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**COAL LOG PIPELINE RESEARCH AT UNIVERSITY OF MISSOURI
1ST QUARTERLY REPORT FOR 1996
1/1/96 - 3-31-96**

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EXECUTIVE SUMMARY

During this first quarter of 1996 (1/1/96-3/31/96), major progress has been made in the following areas of coal log pipeline research, development and technology transfer:

1. Design of the coal log compaction machine is completed. The machine is a 300-ton-hydraulic press semi-automatic machine to manufacture 5.4-inch-diameter coal logs at the rate of 3 logs per minute. Construction specifications have been prepared and included in a Call-for-Proposal. The Call-for-Proposal will be sent to eleven companies in April. (Lin and students)
2. Compaction time has been reduced from 40 seconds in the past to 5 seconds--the fastest that our current 300 kip hydraulic press can compact. The test showed that there is no sacrifice in coal log quality by reducing the compaction time to as low as 5 seconds (perhaps even much shorter time), provided that the coal mixture does not contain excess amount of water that must be squeezed out, and good mixing of bind with coal is accomplished prior to compaction. (Gunnink and student)
3. Using a different machine (slower press), a more thorough investigation of rapid (30-40 second) compaction has been completed to show the effect of water content, binder concentration and other factors on the quality of rapidly compacted coal logs. (Luecke and student).
4. More tests of lubricant effect have been conducted. It was found that lubricating the mold with calcium stearate or MoS_2 produces more uniform quality coal logs. It also produces better logs as long as the binder is more than 0.5%, and worse logs when binder is less than 0.5%. It was found that lubricating flat-ended piston produces worse, not better logs. (Li and students).
5. It was discovered and proved during this period that higher compaction pressure is not necessarily better for coal logs. As the compaction pressure in a given case exceeds a certain critical value, coal particles are crushed in the mold and that produces weaker logs. This critical pressure is around 18,000 psi for the Mettiki coal under the test condition. (Li and students)
6. A 6-inch diameter, 320-ft.-long coal log pipeline test facility was designed and constructed at UMR (University of Missouri-Rolla). It is a closed loop pipeline driven by a jet pump similar to the smaller (2-inch-diameter, 75-ft.-long) test facility at UMC (University of Missouri-Columbia). The UMR facility is approximately 50% complete, and it will be completed in May. The pipeline test facility will greatly enhance UMR's capability in conducting coal log wear-resistance test. Large (5.4-inch-diameter) coal logs produced at UMR will be tested in this new pipe facility. (Wilson, Ding and students)

7. Preparation is underway to test the drag reduction of polymers in the 8-inch-diameter, 340-ft.-long pipe test facility at UMC Research Park. Flow meters and transducers for the test were calibrated and installed during this period. The system will be ready for testing in May. The test will show whether drag reduction results in CLP found in a 2-inch pipeline can be reproduced in an 8-inch pipeline. (Seaba, Liu and student)
8. Simulation of a closed loop CLP system consisting of an 8-inch-pipeline driven by a pump bypass was initiated. The pertinent equations were derived and the equations were used to investigate some special cases. Optimization of results will be done during the next period, and the study will be extended to a complete CLP system including a pump-bypass, a train separator, an injection system, and an ejection system. (Nair and student)
9. Hydrodynamic equations to predict the pressure gradient and the capsule velocity in a straight CLP were reevaluated and improved. The equations were extended to capsule trains. During the next period, the equations will be modified so that they can predict pressure gradient and capsule velocity in sloped and curved pipes. (Liu, Lenau and students)
10. Various alternatives for heating coal for use in CLP have been considered, and three most promising systems are being analyzed in greater details. This study seeks to determine the most promising system for heating coal for compacting coal logs, and the associated costs. The study is scheduled to end on August 31, 1996. (Marrero, Butler, Burkett and student)

PLAN FOR NEXT PERIOD (4/1/96-6/31/96):

Major tasks planned for the next three months include the following:

1. Complete the selection of bid (proposal) for coal log machine. Issue contract to the selected bidder (proposer).
2. Conduct 5-second fast compaction at different binder concentrations and water contents.
3. Complete assessment of lubricant effect including cost analysis. Issue a final report.
4. Complete assessment of the optimum pressure for coal log compaction. Issue a final report.
5. Complete construction of the 6-inch pipeline test facility at UMR and install instrumentation. Start to use it for assessing the wear resistance of the large logs made at UMR.
6. Start the polymer drag reduction test in the 8-inch-pipe. Obtain preliminary results.

7. Complete simulation of the 8-inch CLP system with the pump bypass but without the injection system and the train separator. Optimize the system by trying different valve stroking strategies and use of air chambers (sealed surge tanks).
8. Complete assessment of hydrodynamic equations to predict coal log train behavior in horizontal straight pipe. Issue final report and complete an M.S. thesis.
9. Derive hydrodynamic equations to predict coal log behavior in a sloped pipe. Analyze coal log behavior under different sloping conditions.
10. Complete detailed design and analysis of three alternate promising systems for heating coal for coal log compaction. Compare the cost of each system. Also, get industry to design and offer a coal heating system with cost estimates so that the three UMC designed systems can be compared with the industry offered system.

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report (Period Covered: 1/1/96-3/31/96)

Project Title: Machine Design for Coal Log Fabrication

Principal Investigator: Dr. Yuyi Lin, Assistant Professor of Mech. & Aero. Engineering

**Graduate Research Assistant: Guoping Wen, Kang Xue (50% GRA support),
Huachao Li (37.5% GRA support)**

Purpose of Study:

The purpose of this project is to design and develop fast and efficient machines for manufacturing high quality coal logs.

Work Accomplished During the Period:

During last three months, efforts were focused on the final revision and improvement of the design of the 300-ton hydraulic press machine for coal log production. The November version of the conceptual design, and the December addendum to the design of the machine have been reviewed and commented on by Mr. Infield of the Erie Press. We have implemented most suggestions for improvement made by Mr. Infield.

To ensure the quality and performance in the design of the 300-ton machine, Mr. Rex Gish, who is the supervisor and senior machinist in the Mechanical Engineering Research Machine Shop, has reviewed the design for reducing manufacturing cost and difficulties. We have also discussed with Mr. Larry Hubbard of the Campus Facility, and Mr. Jim Crossley of the Campus Procurement Office about bid specifications.

Dr. Tom Marrero and Dr. Lin attended the 21st Coal Utilization and Fuel Systems Technical Conference in Clearwater Florida. Through our exhibit booth, an investment consultant showed a keen interest in financing a major coal log pipeline project. He plans to visit CPRC on April 22 and possibly attend the IAB meeting to discuss the project with our sponsors. Dr. Lin also met a few Chinese delegates. They showed strong interest in applying our compaction and binder technology to dewater and bind coal fines for mine mouth power plant use.

The following three proposals for additional research funding have, or are being, prepared:

1. A proposal to Society of Manufacturing Engineers for developing a new course to train students for designing better tools for manufacturing, including but not limited to, coal logs. The proposal has been submitted.
2. A proposal to NIST and DOE for additional funding to construct a prototype rotary press is being prepared.

3. An intent to submit proposal has been submitted to NSF for Research-Curriculum Development. The focus will be the mechanism and machine tools for high speed, high quality compaction. A five page conceptual paper is due May 3.

