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Coal Log Pipeline Research at the University of Missouri

2nd Quarterly Report for 1995

4/1/95 - 6/30/95

**Henry Liu
Professor and Director
Capsule Pipeline Research Center**

Project Sponsors:

National Science Foundation (State/IUCRC Program)

State of Missouri (Department of Economic Development)

U.S. Department of Energy (Pittsburgh Energy Technology Center)

Industry Participants:

**Arch Mineral Corporation
Associated Electric Cooperative
MAPCO Transportation, Inc.
Union Electric Company
Willbros Butler Engineers
Williams Pipe Line Company
Williams Technologies, Inc.**

Small Business Participants:

**Bonnot Company
Gundlach Machine Company
Erie Press Systems
Nova Tech, Inc.
PERMALOK Corporation
Pro-Mark Process Systems
T. D. Williamson**

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EXECUTIVE SUMMARY

During this quarter, major accomplishments have been made in the following areas of coal log pipeline (CLP) research, development and technology transfer:

1. Completed the revision of the 1993 economic analysis of coal log pipeline (CLP). The report finds that CLP is always more economical than coal slurry pipeline, it is more economical than trucks unless the throughput is small and the distance is very short, and it is more economical than exiting railroads when throughput is large. The study was a major undertaking, and it sets an example on how the economics of any major emerging technology can be assessed in a most rigorous manner.
2. Completed a national survey of possible coal log pipeline demonstration projects. More than ten submissions were received from industries. Using the newly completed economic model, six sites were identified to be promising for commercial demonstration. Work is underway to further screen the promising sites so that a single site will be selected for demonstration within the next three years.
3. Completed a technology transfer short course on CLP entitled "Coal Log Pipeline Planning, Design, Construction and Operations."
4. Completed the first draft of the MANUAL OF PRACTICE on CLP. Review of the first draft has been completed. Work is underway to prepare the 2nd draft.
5. Completed the design of a coal log manufacturing plant based on the concept of traveling compaction molds with hydraulic presses. Sent the design to a consultant for review.
6. Completed a preliminary design of a coal log manufacturing machine based on the concept of rotary press (tableting machine).

7. Conducted extensive R&D in coal log manufacturing. Demonstrated that coal log capping can be prevented by controlled decompression of coal logs during the ejection phase, good-quality coal logs can be produced rapidly provided that the feed material (coal) does not possess excess water and air, proper use of solid lubricants such as calcium stearate and MoS_2 enhances the coal log quality, and use of a small amount (0.4% by weight) of fiber (pulp) greatly enhances the strength of coal logs produced at room temperature.
8. Completed preliminary tests on vacuum effect on coal log manufacturing. Demonstrated that proper use of vacuum enhances coal log quality. Explored vacuuming conditions conducive to making good coal logs.
9. Demonstrated that tempering coal has little effect on coal log quality. Also demonstrated that heating coal outside the mold produces better coal logs than those heated in the mold.
10. Started to make large (5.3-inch-diameter) coal logs in a single-piece mold with tapered end. Demonstrated that good-quality logs can be made with such a mold.
11. Conducted additional tests on factors affecting coal log abrasion in pipeline, including effects of temperature, velocity, coal type, etc.
12. Improved the theoretical model for predicting pressure gradient, incipient velocity, tilt, lift and drag of capsules. The improved model gives more accurate results than the existing model, and hence it will be used in all future works.
13. Reconditioned the 8-inch-diameter, 430-ft-length pipeline loop for testing the effectiveness of polymer for drag reduction in large commercial CLP. Prepared for the polymer test.

14. Completed the assessment of CLP effluent water treatment--research completed under sponsorship by the U.S. Department of Education Patricia Robert Harris Fellowships. The two fellowship students received their M.S. degrees and accepted jobs with industry.
15. Completed preliminary assessment of the computer control system (SCADA and PLC) for commercial CLP
16. Constructed and successfully tested a coal-log train separator in the small laboratory CLP demonstration/test loop.
17. Completed a legal manual of coal log pipeline which addresses various issues related to CLP including eminent domain rights, water rights, rights to cross railroads, etc.

Important future works planned for the next quarter include:

1. Prepare the final economic report based on comments received on the draft report. Send final reports to all sponsors. Use the revised model to analyze several promising commercial projects.
2. Negotiate with companies that have submitted promising demonstration sites for evaluation.
3. Complete the revision of the MANUAL OF PRACTICE.
4. Start construction of a 6-inch coal log manufacturing machine based on hydraulic presses and rapid compaction, and a 2-inch coal log manufacturing machine based on rotary press.
5. Complete tests on coal log abrasion in pipe and prepare a final report (M.S. thesis).
6. Continue unfinished research in coal log manufacturing, such as optimum mold shape, piston shape, rapid compaction, and so on.
7. Conduct rapid compaction tests with large (5.3-inch-diameter) mold. Focus on processes that require less than 1% Orimulsion and no more than 97°C.

8. Extend theoretical model for single capsules to predict coal log train behavior. Use model to analyze the effect of slopes and bends.
9. Test polymer drag reduction in 8-inch pipe with capsules. Add a small amount (less than 1%) of fiber to enhance polymer drag reduction in large pipe.
10. Complete testing of coal log train separator in the Hydraulic Laboratory. Complete construction and test of the recirculation system of the small demo/test loop in the lab.
11. Complete a model legislation on coal pipeline eminent domain for future enactment in states that currently do not have eminent domain for coal pipelines or pipelines in general.

Capsule Pipeline Research Center (CPRC)

Quarterly Report

(Period Covered: 4/1/95-6/30/95)

Project Title: CLP Economic Model and Analysis

Principal Investigators: Henry Liu, Professor of Civil Engineering
James Noble, Assistant Professor of Industrial Engineering

Post Doctoral Fellow: Jianping Wu

Research Assistant: Robert Zuniga

Work Accomplished During the Period:

A major revision and update of the 1993 economic report has been completed during this period. The main changes include:

1. Use of the net cash flow (NCF) method which is used by pipeline companies rather than using the revenue requirement (RR) method used by the Office of Technology Assessment, U.S. Congress. The NCF method yields higher unit costs than the RR method does and so it is more conservative.
2. Use of different compaction processes for different types of coal over different distances. This is a sophistication brought about through extensive testing of coal logs in pipelines in the last two years.
3. Use of compaction rather than extrusion. In the 1993 report, extrusion was allowed as an alternative to compaction. Through extensive research in the last three years, extrusion was judged to be inferior to compaction and hence has been eliminated from the revised (1995) economic report.
4. Updating of all cost data.
5. Greater discussion on cost breakdown and on various ways to save money.

