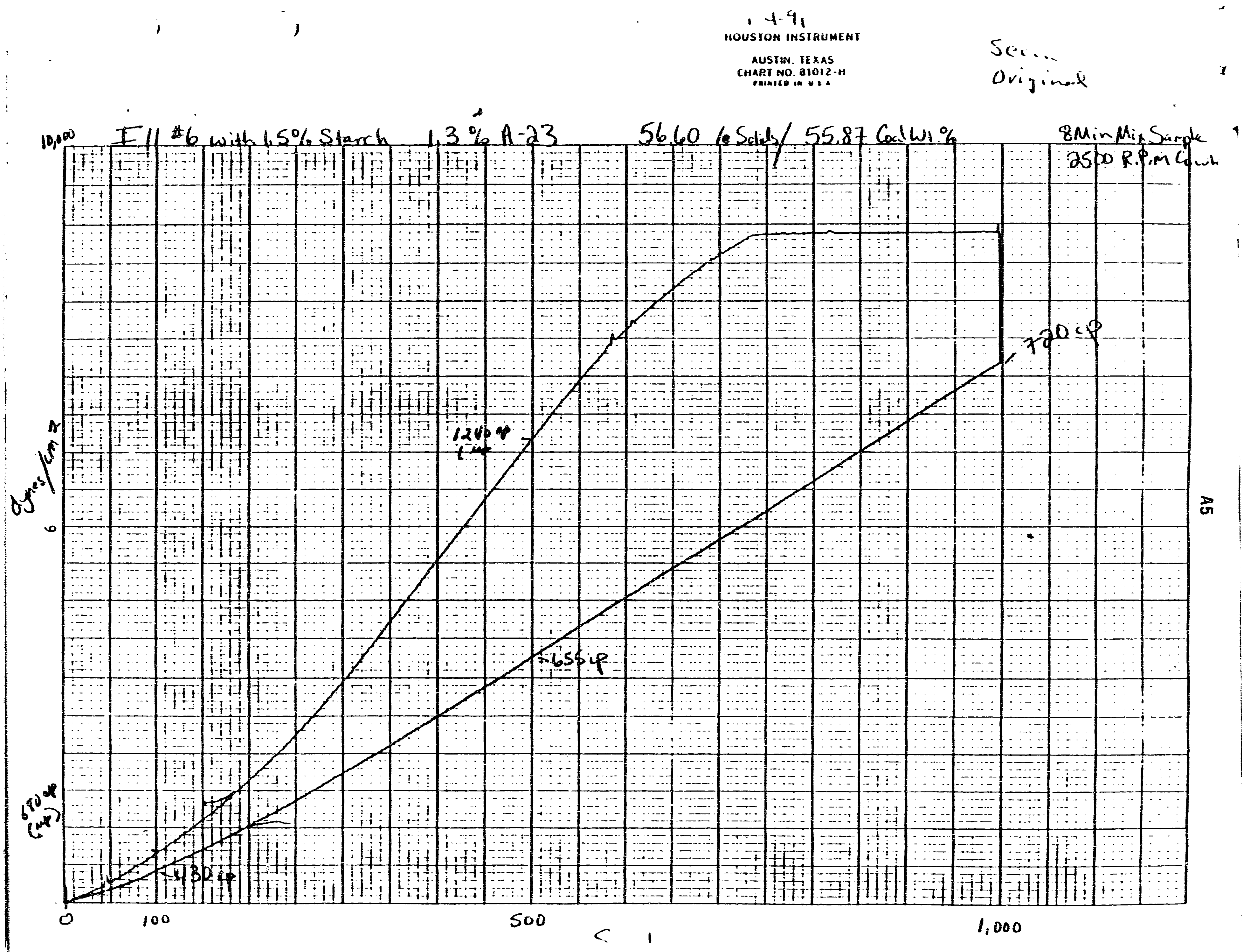

1-4-91
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AUSTIN, TEXAS
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Seco...
Original
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8 Min Mix Sample
2500 R.P.M Count
10,000
Dynes/cm²
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1240 cP
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430 cP
0
100
500
1,000
A5