Future Plans:

For the next three months, the emphasis of the machine design group will be to complete the shop drawings and the specifications of construction details for the 300-ton hydraulic press, so that the machine can go on bid and then be constructed. These include:

1. The control subsystem design for the 300-ton press using a Programmable Logic Controller. The design work should include selection of hardware and software programming. The purposes of designing this subsystem are:

a. If the manufacturer for the 300-ton press cannot supply, or charge excessively for, the PLC hardware and software with the press, we can supply the hardware and software with small cost (hardware \$800 est.) and effort.

b. The PLC sequence will be adjusted in the future. We need to have the capability to re-program the PLC in-house.

2. The material feeding subsystem design for the 300-ton press.

3. Compacted log removal device design for the 300-ton press. In order not to delay the bid for manufacturing, tasks #1 through #3 have not been included in the 300-ton press design specifications. These three tasks must be completed to make the machine semiautomatic. The requirements for the first task, however, have been included in the bid document.

4. Advanced piston and mold-exit shape designs, which require detailed modeling of the compaction process for the coal logs. This work is planned for Mr. Wen's Ph.D thesis topic. Finite element analysis will be used to design the best piston head profile and mold-exit shapes. Based on our experience and information, piston and mold-exit shapes affect the capping phenomenon and the quality of the compacted logs. Before more advanced shapes are designed, the 300-ton press uses a design in the bid document derived from small-scale tests.

Publications:

Lin, Y. Y., Wen, G. P. and Xue, K., March 1996, "Machine for Rapid Production of Coal Logs: Design and Preliminary Tests," Proceedings of the 21st International Technical Conference on Coal Utilization & Fuel Systems, pp. 461-473.

Lin, Y. Y., Li, H. C., Wen, G. P. and Xue, K., March 1996, "The Design of A 300-Ton High Speed Hydraulic Press for Compaction of Coal Logs," extended abstract submitted to the 1996 ASME Winter Annual Meeting for consideration of publication in case studies.

Lin, Y. Y., Wen, G. P., Xue, K. and Li, Huachao, March 1996, Final Design Specifications of the 300-Ton Hydraulic Compaction Machine (28 pages and 31 drawings).

Deng, Q. W. and Lin, Y. Y., December 1995, "Modeling of RAM Extrusion Process and Optimal Die Design," accepted for presentation and publication in the Proceedings of the 1996 ASME Design Technical Conference. It is under review for publication by *Journal of Manufacturing Science & Engineering*. (22 pages) This paper is partially based on Deng's MS Thesis with extension on optimal shape design for extrusion die.

Capsule Pipeline Research Center

Quarterly Report

for

Individual Projects

(Period Covered: 1/1/96-3/31/96)

Project Title: Very Rapid Compaction of Coal Logs

P.I.: Dr. Brett Gunnink, Associate Professor of Civil Engineering

Research Assistants: Shiping Yang

Purpose of Study: To advance the speed of compaction of laboratory scale coal logs from approximately 30 seconds to less than 2 seconds.

Work Accomplished During the Period:

We have decreased the compaction time for the fabrication of 1.9 inch diameter coal logs in the laboratory from about 30 seconds to 6 seconds. This required the use of servo-controlled hydraulic test equipment that is available in the MU Civil Engineering Material/Structures laboratory. The results of the testing that was completed this quarter are described in the following paragraphs.

All data in this report are for 1.91" diameter Mettiki coal logs made at room temperature with 3% Orimulsion binder. After 1 hour exposure to 500 psi water, the logs were circulated in the CPRC test loop for 350 cycles at 85% of their theoretical liftoff velocity. Other details concerning the fabrication and testing of these logs are shown in Table 1.

Initially, coal logs were made using load control. This means that the function generator that controls the hydraulic ram of the compaction machine was programmed to make the log at a prescribed loading rate (i.e. 4,000 lb./sec). Figure 1 shows the function generator program signal for a 25 second compaction cycle. This is the curve labeled program in Figure 1. For this program, there were three stages, an initial slower loading stage (0 to 1,000 psi in 12 seconds), a second faster loading stage (1,000 to 20,000 psi in 12 seconds) and an unloading stage (20,000 psi to 0 psi in 1 second). This program should have produced a log in 25 seconds. However, the hydraulic servo controller was

unable to maintain these loading rate for the amount of displacement required to make a coal log. As a result the machine response lagged the program input. The machine response is also shown in Figure 1. The end result was that the 25 second load control program produced a log in 30 seconds (total time from zero load to peak load and return to zero load). Similarly, a 15 second load control program resulted in a 20 compaction time and a 6 second load control program resulted in a 15 second compaction time.

Circulation test results for logs made with load control are shown in Figure 2, Figure 3 and Figure 4 for 25 second, 15 second and 6 second program times respectively. Two important observations can be made from examining these figures. First accelerating the program time from 25 to 6 seconds, which resulted in accelerating the compaction time from 30 to 15 seconds had no significant effect on log performance. Second, log circulation performance was quite good, with approximately 5% weight loss after 350 circulation cycles. Flat-end logs were tested. Had beveled-end logs been made the weight loss after 350 cycles would have been less than 4%.

To further accelerate the production of coal logs and to have function generator program output more closely match coal log response, several logs were made using a displacement control program. With displacement control, the hydraulic ram is directed to move at a specified displacement rate (i.e. 0.5 inches/second). Figure 5 shows the displacement control program output in contrast with the machine response for 6 second displacement control program. From Figure 5, it can be seen that the machine response closely matches the program. In other words, for the 6 second displacement control program, the actual compaction time was 6 seconds as well. Figure 6 and Figure 7 show the circulation test results for logs made with 12 second and 6 second displacement control programs, respectively. Again, there was no significant change in coal log circulation performance associated with decreasing compaction time. All three coal logs made with a 6 s compaction time had less than 5% weight loss after 350 circulation cycles.

Figure 8 summarized the test results. Plotted in Figure 8 is weight loss versus number of circulation cycles for varying compaction times. Each curve is the average for three logs. After 350 cycles, the differences in log weight loss were not large, but the logs made most rapidly (6 seconds) had the least average weight loss ($\approx 4.3\%$). Again flat-end logs were tested. Had beveled-end logs been tested the weight loss for the 6 second logs would have been less the 3.5%.

Work Proposed for Next Quarter:

During the next quarter, we will continue our investigation of the circulation behavior of very rapidly compacted coal logs. We will continue to accelerate the compaction time to our compaction presses limits of operations (≈ 2 -3 seconds). We will also explore the effects of compaction temperature, pressure and binder concentration on the performance of very rapidly compacted coal logs.

Table 1. Experimental Conditions for Rapid Coal Log Compaction

Coal	Mettiki coal
Particle Size	Through #30 mesh
Temperature	Room
Mold	#8 (1.91", single piece, tapered exit)
Binder	Orimulsion(70% bitumen+30% water)
Binder Concentration	3% Orimulsion
Moisture	4.4% initial moisture
Aspect Ratio	1.68-1.69
Compaction Style	Floating mold
Compaction Pressure	About 20,000 psi (57,000 lb)
Compaction Time	30s, 20s, 15s, 12s, 6s
Ejection	Right after compaction
Water Absorption	1 hour @ 500 psi
Circulation	350 cycles @ 85% theoretical lift-off velocity

Comparison of the Processes of Function Generator and Compaction Machine for 25s Compaction

Figure 1 - Comparison of load control function generator program voltage output and actual applied machine pressure as functions of time.