As a result of this study, a draft report entitled "Economic Analysis of Coal Log Pipeline Transportation of Coal" has been completed and is being distributed to sponsors for comments. Prior to finishing the draft, extensive discussion about the cost model took place with Williams Technologies, Inc. (WTI) which is serving as the Center's Principal Consultant. WTI also

provided detailed written comments which were either incorporated into the draft or answered in writing separately.

The economic study finds that CLP is always more economical than coal slurry pipeline. This is due to the fact that twice as much coal can be transported by a CLP than a coal slurry pipeline of the same diameter.

As compared to trucks, CLP is more economical except when the throughput is small and the distance is very short.

When compared to unit train, generally CLP is more economical when the throughput is large and the distance is long. However, even in cases where the throughput is moderate and the distance is short, there are occasions where CLP is less costly than unit trains, as demonstrated by the demo projects submitted to the Center for evaluation.

This report also points out many other factors that favor CLP:

- (1) Railroad distance is longer than pipeline distance by 30%, approximately. The cost for a 1,000 mile haul of coal by rail should be compared to a 700 mile CLP.
- (2) Rail tariff does not include the extra costs encumbered by electric utilities for building rail terminals at power plants, spurs and the purchase and maintenance of hundreds of railroad cars owned by utilities.
- (3) As the technology of CLP further improves through R & D, the cost of CLP will go down. Optimization of the CLP system will also cause major cost reduction.
- (4) CLP has many major environmental and safety benefits to the public resulting from reduced use of trains and trucks for hauling coal.

Future Plan:

The draft economic report is being sent to sponsors for review and comments. As soon as the comments are back, a final report will be issued which will take into account the comments received. This will be done during the next quarter.

After the final report is issued, some work will still be needed to continue to improve and update the economic model, and to use the model for evaluation of future commercial projects.

Another revision of the report is contemplated for 1997. Due to the great amount of efforts and time required to revise and update this economic report, it will not be revised (updated) again until 1997.

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 4/1/95-6/30/95)

Project Title: Machine Design for Coal Log Fabrication

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

Graduate Research Assistant (50% of GRA support): Guopin Wen, Kang Xue

Work Accomplished During the Period:

The design of a fast coal log compaction machine is finished with production details. This design is important, since there is no available laboratory machine that can compact coal logs rapidly (30 seconds or less). From previous design of the manufacture plant (Ji, 1995), we know that increased production rate reduces unit cost of coal log manufacturing, and that log quality is affected by the rate of compaction. From market research it was found there is no such machine with reasonable cost available.

A design report (7 chapters, 120 pages) describes each of the subsystems. The machine has the following major components:

1. Hydraulic power system design and component selections.
2. Two control systems one using personal computer (PC) and the other using programmable logic controller (PLC). PC is flexible, and is useful for recording experimental data for research and study. PLC is very economical for commercial compaction machines. One system is enough to control the machine.
3. Mechanical structure analysis and design.
4. Finite element analysis and optimal design of the compaction mold.

Two companies have estimated the cost of manufacturing the system designed to be \$50,000 to \$60,000, without the compaction mold. The cost estimated by Science Instrument Shop for building the machine in house is about \$35,000, with the compaction mold.

The second design we are working on is a rotary press for making 1.9" logs. This machine is expected to have high production rate (2 seconds per log). Again, from market research and information from consultants, there is no such machine available to compact coal logs. There are quite different from those readily available medical tablet press. It is estimated the design of such a machine costs \$100,000 to \$150,000. An existing tableting press with slower speed, much shorter stroke costs about \$600,000. We planned to completely finish this design in 6-9 months with production details. We have worked on it for 3 months now. The following tasks have been completed:

1. Compaction force analysis,
2. Worm gear design and speed reducer selection,
3. Cam profile design.

Future Plans:

For the next three months, the emphasis of our group will be on the following two major tasks:

1. Continue the design of 1.9" rotary press. At the same time, we will continue to search the market of available parts and subsystems to reduce the manufacturing cost.
2. Start the design of a hydraulic compaction machine for 6" pipe line. The need to design this machine is that the CPRC is moving quickly to commercialization of coal log pipeline technology. The first test site has not being decided, but will use a nominal 6" pipe. With the experience from designing the 1.9" hydraulic compaction machine, this design work should be easier and faster. It may take 3-6 month to finish the design, with production detail and cost estimate. The emphases are slightly different from the just finished 1.9" machine. This is a production machine to manufacture test logs. It need not be as faster as a commercial machine. However, its main function is not for testing new compaction procedures or materials.

Publications:

Lin, Yuyi and Wen, Guoping, 1995, Production Design of A Hydraulic Press for Fast Compaction of 1.9 Inch Coal Logs. (7 chapters, 120 pages)

Capsule Pipeline Research Center Quarterly Report

(Period Covered : 4/1/95 - 6/30/95)

Project Title : Automatic Control of Coal Log Pipeline System

Principal Investigator : Satish S. Nair, Asst. Professor of Mechanical and Aerospace Engrg

Graduate Research Assistants : Hongliu Du and Sanjay Mistry

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 :

Train-Separator Design (Hongliu Du)

The novel train separator sub-system designed to ensure proper functioning of the booster station has been tested extensively for reliability. The laser-based sensing system associated with the design, the only active component in the carefully designed train separator, has functioned very well. Work on a patent application for the train separator system has been initiated. Also a paper that includes discussion of the train separator design has been accepted at a major American Society of Mechanical Engineers (ASME) conference :

Nair, S. S. and Du, H., "Automation and Control Design Issues for Hydraulic Capsule Pipelines," *ASME International Mechanical Engineering Conference and Exhibition*, San Francisco, CA, 12-15 Nov. 1995. (accepted for publication).