A6

10-1-91
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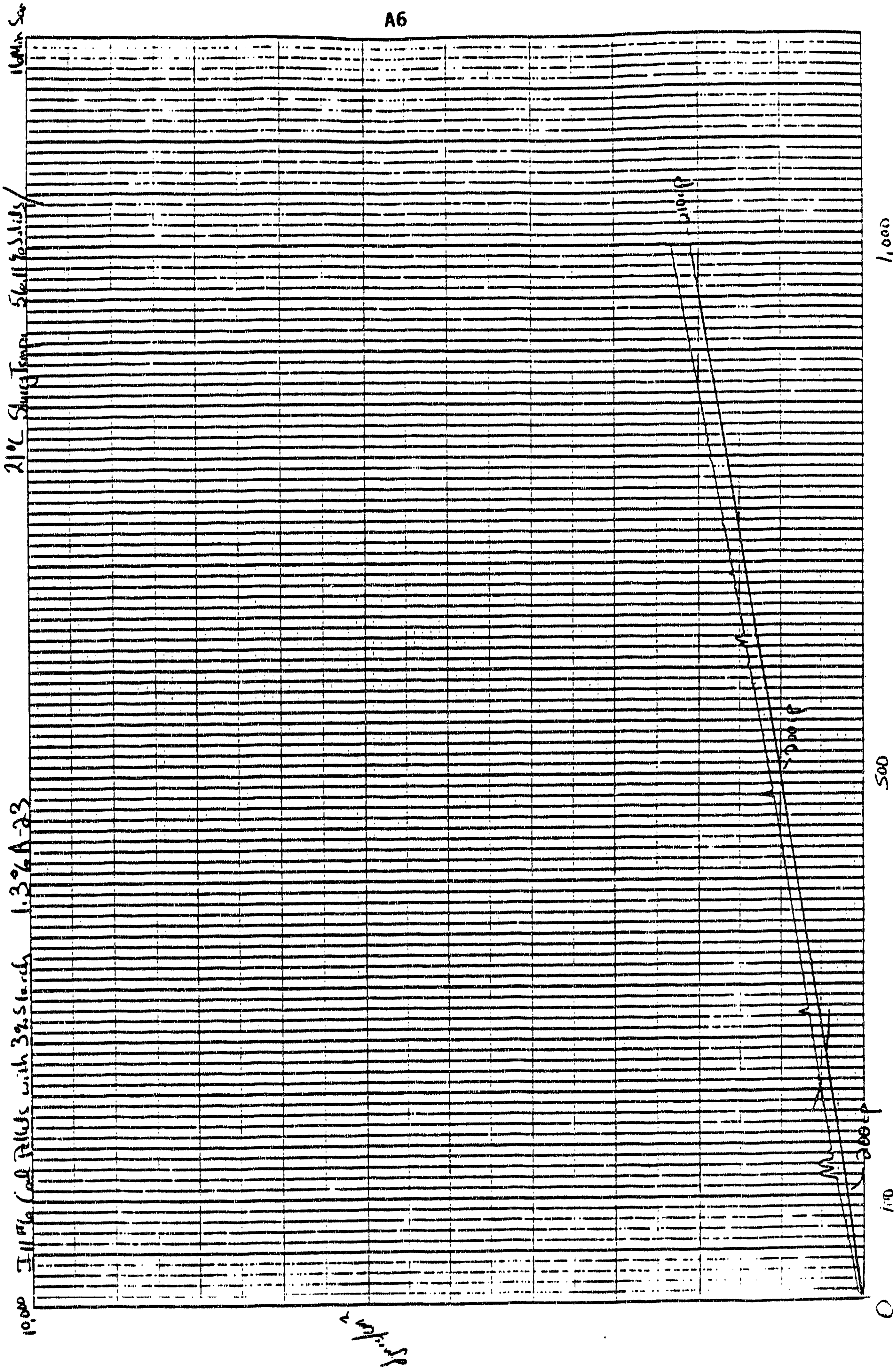

# END

# DATE FILMED

9/17/92