**Circulation Performance of 25s Coal Logs
with Load Control
(RT, 3% Orimulsion, 4.4% moisture)**

Figure 2. - Circulation test weight loss versus number of circulation cycles for coal logs made using a 25 second load control program (30 second total compaction time).

**Circulation Performance of 15s Coal Logs
with Displacement Control
(RT, 3% Orimulsion, 4.4% moisture)**

Figure 3 - Circulation test weight loss versus number of circulation cycles for coal logs made using a 15 second load control program (20 second total compaction time).

**Circulation Performance of 6s Coal Logs
with Load Control
(RT, 3% Orimulsion, 4.4% moisture)**

Figure 4 - Circulation test weight loss versus number of circulation cycles for coal logs made using a 6 second load control program (15 second total compaction time).

Comparison of the Processes of Function Generator and Compaction Machine

6s

Figure 5 - Comparison of displacement control function generator program voltage output and actual applied machine pressure as functions of time.

**Circulation Performance of 12s - Coal Logs
with Displacement Control**
(RT, 3% Orimulsion, 4.4% moisture)

Figure 6 - Circulation test weight loss versus number of circulation cycles for coal logs made using a 12 second displacement control program (12 second total compaction time).

**Circulation Performance of 6s Coal Logs
with Displacement Control
(RT, 3% Orimulsion, 4.4% moisture)**

Figure 7 - Circulation test weight loss versus number of circulation cycles for coal logs made using a 6 second displacement control program (6 second total compaction time).

Circulation Performance of Rapidly Compacted Coal Logs
(RT, 3% Orimulsion, 4.4% initial moisture)

Figure 8 - Circulation test performance comparison for rapidly compacted coal logs; compaction time vary form 30 to 6 seconds.

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 1/1/96 to 4/31/96)

Project Title: **Rapid Compaction of Coal Logs**

Principal Investigator: Dr. Richard H. Luecke, Professor of Chemical Engineering

Graduate Student Assistant: Marcus Bahr

Purpose of the Research: To reduce the time required for the compaction cycle for coal logs.

Work Accomplished During the Period: Thesis and final examinations were completed.

SUMMARY

Manufacture of suitable coal logs for use in a pipeline has been one of the major challenges and priorities for the Capsule Pipeline Research Center. In the early coal log research, robust logs were achieved using relatively slow and gradual application of compaction pressure. The "standard" compaction cycle that evolved consisted of 3 minutes to apply pressure (at a uniform rate), 5 minutes hold at pressure, and 3 minutes for uniform pressure release.

Economic analyses showed, however, that much shorter compaction cycles were needed to reduce capital expenditure in heavy compaction machinery. When scouting experiments showed that a shortened compaction cycle with a load time of two minutes, no hold time at high pressure, and one minute ejection time had only a marginal deleterious effect on log quality, a program was begun to find the shortest possible compaction cycle for acceptable logs.

The results of this research showed that the crucial factors involved temperature, initial moisture, particle size and sufficient mixing (Table 1). Proper adjustment of these variables, along

with lower lift-off velocities for larger diameter logs, allowed the rapidly compacted logs to pass the standard test criteria. This very rigorous test requires less than 3% weight loss in 350 cycles of circulation following a high pressure water immersion procedure and is considered to be the defining delimiter for satisfactory logs.

Table 1

Standard Conditions with "Fast" Compaction

Coal	Metiki coal (from MAPCO). Through 30 mesh, from a hammermill.
Compaction Cycle	30-40 second loading, 0-1 second unloading, No hold time at pressure.
Maximum Pressure	19,100 psi.
Binder	0.5% binder (0.75% Orimulsion) based on dry coal.
Moisture	5-9% present in initial mix.
Temperature	Coal preheated to 97°C; mold at room temperature.
Circulation conditions	85% of lift-off velocity; diameter 1.9 inches ... 90% of pipe ID.
Mold	Single-piece chrome-plated, with flat pistons.
Ejection from mold	Ejected hot and quickly as possible.
Curing	None; logs subjected to high pressure water test immediately after manufacture; Storage thereafter under water.
Tempering	Variable from 1/2 hour to 4 days...no effect noted.

The minimum compaction cycle time of 30 to 40 seconds that was developed in this work was limited by the physical capabilities of our compaction equipment rather than by a real physical

bound arising from the properties of the coal itself. The time versus displacement compaction curves indicate that much shorter compaction cycle times are feasible since less than half of the compaction time is spent above 4000 psi.

Variables in Fast Compaction

The investigations with the fast compaction cycle explored six major areas:

1. Western and Eastern coal.

While Western (sub-bituminous) coal responded well to fast compaction, Eastern (bituminous) coal required extensive investigation to determine satisfactory conditions.

2. Compaction Temperature

Both room temperature and 97°C were explored. The ostensible economic advantages of the lower temperature may be lost because of the higher binder levels (2.2%) and post-processing log curing time of 24 to 48 hr. required. At higher temperatures (97°C), even with binder content reduced to a very low level (0.5%), logs could be manufactured with the fast compaction cycle that more than met circulation criteria in the 2 inch steel pipeline loop. This result is illustrated in Figure 1 showing rate of weight loss for logs produced at the conditions of Table 1. The tempering time (depicted in this graph and discussed below) is seen to have very little effect.

This figure demonstrates that 7 of the 8 test logs passed the nominal circulation criteria of 3% loss in 350 cycles and the other was only slightly higher at about 3.4%. Note that these results were not optimized; for example these logs had sharp rather than beveled edges.

The relatively large weight loss from these logs that occurred very early in the circulation test are probably small chunks from non-beveled edges or from "capping" which we believe is preventable in commercial sized logs.

3. Initial Moisture Levels

With either fast or slow compaction, the ultimate moisture requirement is the equilibrium moisture level. Initial moisture levels in the mix are more critical with fast compaction than with slow compaction. During compaction, excess moisture above the equilibrium level is pressed out.

With slower compaction, there is plenty of time for water to be pressed out of the porous mix. With fast compaction, the time required for liquid flow from the interior of the log could limit intimate particle-to-particle interactions.

In these experiments, good mixing was difficult to accomplish with lower moisture levels since excess water acts as a carrier to help distribute the binder. The moisture level for the performance of the logs depicted in Figure 1 was attained by mixing with an excess of water (25-35%) to facilitate mixing (see below) and then air drying to 7.5% before compaction.

4. Mixing of the Ground Coal with Binder and Moisture

A key overall finding of this work was this importance of adequate mixing of the binder in the powdered coal charged to the mold. Careful design of full scale mixing facilities will be required.

In our experiments, better mixing was accomplished by lengthening the mixing time from 4 to 10 minutes and by using extra care in the initial distribution of water and Orimulsion. The best

results were obtained by mixing the coal with a relatively large excess of water (25-35%) and then before starting the compaction, removing the excess water by air drying.