Recirculating System Design (Hongliu Du and Sanjay Mistry)

A recirculating loop to be added to the small-scale system has been designed so that long duration train travel can be simulated resulting in capsules arriving at the booster station with random intra-capsule spacing. This would also be important to check the reliability of the laser sensors and the stopper design. Detailed drawings of the diffuser, Y-joints, and several other associated

components have been developed and provided to the machine shop for manufacture. An overall figure of the recirculating system for the small scale prototype is shown in Figure 1.

Figure 1. Modification to incorporate the recirculation feature.

SCADA System Design Issues(Sanjay Mistry)

Part of the work accomplished is best illustrated by the following internal reports that were written and submitted to CPRC :

1. Design of SCADA for Prototype Coal Log Pipeline System at MU, 45 pages.
2. Valves, Pumps, and Related Automation and Control Components for a Commercial CLP System - Selection and Cost Estimates, 165 pages.
3. SCADA : Supervisory Control and Data Acquisition - A Book Summary, 22 pages.
4. On-Going and Future Work (to be completed by 31 July '95).

The first report addresses the monitoring and control requirements for the small scale prototype pipeline in the Hydraulics laboratory. A design for the SCADA system is then provided using PLCs with communication modules for the Remote Terminal Units (RTUs) (one each with the injection, booster, train separator, and ejection subsystems) and with a 486 computer as the Master Terminal Unit (MTU). The specific tasks for each of the RTUs associated has been listed. Specification sheets associated with the PLCs to be purchased have also been documented in the report. Currently we are awaiting funding to implement the SCADA design.

The second report addresses selection criteria used in the design and selection process for pumps and valves for a commercial-scale prototype coal log pipeline system. Specifically, centrifugal and positive displacements pumps; ball, water, and pressure-relief valves; and actuators are considered. Components available for both slurry operation as well as sludge operation are

also compared as far as their desirability. In addition to the technical details, cost estimates for the designs are also provided. Extensive documentation of the specifications are also provided in the appendix.

The third reports is essentially a summary of an excellent reference book related to SCADA design. The fourth report is scheduled to be completed by 31 July and it will deal with the issues to be considered by the Automation and Controls group in the coming years.

Dr. Sanjay Mistry is scheduled to leave on 31 July 1995, and the group is already looking for a replacement for him to continue the work.

Work Proposed for the Next Quarter :

- (i) The recirculating sub-system design is in the fabrication stage to be completed by end of July 1995. After this sub-system is incorporated into the small-scale prototype experimental setup, extensive observation experiments will be conducted including investigating train spacing changes, effectiveness of flow bypass in reducing capsule speeds, energy loss analysis, etc. (Hongliu Du).
- (ii) Complete a patent application for the novel train separator sub-system developed by CPRC. (Hongliu Du).
- (iii) Develop a control strategy for the distributed control architecture, taking into account reliability and safety. (Hongliu Du and new student who will replace Dr. Sanjay Mistry)
- (iv) Acquire all the components needed for the SCADA system and interface them with the computer. In the chapter written for the manual of practice this design has been developed in some detail and implementation on the small-scale system will begin immediately (will require a new student who will replace Dr. Sanjay Mistry).
- (v) Initiate development of a SCADA type display package for the small scale system using Visual-C (new student who will replace Dr. Sanjay Mistry).

Capsule Pipeline Research Center
Quarterly Report
(period covered: 4/1/95 to 6/31/95)

Project Title: Coal Log Train Transport

Principal Investigator: Dr. James Seaba, MAE Dept. *JS*

Research Assistants: Wenwei Xu, Dong-Qing Zhai

Purpose

The behavior of a capsule train is studied; pressure drop, capsule velocities (regimes I through IV, corresponding to stationary to lifted capsules), clearance between pipe and capsule, and capsule-capsule interaction during transport are correlated to water velocity, capsule aspect ratio and diameter ratio. Previous work on capsule train behavior over the four transport regimes is incomplete. In addition, new and better pressure measurement techniques have been developed to evaluate capsule train behavior. Capsule trains exhibit different pressure and transport properties compared to the single capsule due to capsule-capsule interaction. In this study, the effects of capsule train lengths will be assessed as well as the geometry and density of the capsules over the four transport regimes.

A numerical model is being developed for capsule train transport. Currently, a transport model has been developed by Dr. Liu for a single capsule. The new model will be applied to capsule train transport and used to predict the headloss, capsule velocity, and bulk fluid velocity. The new model will then be applied to the commercial size CLP systems. The information from the laboratory scale experiments as previously discussed is essential to validate and develop this model.

Work Accomplished During this Period

The measurement of the total pressure drop in the pipe (capsules and water) and the pressure drop due only to the capsule train will be directly measured. The capsule train

pressure drop is measured by the difference of two differential pressure transducers referenced to the total pressure in the pipe flow without capsules. The new pressure measurement technique has been applied to the closed loop Plexiglas pipeline. All hardware is installed and interfaced with the data acquisition system.

A data acquisition program using Labview software has been developed to take multiple analog inputs; pressure transducers, electromikes, ultrasonic flowmeter, and a trigger device. Presently, pressure drop measurements of pure water and capsule trains of 5 and 10 capsules have been measured. The pressure gradient of the water in the pipe agrees with the Moody diagram using a nondimensional friction factor of 0.00002. For the first time, the pressure spike associated with the capsule train between regimes I and II has been recorded. This represents the pressure increase and then sharp decrease as the capsule train begins to move along the pipe bottom. More data is required to obtain a better understanding of capsule train transport. However, the preliminary results from the experimental data and numerical model is very promising.

The numerical model being developed for capsule train transport is an extension of the one Dr. Liu has developed for the single capsule in the pipeline. Presently, the model agrees with the trends of the experimental data and also predicts the train pressure drop accurately at the higher bulk fluid velocities (the operational velocity range of the commercial pipeline). However, the current data base is very limited and the model still being developed.

Future Work

Capsule train measurements in the 2-inch pipeline will continue through September. A test matrix has been formed consisting of capsule train lengths 5 to 15 capsules, at various aspect ratios, diameter ratios, and densities. The flow conditions will cover all capsule flow regimes. This data base will provide important information to improve the current capsule train transport model under development.

To: Veronica Boneparte, Capsule Pipeline Research Center

From: James Seaba, MAE
and Eng-Seong Yap, Graduate Student

Subject: Quarterly report

Title: Capsule train behavior in pipeline

Purpose:

The behavior of a capsule train (>200 capsules) is studied; pressure drop, capsule velocities (regimes I through IV, corresponding to stationary to lifted capsules), clearance between pipe and capsule, capsule-capsule interaction during transport, and capsule jamming and trapping are correlated to water velocity, capsule aspect ratio and diameter ratio. Past experiments have focused on a few capsules (32 maximum) in the pipeline. Large capsule trains may exhibit different pressure and transport properties compared to the short trains due to capsule-capsule interaction. Capsule interaction and pipeline curvature may also contribute to jamming problems in the pipeline.

Present Work:

The Plexiglas test loop in the hydraulics lab will be used for this experiment. Capsules with aspect ratios of 1.5 and 2.5 and a diameter ratio of 0.75 have been assembled and tested. The test loop has been filled up to 95% capacity (approx. 300 capsules) and successfully run from startup to continuous operation for both capsule sizes. No jamming has occurred for the capsules tested, however, jamming problems did exist when the joints were not "smooth". Further assessment of allowable joint "smoothness" will be defined in future work. At high linefill loadings (>92%) capsules would become "trapped" in the jet pump. When this occurred the capsule train could not achieve startup condition. Since the commercial pipeline will not use jet pumps this problem is presently of academic interest, but will be investigated to evaluate the causes of "trapping" to ensure that this phenomena will not exist somewhere in the commercial pipeline.

Future Work:

Pressure and flow measurements will be performed in the Plexiglas pipeline for capsule trains. A new data acquisition system will be employed capable of directly measuring the capsule pressure drop insitu. The measurements will be compared to previous works of Richards and Xu to assess the capsule-capsule interaction or long capsule train effect. The capsule train will also be compared to the current capsule transport model.

Quarterly Report Coal Log Pipeline Project

Apr. 1 - Jun. 30 1995

Project Title: Coal Log Fabrication Using Hydrophobic Binders

PI: Dr. John W. Wilson

Res. Asst. Prof.: Dr. Yungchin Ding

Graduate Research Assistant: Bing Zhao and Brent Ward

OVERVIEW:

Powder River Basin coal and Mettiki coal were used to fabricate 1.75" and 5.3" in dia. coal logs respectively. The emphasis of this period was to determine: 1) the effect of the two-stage mixing on the performance of coal logs, 2) minimum binder concentration and 3) the influence of decreasing loading and compaction time on the competence of coal logs.

The effect of two-stage mixing was evaluated by separating large coal particles at 10M, 20M and 50M for small logs and at 20M, 30M, and 50M for large logs, before mixing operation. The large particles were mixed with Orimulsion, and then with fine particles. Binder concentrations were lowered from 2% in previous tests to 1% for the fabrication of small coal logs and from 2% to 0%, 0.5%, and 1% for the fabrication of large coal logs. The loading time was also reduced to 12 sec. and compaction time reduced to 0 sec for the large coal logs, while the loading and compaction times remained the same as in the previous tests for the small coal log fabrication.

The small coal logs were tested in the 2" pipeline loop at the Columbia campus and the large coal logs were tested in the tumbler at the Rolla campus. Although not all of the 27 small coal logs and 14 large coal logs withstood testing long enough to give worthwhile results, some promising data were obtained and elucidated as follows.

PROGRESS TO DATE:

1.75" Powder River Basin Coal Logs:

As discussed in earlier reports the small logs were fabricated using Powder River Basin coal in a 1.75" in dia. split mold. The fabrication parameters include two-stage mixing of coal particles (-6M x 0) that were separated at 10M, 20M, and 50M, compaction pressures of 8,000 and 10,000 psi and compaction temperatures of 60°C, 80°C, and 97°C, using 1%, 2%, and 3% binder concentration. In order to evaluate the influence of two stage mixing on the performance of coal logs. The large coal particles, such as +10M, +20M and +50M, were separated from the bulk sample and mixed with pre-determined amount of Orimulsion. After thorough mixing, the large coal particle-binder mixtures were then mixed with the fine particles, i.e., -10M x 0, -20M x 0 and -50 M x 0. By doing so, the fine coal particles attached onto the thorough Orimulsion coated large coal particle surfaces and resulted in better binding capability. The competence of the logs were then tested in the 2 in. pipeline loop at the Columbia campus.

Table 1. shows the results of logs formed under 10,000 psi compaction pressure since those formed under 8,000 psi did not demonstrate adequate competence to provide meaningful results. From the test results shown in Table 1, it is clear that the coal logs fabricated using two-stage mixing possessed greater abrasion resistance than single stage mixing process. This is believed to be due to the large surface area of small particles that absorbed a large portion of the Orimulsion, and thus resulted in uneven coating of Orimulsion on the large particles and reduced overall binding capability. In the two-stage mixing, the large coal particles were mixed with Orimulsion before adding the fine coal particles. The thick Orimulsion coating of the large particles provide direct contact and stronger binding between large particles, while the small particles fill into the gaps that were left between large particle.

From Table 1, the effect of compaction temperature also play an important role on the performance of the coal logs. It is obvious the higher the compaction temperature, the better the abrasion resistance of coal logs. However, some of the test results shown in Table 1 were not consistent as anticipated. More thorough and repetitious tests are currently carried out to provide more consistent results.

Table 1: Performance of PRB (1.75" in dia.) Coal Logs

Temp., °C	% Wt. Loss (300 Cyc.)			% Water Abs.		
	60	80	97	60	80	97
Single stage mixing						
Binder, %						
2	NA	4.6	2.0	-	11.8	10.1
10 Mesh Size Separation						
Binder, %						
2	8.9	0.6	0.3	14.2	11.2	9.4
3	NA	3.4	2.1	14.7	11.2	10.4
20 Mesh Size Separation						
Binder, %						
1	4.8	3.4	0.7	11.5	10.8	9.4
2	0.8	0.6	2.4	12.3	11.6	10.0
3	10.3	1.1	0.1	13.6	11.8	7.7
50 Mesh Size Separation						
Binder, %						
2	17.8	13.7	1.9	21.3	13.3	11.5

- Note: 1.) Coal-Ormulsion mixtures were prepared by separating and mixing >10M, >20M, and >50M particles with Orimulsion and then adding the fine particles.
2.) Peak loading time was 5 min.