5. Tempering

In some earlier experiments, there were indications that storage of the powdered and mixed coal before compaction had an influence on the strength of the finished log. Storage of the pre-mixed coal charge was called "tempering" to distinguish it from "curing" of finished logs.

Specific experiments designed to isolate the effect of tempering showed that, if it exists at all, the effect is less than the normal variability observed in log production. Figure 1 show the lack of correlation of circulation performance with tempering.

6. Preheating the Coal Outside the Mold

In laboratory compaction of coal logs, the premixed powdered coal at room temperature is charged to the mold preheated to 97°C with external electric resistance heaters. The coal is then heated in the mold (no pressure) for 10-20 minutes until the temperature reaches 97°C before compaction.

In a commercial-sized unit, coal would be preheated and charged at an elevated temperature to the mold. As part of the general investigation of fast cycle compaction, the use of externally preheated coal was considered. It was not expected that the different heating modes would impair the quality of the logs. And indeed, it did not. Instead the surprise was that a distinct and important quality improvement was found.

Figure 2. shows the dramatic improvement attained by preheating the coal mix. Other experiments showed similar but less dramatic improvement. In all cases, the improvement comes primarily because of the reduction in the losses of chunks in the early part of the circulation cycle.

FUTURE PLANS

The highest rate of compaction was limited in these studies by the mechanical capability of the compaction equipment available for these experiments. With the graduation of this student, rapid compaction study must now move to different equipment with newly developed procedures. Dr. Brett Gunnick has begun the next stage of this work using compaction equipment that will permit compaction times of 10 seconds or less. Dr. Luecke has begun a study of modeling the flow of fluids through the mold and their ultimate disposition and expulsion rates during rapid compaction.

Weight loss percent vs. cycles of circulation at various tempering times.

Figure 1. Weight Loss of Fast Compacted Coal Logs (Conditions in Table 1)

Figure 2. Preheated vs. Mold-Heated Coal Mix

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 01/01/96-03/31/96)

Project Title: Fast-track experiments

Principal Investigator: Yin Li

Co-Investigator: Dr. Henry Liu

Research Assistant: J. Burris, K. Clark, and B. Tao

Purpose of Study:

1. Threshold binder concentration

Binder is important to coal log quality and fabrication cost. The purpose of this study is to find out the lowest binder concentration that produces acceptable coal logs (<5% weight loss at 350 cycles for flat-ended, room temperature coal logs) with and without lubrication. If bevel-ended coal logs are made, 3% weight loss at 350 cycles can be achieved.

2. Piston lubricating effect

To test the effect of lubricating the piston ends with calcium stearate and MoS₂ powders on coal log quality.

3. Effect of Pressure on Coal Log Quality

During coal log circulation it has been noticed that very fine (around 0.02 mm in width), circumferencial cracks appeared on most of the coal log surfaces. Such cracks introduce relatively faster weight loss at the beginning of a circulation. Overpressure is suspected for causing such cracks to occur. Therefore, a preliminary test was conducted to investigate the effect of compaction peak pressure on coal log quality.

Work Accomplished during the Period:

Threshold binder concentration

In the last quarterly report, the preliminary results were reported on coal logs made with unlubricated mold. After last report the experiments were completed and the final results were given here. A total of 81 flat-ended coal logs were compacted using unlubricated, calcium stearate powder lubricated, and MoS₂ powder lubricated stainless steel molds. The coal used was Mettiki coal. The logs were compacted at room temperature, a peak pressure of 19,545 psi and with 6 minute loading-6 minute unloading without holding. All the logs were tested for water absorption and wear resistance. Detailed analysis on coal log dimension, moisture content, density, porosity and weight loss were conducted. A project completion report was submitted (Li, et al., 1996).

The following major conclusions have been reached:

- 1). Due to particle fracture during compaction and the difference in circulation velocity, the threshold binder concentrations with and without lubrication cannot be clearly identified based on current results. The approximate threshold binder concentration appears to be 0.5% for both calcium stearate lubricated and unlubricated molds and 1% for MoS₂ lubricated mold under the

given experimental conditions (Figs. 1 to 3). The threshold binder concentrations were determined based on the following:

- (a). The coal logs were able to be circulated to or close to 350 cycles.
 - (b). The average weight loss of three coal logs was $< 5\%$ at 350 cycles or the weight loss of the best coal was less than 5% at 350 cycles.
 - (c). Coal logs satisfied (a) and (b) but had the lowest binder concentration.
- 2). The volumes of the coal logs compacted in the lubricated molds are generally smaller than that of the logs made in the unlubricated mold, and are less dependent on binder levels comparing with the unlubricated mold. Volume expansion during water absorption is independent of binder concentration.
- 3). Logs compacted with Orimulsion, even as low as 0.25% , performed significantly better (have less weight loss due to wear) than those compacted without binder. The variations of the weight loss of coal logs made in lubricated molds are generally smaller than that of coal logs made in the unlubricated mold. This means lubricated molds produce more uniform quality coal logs.
- 4). When the binder concentration is less than 1% , logs compacted with lubricated molds did not show improvement in wear resistance as compared to logs compacted with unlubricated mold. In fact, for **binderless logs**, the unlubricated mold produced the best (most wear resistant) coal logs, and the MoS_2 lubricated mold produced the worst coal logs. Particle fracture due to higher force transmission resulting from lubrication and a slight increase in circulating velocity both contribute to this. With 1% Orimulsion, the wear resistance of the coal logs compacted in the lubricated molds are better than those of the unlubricated mold, particularly with the MoS_2 lubricated mold.
- 5). Preventing particle fracture during compaction may be the key for producing wear-resistant coal logs with less than 1% binder.

Piston Lubricating Effects

A total of 9 logs were compacted using an unlubricated mold and flat-ended, stainless steel pistons without lubrication, with calcium stearate powder lubrication, and with MoS_2 powder lubrication. The logs were compacted at room temperature, a peak pressure of 19,545 psi and with 1% Orimulsion and 6 minute loading-6 minute unloading without holding. All coal logs were subjected to water absorption and wear loss tests. Density, moisture content and porosity were analyzed. A project completion report was submitted (Li, et al., 1996).

The following conclusions were reached:

The wear losses of the coal logs compacted with lubricated pistons were higher than those of the control logs compacted with unlubricated pistons (Fig. 4). This may be due to the creation of a more impermeable layer near the piston by lubrication. This layer impedes water drainage during compaction resulting in weak logs.

Effect of Pressure on Coal Log Quality

In this preliminary study, 21 coal logs with 1% Orimulsion were made with an unlubricated mold and flat-ended pistons. The compaction peak pressure ranged from 19,454 to 17451 psi with a loading speed of 9334 lb/min. Water absorption and wear testes were conducted to assess the coal log quality.

Conclusions:

1. In the range of peak pressures tested, decreasing peak pressure produces better coal logs (Fig. 5).
2. Same test needs to be conducted at pressure below 18,000 psi to see if the trend continues. It is expected that an optimum pressure will be at a peak pressure less than 18,000 psi.
3. Overpressure should be prevented to assure the good quality coal logs can be produced.