Large 5.3" in dia. Mettiki Coal Logs:

The factors affecting large coal log compaction, such as compaction time, binder concentration and two-stage mixing, were evaluated to determine their influence on the performance of coal logs.

As discussed earlier the large logs were fabricated using Mettiki coal (-6M x 0) in a 5.3" in dia. single piece mold. The fabrication parameters include particle separations at 20M, 30M, and 50M, a compaction pressure of 10,000 psi, loading times of 12, 45 and 60 sec. and peak compaction times of 0 sec, 15 sec, 30 sec. and 5 min, using 0%, 0.5%, 1%, and 2% binder concentrations. The abrasion resistance of the coal logs were evaluated in a 24" in dia. tumbler.

Test results shown in Table 2 are some preliminary test data which are arranged in decreasing order of their durability. More tests are currently being conducted to provide more conclusive results.

Table 2: Mettiki 5.3" in Dia. Log Fabrication Parameters

Log #	Binder, %	Size Separation	Loading Time	Peak Comp. Time	20 min. Tumbling Wt. Loss, %
1	2	Max. Pack.*	1 min.	5 min.	3.5
2	2	50M	1 min.	5 min.	3.9
3	2	None	1 min.	0 sec.	4.2
4	2	20M	1 min.	5 min.	5.4
5	2	30M	1 min.	5 min.	7.1
6	2	None	45 sec.	30 sec.	8.9
7	2	None	45 sec.	15 sec.	17.3
8	1	30 M	45 sec.	5 min.	NA

As shown in Table 2 and Figure 1, the coal log fabricated with the maximum packing density particle distribution possessed the greatest abrasion resistance within coal logs made under 1 min loading and 5 min peak compaction time (log# 1, 2, 4 and 5). Table 2 also shows that the coal log made with zero peak compaction time had good abrasion resistance.

Several coal logs were fabricated at peak compaction time of less than 30 sec. These coal logs also demonstrated satisfactory abrasion resistance, even though the test results are not consistent. However, it has been proved that a competence large coal logs can be made at short peak compaction time to increase the coal log production rate and benefit the overall coal log fabrication process.

CONCLUSIONS:

Although no definite conclusions can be drawn from the test results obtained in this quarter, because of inconsistent data, some encouraging results have been obtained. It is believed that the inconsistencies are likely a result of variances derived from the testing apparatuses at the time of testing rather than differences in the fabrication parameters.

In the case of the 1.75" coal logs made with PRB coal, it was learned that durable logs can be produced with only one percent binder. The

compaction temperature also plays an important role to the abrasion resistance of PRB coal logs. The higher the compaction temperature, the greater the abrasion resistance of coal logs. From the test results, the compaction temperature of 80°C is believed to be the appropriate temperature for fabricating coal log using PRB coal.

From the 5.3" coal logs test results, the maximum packing density was found to be an important factor to improve the abrasion resistance of coal log. For commercial coal log fabrication, the crushing and grinding machines for size reduction need to be carefully selected to produce particle size distribution close to the maximum packing density particle distribution.

Figure 1. The influence of two-stage mixing on the performance of large 5.3" coal logs.

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 4/1/95 - 6/30/95)

Project Title: Vacuum Systems to Enhance Coal Log Production and Quality

Principle Investigator: Dr. Alley C. Butler, Asst. Professor, Mechanical & Aero. Engineering

Graduate Research Assistants: Jun-Jun Tang

Purpose of the Research:

To investigate the effects of vacuum (and steam preheating) on the fabrication of coal logs, as a means of improving the speed of manufacture as well as increasing coal log quality. The focus is on improving compressive processes as a method for coal log fabrication.

Work Accomplished During the Period:

This research task is developed around a two phase experimental program. In Phase I vacuum and steam preheat are applied to coal in the 1.75 inch floating, split mold. In Phase II the vacuum and steam preheat are applied to the coal prior to loading into the mold. Work undertaken in this period involves Phase I experimentation, with the Phase I apparatus shown in Figure 1. This experimentation involved two parametric studies in which the amount of asphalt binder (as Orimulsion) was varied, and the time used for compaction was also varied. One set of parametric studies determined the effects of vacuum, at various levels, against the use of atmospheric pressure (no vacuum) as a control. The other set of parametric studies evaluated the effects of indirect heating against the effects of direct contact steam heat. The relationships inherent in these studies are summarized in Figure 2.

In each experiment, a consistent set of procedures were followed. This included heating the mold to 97° C before commencing the experiment, and allowing the mold to cool for 45 minutes after the experiment. For vacuum experiments, the vacuum was applied for 5 minutes before compaction through 5 minutes after compaction. The "slow" logs which took 16 minutes for compression spent: 1) five minutes to achieve the 20,000 pi maximum compression pressure, 2) six minutes at peak load, and 3) five minutes for unloading. In contrast, the "fast" logs took 58 seconds to achieve the 20,000 pi peak load and 2 seconds for unloading, without holding the peak load. Additionally, binder percentages were based on weight of asphalt to dry weight of coal, with water added to achieve 18% water in the asphalt-coal mixture used for compaction. These procedures, also, included techniques to minimize variation in results due to other process parameters.

The results of these parametric studies are shown in Figures 3 through 8 which provide a graphical representation of results from laboratory pipeline wear tests on the 1.75 inch coal logs. It is apparent that vacuum generally has a positive effect on coal log compacts. The effect of vacuum appears to change with the amount of binder used and with the speed of compaction. With slow compaction and 2% asphalt higher levels of vacuum (-27 inches of mercury) seem to produce better results, as shown in Figure 3. However, as the level of asphalt drops the vacuum level at which the best logs are made also drops to -9 inches of mercury, as shown in Figure 4.

Figure 1 - Experimental Apparatus for Phase I

		Method & Binder Parameter			
Speed Parameter		Vacuum 2% Binder	Vacuum 0.5% Binder	Steam 2% Binder	Steam 0.5% Binder
	Slow (16 min)	See Figure 3	See Figure 4	See Figure 7	See Figure 8
	Fast (1 min)	See Figure 5	See Figure 6	Experiment In Progress	Experiment In Progress

Figure 2 - Experiments with Vacuum and Steam Heating

Figure 3. Coal Log Weight Loss for 2% Asphalt, 16 Minute Compaction under Vacuum Conditions (Average of 3 Logs)

Figure 4. Coal Log Weight Loss for 0.5% Asphalt, 16 Minute Compaction under Vacuum Conditions. (Average of 3 Logs)

Figure 5. Coal Log Weight Loss for 2% Asphalt, 1 Minute Compaction under Vacuum Conditions (Average of 3 Logs)

Figure 6. Coal Log Weight Loss for 0.5% Asphalt, 1 Minute
Compaction under Vacuum Conditions (Average of 3 Logs)

Figure 7. Coal Log Weight Loss for 2% Asphalt, 16 Minute
Compaction with/without Steam Heating (Average of 3 logs)

**Figure 8. Coal Log Weight Loss for 0.5% Asphalt, 16 Minute
Compaction with/without Steam Heating (Average of 3 logs)**

Work Accomplished During the Period (Continued):

For "fast" compaction, intermediate levels of vacuum are best with 2% asphalt, and this effect is even more pronounced for "fast" compaction with 0.5% asphalt. See Figures 5 and 6 respectively. With direct contact steam heat, wear tests results presented in Figures 7 and 8 show that direct contact steam heating produces better logs. The beneficial effect is apparently more pronounced for logs made with 0.5% asphalt.

Future Plans:

Research with the Phase I apparatus will continue with first priority on completing experiments with direct contact steam heat. Then, emphasis will be placed on confirming the results already obtained. Additional efforts will also be made to document results through publication and completion of a student thesis. Future experiments will involve development and use of the Phase II apparatus for direct contact steam heating and vacuum prior to compaction.

In the related Phase II effort, the effects of vacuum (and preheating) of coal will be tested prior to loading in the 1.75 inch mold. This involves the use of a conveyor for moving and preparing the coal, as shown in figure 9. This process uses vacuum (and/or preheating) of the coal and asphalt mixture prior to feeding the mixture into the compaction mold with a prototype system. Measurements regarding increases in the speed of compression will be taken, and automation through process instrumentation and control will be employed. As with the control system in Phase I, the experiment will be controlled using a micro-computer with Labview software. This will result in experience with automatic feeding of compaction molds, and increases in the speed with which coal logs can be manufactured will be determined. By demonstrating automated coal feeding with a manufacturing prototype system, confidence in the commercialization of the coal log fabrication process can be gained.

Figure 9 - Manufacturing Prototype System

Capsule Pipeline Research Center

Quarterly Report

for

Individual Projects

(Period Covered: 4/1/95-6/30/95)

Project Title: Effectiveness of Adding Fiber to Enhance Coal Log Quality

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

Research Assistants: Shiping Yang

Purpose of Study: To determine whether using a small amount of low-cost, combustible fiber, such as wood pulp, can improve the wear resistance of coal logs.

Work Accomplished During the Period:

We have continued studying the effects of fiber addition on coal log circulation performance. Specifically, we have been investigating the effects of fiber concentration, compaction temperatures, and binder concentrations. Initially, wood pulp fibers produced by the Buckeye Cellulose Corporation of Memphis, Tennessee were used. The estimated cost of these fibers is \$800-\$1000/ton. Fiber that costs this much is too expensive for CLP use. Therefore, we have begun investigating the economics of adding waste fiber to coal logs. Preliminary information indicates that waste fiber is available at \$80 - \$100/ton of fiber. At a fiber addition rate of 0.4%, this amounts to approximately \$0.40/ton of coal logs. Preliminary cost estimates for the additional equipment, personnel, etc. to operate a hydropulper for handling the fiber indicate an additional cost of approximately \$0.15/ ton of coal logs. Raw material costs for emulsified bituminous binder is approximately \$1.11/ton of coal log/% bitumen added. Therefore, the partial replacement of binder with waste fiber appears to be economically attractive.

Mr. Shiping Yang has prepared a report that summarizes the results of this study. His report follows. We have found fiber addition effective for improving the quality of coal logs made at room temperature. However, at a compaction temperature of 97 °C there was little benefit associated with the addition of fiber.

Work Proposed for Next Quarter:

We will continue studying the effects of fiber addition on coal log circulation performance. Specifically we will investigate the stability of fiber reinforced coal logs after long term exposure to water and we will also optimize the circulation performance of room temperature fiber reinforced coal logs.

Progress Report

July 5, 1995

Project Title: Effectiveness of Adding Fiber to Enhance Coal Log Quality

Principal Investigator: Dr. Brett Gunnink

Research Assistant: Shiping Yang

Purpose of Study: To determine whether using a small amount of low-cost, combustible fiber, can improve the wear resistance of coal logs

I. Fiber Reinforced Coal Logs at Room Temperature

In order to see the effectiveness of fiber addition, first, we made some logs with different amount of fiber at room temperature. The fiber we used is wood pulp which is produced by Buckeye Cellulose Corporation of Memphis, Tennessee. After some trial and error, following preparation process is used for making fiber reinforced coal logs(Table 1):

Table 1. Preparation process for making fiber reinforced coal logs

1. Fiber mat is soaked in water for 24 hours;
2. Fiber and water are placed in a blender to separate and disperse individual fibers;
3. Coal, water(25% of the dry weight of the coal), and saturated fiber are mixed for five minutes, and then allowed to soak for at least 1 hour;
4. Diluted Orimulsion(3% of the dry weight of the coal of Orimulsion and 5% of the dry weight of the coal of water) is added and mixed for 5 minutes;
5. The mixture is placed in the compaction mold and the log is made.