Future Plan:

During next quarter, the following experiments will be completed:

1. Pressure Effects

The pressure effect tests will be repeated and extended to pressure below 18,000 psi to determine what the optimum pressure is for binderless logs made of Mettiki coal in unlubricated mold.

2. Diameter Ratio Effects

To investigate the log diameter ratio effect on coal log wear resistance, coal logs will be made from Mettiki coal using three molds with different diameter: 2.18", 1.91", and 1.75". A total of 9 coal logs will be compacted at room temperature and with a binder concentration of 1.0%. The surface condition of the mold will be an unlubricated, stainless-steel mold. The peak pressure will be 18,000 psi. Wear resistance will be used to assess the log quality. Previously, comparisons were made between only the 1.75" and 1.91" logs. The new test will include 2.18" logs, thereby extending the test to larger diameter logs than done previously.

3. Endurance Life of Lubricants

To investigate the endurance lives of using calcium stearate powder, MoS_2 powder, and MoS_2 dry film as lubricant for coal-log compaction, coal log ejection force (or friction force) will be measured to determine the endurance life of the lubricants.

4. Ejection Orientation Effects

To investigate the effect of ejecting orientation on coal log quality, the following experiments will be conducted. First, 3 coal logs will be compacted using No. 8 mold **with the taper end at the bottom**. After unloading, the coal log will be ejected as usual (coal log bottom comes out first). Another 3 logs will compacted using the same mold **with the taper end at the top**. After compaction, turn the mold over so that the taper end is at the bottom before ejection taking place. Eject the coal log so that the top of the coal log comes out first. Bituminous coal (-30 mesh) from Mettiki Mine of the MAPCO Coal Company in Maryland will be used. The coal logs will be compacted at an initial moisture content of 20% by weight; 1% Orimulsion (water included) dry coal basis; room temperature; 18,149 psi peak pressure; 18,667 lb/min loading speed; immediate ejection following unloading.

Future fast track experiments on coal log compaction will shift from slow compaction to 45 second compaction using the current hydraulic press. This will substantially improve the productivity of the tests.

References:

Li, Y., B. Tao, and H. Liu. "Threshold binder concentration", Project completion report, March 5, 1996.

Li, Y., J. Burris, and H. Liu. "Piston lubrication effects", Project completion report, Feb. 10, 1996.

Li, Y., K. Clark, and H. Liu. "Effects of overpressure on coal log quality", Report on preliminary results, March 26, 1996.

Figure 1. Weight loss of coal logs compacted in an unlubricated, stainless steel mold at different binder concentrations (Flat-end coal logs).

Figure 2. Weight loss of coal logs compacted in a calcium stearate lubricated, stainless steel mold at different binder concentrations (Flat-end coal logs).

Figure 3. Weight loss of coal logs compacted in a MoS₂ lubricated, stainless steel mold at different binder concentrations (Flat-end coal logs).

Figure 4. Effects of piston lubrication on coal log weight loss as a function of circulating cycles (1% Orimulsion).

Figure 5. Effects of compaction pressure on weight loss of coal logs with 1% binder.

COAL LOG PIPELINE RESEARCH PROJECT

1st Quarterly Report For 1996

(Period Covered: 1/1/96-3/31/96)

Project Title: Coal Log Fabrication Using Hydrophobic Binders

Project Investigator: Dr. John W. Wilson

Research Assistant Professor: Dr. Yungchin Ding

Graduate Research Assistant: Bing Zhao

OVERVIEW

In order to accelerate the commercialization of the coal log pipeline technology, the durability of commercial size coal logs is considered to be one of the most important tasks that must be evaluated in the large pipeline degradation tests. In the previous tests, large coal logs were evaluated from the tumbling test results. However, the tumbling test results can only provide a relative index to compare the abrasive resistance of coal logs that were made under various conditions. It is believed that only the pipeline degradation test can accurately reveal the true durability and abrasive resistance of coal logs. Therefore, a 6" diameter pipeline test loop was planned and is currently being constructed at UMR for testing 5.3" coal logs that are manufactured there.

In the past three months, the major efforts of the UMR team has been focused on designing and constructing the 6" pipeline loop. The 6" pipeline loop is a scale-up design based upon the 2" loop at UMC. Todate, the construction of the main body of the pipeline has been accomplished ahead of schedule through the joint effort of the Williams Pipeline Company and the Rolla team.

The preparation of the supplementary facilities for completing the 6" pipeline loop is underway.

The fast compaction of large (5.3" diam.) coal logs have also been carried out and evaluated using tumbling tests. By comparing the large coal log tumbling results with small coal log (1.9" diam.) pipeline degradation test results, a correlation between these two different sizes of coal logs which were fabricated using fast compaction method, was evaluated.

WORK ACCOMPLISHED DURING THE PERIOD

Pipeline Design

1. Construction site

The 6" pipeline was planned to be built at the Mining Engineering Dept. Experimental Mine at UMR, as shown in Figure 1.

2. Pipeline loop components

The overall 6" pipeline loop layout and detailed components are shown in Figure 2.

- a. 6.187" (internal diameter) steel pipe - 320' long.
- b. 25 HP water pump - Bell & Gossett 6BC Series 1531 Close-Coupled Centrifugal Pump.
- c. Jet pump and diffuser - manufactured at UMC.
- d. Water tank - loading and unloading of coal logs.
- e. Water reservoir - water storage.
- f. 1 HP water pump - pump water from reservoir to 6" pipeline.
- g. 6" (internal diameter) Plexiglas pipe - for coal log monitoring.
- h. Pipe stand - supporting the pipeline loop.
- i. Shed - for covering important components and storage area.

3. Water tank and loading and unloading device

The dimensions of the water tank used for loading/unloading coal logs is 5 ft long, 2.5 ft. wide and 3 ft. height. The material used for the water tank is 1/8" steel plate.

As shown in Figure 3, within the water tank, there is a 4 ft. pipe section that has been cut in half for the coal log loading and unloading operations. The cut-off half pipe section was then re-attached to the main pipe with hinges. Through this simple

design, this half pipe section can be flipped closed when circulating coal logs and then opened when coal logs are loaded and unloaded. A latch will be used to secure the cut-off half pipe section in its close position, when the pump is running.

4. Water reservoir

The water reservoir is used to store water for pipeline tests. The reservoir has the capacity to hold 1,200 gallons of water. A small, one horsepower water pump (50 gal/min. and 20 ft. lift) will be used to pump the water to the pipeline. The pipeline water will be drained to the reservoir when tests are finished. A steel tank has been selected and placed in position for this purpose.

5. Water pump

Using the formula, a lift-off velocity of 9.3 ft/sec. is required to run the 5.3" coal logs in a 6" pipeline.

To calculate the horse power required for coal log transportation, 10 ft/sec. lift-off velocity is used.

V_1 (lift-off velocity) = 10 ft./sec. (assuming water flow rate (V) = lift-off velocity)

f (coefficient of friction, smooth pipe) = 0.0178

L (pipeline length) = 320 ft

g (gravity of acceleration) = 32.17 ft/sec²

D (pipeline nominal diameter) = 0.5 ft

h_f (head loss, ft.) = $f \times (L/D) \times (V^2/2g) = 17.71$ ft

However, a 25 ft. head loss is used here to calculate the horse power requirement for a wider pump operating range.

r (density of water) = 62.4 lb/ft³

Q (water flow rate) = 10 (ft./sec.) $\times 0.5^2\pi/4$ (ft.²) = 1.96 cfs

2 cfs is used for the following calculation:

Power requirement = $r \times Q \times H = 62.4 \times 2 \times 25 = 3,120$ ft-lb/sec.