The common characteristics of the fiber reinforced coal logs are shown in Table 2

Table 2. Common characteristics of the fiber reinforced coal logs

Type of Coal	Mapco coal
Particle Size	Through #30 seive
Type of Fiber	Wood pulp
Amount of Fiber	0%, 0.1%, 0.2%, 0.4%, 0.6%, 1.0% (dry weight of fiber by dry weight of coal)
Type of Binder	Orimulsion(70% Bitumen+30% water)
Amount of Binder	3% (of dry weight of coal)
Compaction Pressure	20,000 psi
Compaction Temperature	Room
Compaction Mold	Chrome plated split mold
Compaction Time	Loading time 1 minute
	Peak load holding time 5 minutes
	Unloading time 1 minute
Water Absorption	500 psi, 1 hour
Cooling in Mold	

For the circulation test, the mean fluid velocity in the pipeline was equal to the theoretical lift-off velocity for the coal log. Figure 1 shows the comparative weight loss results of the circulation tests for different fiber concentration. From figure 1, it is clear that the addition of fiber improves coal log circulation performance. The improvement in circulation performance was minimal for 0.2% fiber addition, medium for 0.6% fiber addition, but very significant for 0.4% fiber addition. The average weight loss after 93 cycles was 18.7 for logs without fiber; the average weight loss after 92 cycles for logs with 0.2% fiber was 10.4%; the average weight loss after 87 cycles for logs with 0.6% fiber was 8.6; and the average weight loss after 88 cycles for logs with 0.4% fiber was 3.2%. after 219 cycles, the average weight loss for logs with 0.4% fiber was 9.5%.

Conclusions:

Logs with 0.4% fiber had best performance at room temperature, this result may not be general because of the restriction of condition in our lab, such as the mixing method, but it still is the optimum fiber addition we can got.

II. Fiber Reinforced Coal Logs at 97°C

1. Slow compaction

At room temperature, some logs with 0.4% fiber addition broke, so we changed the temperature to 97°C to see the effectiveness of 0.4% fiber addition at 97°C.

The cost of Wood Pulp is \$ /ton, this price is not acceptable for commercial application of Hydraulic Capsule Pipeline(HCP), so we used "unbleached kraft paper" instead, its price is about \$80/ton. Other conditions are the same with those at room temperature(Table 2).

The comparative weight loss results of the circulation tests for different amount of binder at 97°C were shown in Figure 2 and Figure 3. The effectiveness of 0.4% fiber addition can be seen from comparison of Figure 2 and Figure 3. The improvement in circulation performance is still clear at 97°C. The average weight loss after 385 cycles for logs only with 2% of orimulsion is 3.1%, almost the same as that for logs with 1% of orimulsion and 0.4% of fiber. But the benefit of fiber addition is not so significant as that at room temperature. Figure 4 shows the comparative weight loss results of the circulation tests for logs with 0.4% of fiber, no orimulsion, and logs without fiber and orimulsion. It can be seen that there is almost no difference between them, this means that at 97°C fiber addition is not effective without binder.

2. Fast compaction

We also made fast compacted logs at 97°C, the fiber concentration was still 0.4%, orimulsion was 3%. We investigated the effect of mixture's moisture for fast compaction. The common characteristics of coal logs and the compaction process we used are shown in Table 3.

The results of circulation tests are shown in Figure 5. From Figure 5, it is obvious that 10% moisture is much better than 20% moisture for fast compacted logs at 97°C, although, in circulation tests, the mean fluid velocity in the pipeline was 85%Lift-off Velocity for 20% moisture and 92%Lift-off Velocity for 10% moisture.

Table 3. The characteristics of 97°C coal logs and the compaction process

Type of Coal	Mapco coal	
Particle Size	Through #30 seive	
Type of Fiber	Unbleached kraft paper	
Amount of Fiber	0.4% (dry weight of fiber by dry weight of coal)	
Type of Binder	Orimulsion(70% Bitumen+30% water)	
Amount of Binder	3% (of dry weight of coal)	
Mixture's Moisture	20%(initial) and 10%(dried by oven)	
Compaction Pressure	20,000 psi	
Compaction Temperature	97°C	
Compaction Mold	Single piece mold	
Compaction Time	Loading time	30 seconds
	Peak load holding time	0
	Unloading time	10 seconds
Ejected	Hot	
Water Absorption	500 psi, 1 hour	

3. Very fast compaction

For very fast compaction, in order to see batch effect on the quality of coal logs, we made logs from three different batches, three logs were made for each batch at three different compaction speed: slow, fast and very fast. The main process we used to compact logs is shown in table 4.

Table 4. Main process for fast compaction

Dried mixture to 10% moisture before heating
heated 20 minutes with hot plate before putting into mold(97°C)
2,000 psi precompaction
Three different compaction speed:
slow(1minute up, 5 minutes holding, 1 minute down)
fast (30 seconds up, 10 seconds down)
very fast (25 seconds up, 0 down)
Ejected hot
Water absorption at 500 psi for 1 hour
Circulated at 95% Lift-off Velocity(mean fluid velocity)

Figure 6 shows the comparative weight loss results of circulation tests. We can see from Figure 6 that:

- a. Compaction speed affects log's circulation performance;
- b. We didn't get good logs for fast and very fast compaction at 97°C even with 0.4% fiber addition;
- c. Coal mixture from different batch may give a totally different result.

At last, we tried 5% moisture, the process is the same as Table 4. The results are shown in Figure 7, we can see that 5% moisture is not as good as 10% moisture, this is because cracks formed during compaction due to dry coal.

Conclusions:

The circulation results of logs made at 97°C with fiber addition were not as significant as we had expected, because the temperature affects fiber's strength. the higher the temperature, the weaker the fiber. This result has been obtained by E.I.E. Didriksson and E.L. Back before 1970. Their paper about temperature's effect on fiber's modulus of elasticity is attached.

Figure 1. Circulation performance for fiber reinforced coal logs
 (3% Orimulsion binder, room compaction temperature, 20,000 psi compaction pressure)

Note: Each line represents one log.