1 horse power = 550 ft.-lb/sec.

HP requirement = $3,120/550 = 5.67$ HP

Due to the low efficiency of the jet pump, estimated at 25%, the horse power required for the water pump will then be 22.68 HP ($5.67/0.25$). Therefore, a 25 HP water pump is considered to be adequate for testing the 5.3" coal logs in the 6" pipeline loop.

6. Pipeline support

The adjustable pipe stand, as shown in Figure 4, was designed to support the pipeline loop. These pipe stands were made with 8" channel steel, 3" ID steel pipe, 2 1/2" ID steel pipe, and 1/2" bolts. These pipe stands were placed at 20 ft. intervals, as shown in Figure 5, except for the section that contains the Plexiglas pipe, water tank and jet pump.

Pipeline Construction

1. Site preparation

The site preparation for the 6" pipeline was accomplished on schedule before the setup of the pipeline loop. The site preparation included surveying, positioning of pipeline supports, ground preparation for pipe stands, ground leveling, and power line surveying.

2. Ground construction

Before the pipeline loop was installed, the ground base for the pipeline stands and water tank were excavated using an backhoe, before pouring concrete and setting the pipe stands. The dimension of a concrete base was 2' x 2' x 1.5' for a pipe stand, and 5' x 6' x 2' for the water tank.

3. Pipeline loop construction

As scheduled, the maintenance crew of the Williams Pipeline company came to Rolla to construct the 6" pipeline on the 18th of March. The installation of the main pipeline body was accomplished by the afternoon of the following day. The pipeline loop leveling was conducted by adjusting the stands after the pipeline was installed. Photographs of the pipeline loop are shown in Figures 6 and 7.

Preparation of Supplementary Facilities

1. Water pump

Bell & Gossett 6BC Series 1531 Close-Coupled Centrifugal Pump suggested by Dr. Lenau, has been ordered at Rolla.

2. Flowmeter

In order to measure flow velocity in the pipeline loop, a portable Ultrasonic Doppler flowmeter has been ordered. This instrument contains a unique flow-monitoring device that utilizes the frequency shift of an ultrasonic signal to measure the flow velocities of liquids by attaching the instrument onto the outside wall of the pipe.

3. Plexiglas pipe

Some Plexiglas pipes have been ordered. The 6" diameter Plexiglas pipe will be used as a segment of the 6" pipeline loop for monitoring coal log motion. The 5.5" diameter Plexiglas pipes will be used to manufacture false coal logs with variable densities by filling with various types of materials. These false coal logs will be used to calibrate the pipeline system before running actual coal logs in the pipeline.

4. Mold shaping

The existing 5.3" coal log mold has been sent to Detroit Tool at Lebanon, Missouri for modifying the exit of the mold from a right angle to a rounded exit. This exit modification was made to investigate the effect of the exit shape of the mold on the quality of coal logs.

Fast Compaction of Large (5.3" diam.) and small (1.9" diam.) Coal Logs

In order to study the influence of fast compaction on the performance of coal logs, the compaction loading times were reduced from 60 to 15 sec. for coal log fabrication. The 5 min. tumbling tests showed that the weight loss of coal logs decreased from 7.8 to 2.3% as the loading time increased from 15 to 60 sec. From the small coal log degradation test results (25 sec. fast compaction, Dr. Gunnink), an

average of 6% weight loss was achieved after 320 cycles of circulation in the laboratory test loop at UMC. By comparing the large and small coal log test results, it appears that there is a clear possibility that fast compaction of large coal logs will survive in a commercial pipeline used for the transportation of coal logs.

FUTURE WORK

1. The construction of the 6" pipeline will be completed as soon as the supplementary facilities are ready.
2. Test and calibrate the 6" pipeline using false coal logs.
3. Manufacture large coal logs for testing in the 6" pipeline.
4. Continue large rapidcoal log fabrication, and compare the test results with small 1.9" coal logs manufactured at UMC under similar conditions.

Figure 1. Location of the 6" pipeline.

Overall 6" pipeline layout

Figure 2. 6" pipeline layout

Water Tank for Coal Log Loading/Unloading

Top View

Scale 1 ft

Front View

Side View

Figure 3. Water tank dimension

Figure 4. Pipe stand components

Pipe stand location for 6" pipeline

Figure 5. Location of pipe stands

Figure 7. Overall view of 6" pipeline

Figure 6. 6" pipeline construction site

Capsule Pipeline Research Center Quarterly Report

(period covered: 1/1/96 -- 3/31/96)

Project Title: Drag Reduction in Large Diameter Hydraulic Capsule Pipeline

Principal Investigator: James P. Seaba
Assistant Professor of Mechanical Engineering

Co-Investigator: Henry Liu
Professor of Civil Engineering

Research Assistant: Gangwei Wu

Purpose of Research:

Test the effectiveness of using drag reducing additives (polymers and polymer-fiber combination) to reduce head loss in an 8-inch-diameter capsule pipeline.

Need for Study:

It has been demonstrated from a previous study (Huang 1994; Huang et al 1996) that drag reduction as much as 75% is possible in coal log pipeline by using polyethylene oxide (PEO) at approximately 25 ppm concentration. This has strong implications to reduce the energy cost of coal log pipelines which is quite substantial when the pipeline is long. However, since the laboratory test was conducted in a 2-inch-diameter pipe, the results may be quite different for commercial CLPs which are of much larger diameter. Testing in an 8-inch-diameter pipeline will yield more realistic results.

Test Plan:

The test will be carried out in our existing 8-inch-diameter, 430-ft-long steel pipe loop located at the UMC Research Park. Metallic capsules containing cement cylinders fixed on a threaded rod will be used to simulate coal logs. The specific gravity of the capsules will be around 1.32--approximately the same as for coal logs. Metallic capsules are chosen not only for convenience but also to enable detection by electromikes when being circulated through the pipeline. The capsules tested will have 4 diameter ratios and 4 aspect ratios. Characteristics of the capsules are shown in Table 1. The polymer used will again be PEO. A small amount (less than 1%) of fiber (pulp) will also be added to PEO to enhance the drag reduction and to

reduce the degradation rate of PEO. The tests will be carried at $0.5V_L$, $0.7V_L$, $0.9V_L$ and $1.1V_L$. Both the headloss and the capsule behavior (capsule speed, angle-of-attack and gap) will be measured.

Work Accomplished in this Period:

1. Optimization and Determination of Pressure Drop Measurement: Analyses and comparison with respect to accuracy, signal dynamic response and other characteristics among the three techniques employed by previous CPRC investigators were conducted to select a most suitable technique for total pressure drop measurement of drag reduction experiments in large diameter pipeline. In this kind of experiments, pressure drop along the test section will change with respect of time due to the polymer degradation. But the changed value is considerably smaller than the line pressure. How to accurately measure this change along a long test section is important to the evaluation of drag reduction. Analyses and comparison show that using Omega Model PX771-100 WDI to directly measure the differential pressure is a good choice, although another method, which has better accuracy but is less convenient, was developed.

2. Calibration of Flowmeter: An 8-inch diameter magnetic flowmeter was calibrated by the weighing tank method. The calibration curve was shown in Figure 1. The calibrated magnetic flowmeter will be installed in the test pipe for on-site calibration of the acoustic flowmeter. Then, the magnetic flowmeter will be removed from the test loop because its diameter is slightly smaller than the pipe diameter and causes impact and damage to capsules and the flowmeter.

3. Calibration of Electromikes: Two electromikes were calibrated with one of the calibration curves shown in Figure 2.

4. Data Acquisition System: The data acquisition system, including both hardware and software, has been set up. The main hardware includes a Macintosh IIfx computer, a NB-MIO-16X I/O board, a 5B-01 series backplane and signal conditioning modules. The software consists of data acquisition programs based on Labview3.1.

5. Experimental Setup: Much of the work relevant to the experimental setup, such as installation of instrument and wiring, has been completed.

Work Planned for the Next Three Months:

1. Complete the preparation of the experimental setup.
2. Calibrate the differential pressure transducer and the acoustic flowmeter.
3. Modify the data acquisition system.
4. Take preliminary data from experiments with water only, water/capsules flow and water/polymer flow.

References:

- Huang, X., Polymer drag reduction in hydraulic capsule pipeline. M.S. Thesis, University of Missouri-Columbia, 1994.
- Huang, X., Liu, H. and Marrero, T.R., "Polymer drag reduction in capsule pipeline", submitted to AICHE Journal, March, 1996.
- Rhee, K., Cylindrical capsules in fiber - water flow in pipe. Ph.D. Thesis, University of Missouri-Columbia, 1989.

Table 1 Characteristics of Capsules

No	Outer diameter, D_c (inch)	Length L_c (inch)	Aspect Ratio $a = L_c / D_c$	Diameter Ratio $k = D_c / D$	Specific Gravity S	Lift-off Velocity V_L (m/s)
1	6	9.5	1.58	0.73	~1.32	3.80
2	6	14.25	2.38	0.73	~1.32	4.65
3	7.25	12	1.66	0.88	~1.32	2.97
4	7.25	17	2.34	0.88	~1.32	3.53

Figure 1 Calibration curve for Magnetic Flowmeter

Figure 2 Calibration of Electromike (#2)

Capsule Pipeline Research Center
Quarterly Report
(Period Covered : 1/1/96 - 3/31/96)

Project Title : Automatic Control of Coal Log Pipeline System

Principal Investigator : Satish S. Nair, Associate Professor of Mechanical and Aero. Engrg

Graduate Research Assistants : Hongliu Du (Ph.D. student)

Purpose of the Research :

To study, design, test, and improve an automatic control system needed for reliable operation of coal log pipeline systems. To model the system dynamics as well as the interactions between the pumps, valves and the capsules for effective control design and system sizing.

Work Accomplished During the Period :

Several experiments were conducted with the small-scale system to check the effect of line-fill rate on the functions of the separator. It was found that, for the small scale system, the separator will not function properly if the capsule train length exceeds approximately 30 capsules, using pump #3 installed in the pump bypass, but that higher line-fill rates were fine if pump #1 is used. The difference between the two pumps is that there is a pressure regulator at the outlet of pump #1, which is not the case for pump #3. Capsules with enlarged head round radius were fabricated to avoid the jam at the T joints in the pump bypass - this eliminated the jamming problem observed.

Specific tasks for the period from 1 Jan to 31 Aug. 1996 were defined as follows:

- (i) Study the assumptions for all the mathematical models developed so and develop a transient model of both centrifugal as well as positive displacement pump driving fixed and time varying loads. Then, extend the model to a recirculating loop system with valves (stroked) using only water. This involves realistic pump curves, start up transients, water hammer effects, etc.
- (ii) Develop the simulation model of the pump bypass with a recirculating loop with valve stroking for the water-only case. Again, study transient effects.
- (iii) Add the train separator designed to the simulation model in (ii).
- (iv) Perform experiments on the small scale system and validate the observations and results in (ii) and (iii). This includes using a high-speed video recording system, a data acquisition board, getting flow and pressure sensors, etc. Modify the control program to accommodate the changes.

Figure 1. Simulation model

g : 9.8 m/s^2

f : 0.018

ρ : 1000 kg/m^3

D : 0.2032 m (8")

C_b : 914.4 m/s (3000 ft/s)

Distance from reservoir to the two branches, $Z = 10 \text{ m}$ (32.8 ft)

Distance from the two branches to pump, $X = 620 \text{ m}$ (2034.1 ft)

Recirculating loop length: 32000 m (20 miles)

Length of bypass, $2Y = 120 \text{ m}$ (393.7 ft)

Reservoir head, $H_o = 20 \text{ m}$ (65.6 ft)

Centrifugal pump with characteristic curve: $H_p = 1050 + 150.7Q - 1550Q^2$ (m)

Based on the results of the experiments, adjust the simulation program to take care of all realistic effects, including friction losses, etc., and

(v) Prepare a report of the subtasks performed.

Simulation Model of the Train-Separator

Task (i) has been completed, and task (ii) is being performed. In task (i) the transients associated with pumps and valves were studied in detail and a simulation program for the model of a recirculating loop system with valves using water was developed. Various pump boundary conditions were investigated and several scenarios simulated. The overall system to be simulated is shown in Figure 1. The objective of the research is to investigate the transients in more detail than has been done before, specifically negative pressure generation, flow reversals, etc., for reliable design of the booster pump system.

SCADA System Design Issues

The Post-Doctoral student associated with this part left the group to join an excellent position with the Product Engineering Center at John Deere, Inc., Waterloo, IA. Before departure he had written several documents, as cited in the previous report, summarizing the tasks related to this area. We are still to hire a replacement for him to continue the development associated with the SCADA system.

Work Proposed for the Next Quarter :

- (i) Include the separator system into the simulation model (Hongliu Du).
- (ii) Conduct extensive experiments with the small-scale capsule pipeline prototype including investigating the flow reversals for the purposes of enhancing the simulation model. (Hongliu Du).
- (ii) Continue work on the patent application for the novel train separator sub-system developed by CPRC. (Nair and Du).

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 1/1/96-4/31/96)

Project Title: Hydrodynamics of CLP

Principal Investigator: Henry Liu, Professor of Civil Engineering

Co-Investigator: Charles W. Lenau, Professor of Civil Engineering
James Seaba, Assistant Professor of Mechanical & Aerospace Engineering

Purpose of Research: Improve the theoretical model for predicting coal log pipeline pressure gradient and capsule velocity in straight pipe. Then, extend the model to cover sloped and curved pipe.

Work Accomplished During the Period:

The existing theoretical models (equations) for predicting coal log pipeline (CLP) and hydraulic capsule pipeline (HCP) were re-evaluated. Relative importance of each term in the equations were compared, and sources of possible inaccuracy were identified. Results of the study were documented in the two References listed below

Based on this evaluation, the existing equations for predicting capsule pressure gradient, capsule velocity, incipient velocity and so forth were modified to produced more accurate results. The model for single capsule was extended to groups or trains of capsules. Experimental data on coal log trains were collected and compared with the theoretical prediction.

Some results of this study are given in Figures 1 through 3.

Future Plan:

For the next 3 months, the existing equations for predicting coal log behavior in horizontal pipe will be extended to sloped pipe, and the effect of slope will be analyzed using the extended equations.

References:

Gao, X., Evaluation of Existing Theories for Regime 1 of HCP, CPRC Report, University of Missouri-Columbia, March 1996.

Xu, W.W., Hydraulic Behavior of Coal Log Train, M.S. Thesis, Department of Civil Engineering, University of Missouri-Columbia, May 1996.

Figure 1 Pressure Variation along a stationary capsule
($L_c=1.0\text{m}$, $D_c=0.2\text{m}$, $D=0.232\text{m}$, $a=5.0$ and $k=0.862$)

Figure 2 Distribution of Lift along Capsule

Figure 3. Capsule Flow Pressure Gradient of capsule train with $a=2$, $k=0.707$, $s=1.314$, $n=10$

Capsule Pipeline Research Center

Quarterly Report

(Period Covered: 1/1/96-3/31/96)

Project Title: Coal Heating System Research

**Project Investigators: Dr. T.R. Marrero, Associate Professor of Chemical Engineering
Dr. Alley Butler, Assistant Professor of Mechanical Engineering**

Research Associate: Mr. W.J. Burkett

Overview:

Research was recently initiated to determine the best possible heating system for coal or coal-binder mixtures prior to coal compaction. This aspect of coal log pipeline has been previously considered, but available results need to better establish a practical system. The heating system, in addition to raising the temperature of the coal to about 90°C, should be able to control the moisture content of the coal. If the coal is too wet, the moisture content is to be reduced, and conversely.

Progress to Date:

Weekly meetings of faculty and students were initiated in February to develop a strategy. Members were Dr. Butler, Mr. Burkett, and myself, two MAE students under Dr. Butler's supervision are participants-- one is supported by CPRC at 1/4-time, the other is unsupported. The first step completed a list of potential coal heating processes. About one dozen processes were identified. For each of these processes simplified-flow sheets (mass, power, and major component size) were to be prepared. These process flow sheets are to be the basis for selection of the most promising heating system. A few processes have been evaluated to date-- see Dr. Butler's report attached.

Companies that design and sell systems capable of heating coal in quantities for CLP are being contacted by Bill Burkett. One company has requested a sample of coal mixture for test purposes.

Plan for Next Quarter:

Complete process flow sheet evaluations and obtain industrial cost data for coal heating systems.

Capsule Pipeline Research Center Quarterly Report

(Period covered: 1/1/1996 to 3/31/1996)

Research Project: Coal Heating System Study
Principal Investigator: Dr. Thomas Marrero
Co. Investigator: Mr. Bill Burkett/Dr. Alley C. Butler
Research Assistant: Shensheng Wang, Joshua Summers

Purpose:

To study and complete systems level design for the most practical/economical coal heating system, together with the conveyor system, and to assess its capital/operating costs. Typically, the economic feasibility for several alternate heating and convey systems such as a pneumatic conveyor, fluidized bed, chain/pan conveyor, screw conveyor, and microwave heating are to be studied.

Work Accomplished During this period:

1. In order to study the economic feasibility for alternate coal heating and conveying approaches, the coal physical properties were first studied by library search. The main properties of the coal were determined as basic data for the further use in this study.

2. Several heating and conveying systems were examined and evaluated by analysis.

A. Study of pneumatic conveying and heating system:

By studying the materials obtained from the library on pneumatic conveying systems, it was found that a low-pressure (less than 30 psig) system can be used to convey coal. But, after calculating the amount of air and the temperature of hot air required to convey and heat coal, it is apparent that this approach is not feasible. Figure 1(a) provides a sketch of this alternative.

The result of analysis shows that, if a total of six pipelines were used, the inlet temperature of hot air must be $2100^{\circ}F$ or $1167^{\circ}C$ to insure the air exit temperature of

110°C (230°F). This would provide a coal exit temperature of 100°C. Obviously that inlet temperature (1167 deg.C) of hot air needed is too high to be used in practice.

By using dimensional similitude with Reynolds numbers, the steam used to directly convey and heat coal was estimated, and the result of this analysis showed that the steam should have inlet enthalpy of 1630.74Btu/lb to meet the need of conveying and heating coal. This represents approximately 500 deg.C of superheat. Therefore, this approach is also questionable. Figure 1(b) shows this proposed system.

B. Study of chain conveying and heating system:

The finite-difference method was used to calculate coal heating for a chain conveying system. In this proposed system, a chain conveyor would be used with the bottom of the conveyor being heated by steam. This could be accomplished by coils welded to a plate or through the use of a steam chest, as shown in Figure 2. With the results obtained from the calculation, it should take about 11 minutes to heat the sub-bituminous coal of height of 0.1 ft from 0 °C to 100°C with no mixing during heating, and it should take more than 20 minutes to heat the coal of height of 0.2 ft from 0 °C to 100°C, also with no mixing during heating. The coal height of around 0.1 ft appears to be an acceptable thickness of coal to heat along with conveying. In the case of coal height of 0.1 ft, to meet the requirements of conveying and heating at a rate of 9677 lb/min, a total of about 30 chain conveyors, each with a velocity of 10 ft/min, are needed.

The results with the chain conveying and heating system are based on the conditions of the coal of no mixing when heated. The coal is assumed to be homogeneous material with an identified thermal conductivity and no other thermal process included during heating. These assumed conditions are being examined in order to assess the validity of the current analysis. An experimental approach for determination of heat transfer coefficients has been considered, and other analytical approaches are being tried first. It is hoped the derivation of improved heat transfer constants and consideration of mixing may significantly improve the practicality of this alternative.

C. Study of fluidized bed system:

A survey of literature available on the topics of heat transfer in a fluidized bed was conducted. Several equations were found that seem to apply to the conditions set in the heat transfer from hot gasses to coal in a fluidized bed. However, calculations of these transfer coefficients have yielded high numbers. Further analysis is needed in order to find an acceptable parameters and equations for determining the heat transfer coefficient in the fluidized bed.

All calculations were initially based upon the values for coal and heated carbon-dioxide at 600 degree K. Carbon-dioxide was used because it is the primary waste product in a coal

combustion process. This may be mixed with air to control temperature. Additionally, environmental issues with particulates and evolution of undesirable gasses must be considered.

Future Work:

The study of remaining methods to heat and convey coal such as screw conveying and rotary kiln heating is to be continued. Additionally, a more acceptable value for the heat transfer coefficient in a fluidized bed will be sought. Further refinement of system parameters and examination of environmental issues for the fluidized bed alternative will continue. After completing above work, the best way to heat and convey coal should be selected from these methods after comparing their advantages, cost, and disadvantages.

(a) Hot Air Conveying/Heating System

(b) Steam conveying/Heating System

Figure 1. Potential Air/Steam Conveying & Heating Systems

Figure 2. Possible Chain Conveyor Arrangement

Figure 3. Fluidized Bed Heating System