Figure 2. Circulation performance data

(97 C compaction temperature, 20,000 psi compaction pressure, 0.4% fiber)

Note: 1. Each line represents the average of three logs;

2. Each error bar represents max/min value of three logs.

Figure 3. Circulation performance data

(97 C compaction temperature, 20,000 psi compaction pressure, no fiber)

- Note: 1. Each line represents the average of three logs;
2. Each error bar represents max/min value of three logs.

Figure 4. Circulation performance data

(97 C compaction temperature, 20,000 psi compaction pressure)

Note: 1. Each line represents the average of three logs;

2. Each error bar represents max/min value of three logs.

Figure 5. Circulation performance data

(3% Orimulsion binder, 97 C compaction temperature, 20,000 psi compaction pressure)

Note: Each line represents one log.

Figure 6. Circulation performance for fast compacted logs

(3% Orimulsion binder, 97 C compaction temperature, 20,000 psi compaction pressure, 10% moisture)

Note: Each line represents one log.

Figur 7. Circulation performance for fast compacted logs

(3% Orimulsion binder, 97 C compaction temperature, 20,000 psi compaction pressure, 5% moisture)

Note: Each line represents one log.

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 4/1/94/ to 7/31/95)

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:

SUMMARY

One year ago, a program was begun to decrease the compaction time required for coal logs.

It was learned quickly that good logs could be made with fast compaction from Western coal (Powder River basin). With Eastern coal (Metiki), considerable research effort on the faster compaction cycle has been required to define satisfactory conditions. During the recent quarter, definition of conditions were completed for a rapid compaction cycle that yields satisfactory coal logs with Metiki coal. The crucial factors involved temperature, initial moisture, particle size and sufficient mixing (Table 1) which, along with lower lift-off velocities for larger diameter logs, allow all standard logs to pass circulation test criteria. Other important factors are also in Table 1. The minimum cycle time of 30 to 40 seconds used 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. Analysis of the data indicates that much shorter compaction cycle times are feasible.

The first part of this report gives an overview of the "fast" compaction cycle. Since definition of these conditions were achieved early in the quarter, further work was directed to examine the effect of "tempering" (storage of the premixed coal, binder and moisture) and to the effect of preheating the coal as opposed to heating it in the mold (as used in the standard experimental compaction procedure). Although initial results indicated a beneficial effect of tempering, later work with lower moisture and larger diameter logs show very little if any effect. Preheating, however, produced superior logs to those from the standard procedure.

Further work has begun to investigate the effect (if any) of piston temperature on the quality of the finished log.

Table 1
"Fast" Compaction Parameters

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.

Discussion

One of the major cost components of the CLP is making the log. Compaction cycle time has a large influence on the economics of log manufacture. The compaction procedure for making coal logs as previously developed used slow, programmed pressure increases and decreases and required maintaining elevated pressure on the log in the mold for an extended period (5 to 10 min.). It was desirable to reduce the length of the cycle for compaction of the log.

The Compaction Cycle

The "slow" compaction cycle included a minimum of 3 minutes of loading and unloading and 5 minutes of holding at maximum pressure. The "fast" compaction cycle represents about the shortest time that the log can be compacted using the equipment currently available. The "fast" compaction cycle with the 1.9 inch diameter log has a typical loading time of 30-40 seconds and is unloaded in 0-1 seconds.

It seems likely that, with different equipment, further reduction in cycle time can be achieved without a significant decrease in log quality. The minimum cycle time depicted in Figure 1b is a result, not of a performance criteria of the coal logs, but rather by physical limitations of the available compaction equipment. In the "fast" compaction cycle, the largest fraction of the compaction time is below 6000 psi pressure. Since we believe that very little of the strength of the log is formed below 6000 psi, this part of the compaction cycle probably could be speeded up without a significant effect on the results.

Variables in Fast Compaction

The investigations with the fast compaction cycle touched on 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 advantages of the lower temperature are lost because of the additional binder and post-processing log retention time required. Room temperature compaction used 2.2% of binder and even with this level of binder, logs as ejected from the mold after fast compaction were too fragile to pass the circulation test in the 2 inch diameter steel pipeline loop. It was necessary to store finished logs made in this way for 24 to 48 hours ("curing") in order for them to pass the circulation test. The commercial cost of such storage, along with binder costs, overwhelms the economic advantages of room temperature operation and subsequent efforts were focused on rapid compaction at high temperature (97°C).

Much better results were obtained at the higher temperature (97°C). Ultimately it was found that even if the binder content were reduced to a very low level (0.5% binder from Orimulsion based on dry coal weight), logs could be manufactured with the fast compaction cycle that more than meet circulation criteria in the 2 inch steel pipeline loop.

3. Initial moisture levels

With either fast or slow compaction, the ultimate moisture requirement is the equilibrium moisture level. During compaction, excess moisture above the equilibrium level is pressed out.

Too little moisture in the feed results in additional moisture absorption after the log is completed. This water absorption weakens the bonding and alters the dimensional stability of the log.

Initial moisture levels are more critical with fast compaction than with slow compaction. With slower compaction, there is plenty of time for water to be pressed out of the porous mix and through small exit routes from the mold. With fast compaction, the time required for liquid flow from the interior of the log could limit intimate particle-to-particle interactions.

Various moisture levels were investigated. The best results were obtained when the initial mix contained a great excess of water (25-35%) for mixing (see below) and then was dried to 5-9% before compaction.

4. Mixing of the Ground Coal with Added Binder and Moisture

A key overall finding of the 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 but it is anticipated that mixing problems at full scale will be more amenable than at the small scale. Mixing at the small scale is more demanding and perhaps quite different than might be expected at large scale because uniformity is measured with a smaller metric. Good mixing can be particularly difficult to accomplish with lower moisture levels since excess water acts as a carrier to help distribute the binder.

In our experiments, better mixing was accomplished by:

- a) lengthening the mixing time from 4 to 10 minutes.
- b) Mixing the coal with a large excess of water (25-35%). After mixing, this was then air dried to the desired level of 5-9% in a oven. Air temperature in the oven is 95°C

but coal temperature is 45-50°C corresponding approximately to the wet bulb temperature.

- c) Using extra care in the initial distribution of water and Orimulsion. Water and Orimulsion are premixed and distributed as uniformly over the coal before mixing.

5. Tempering

As mentioned above, it was found that storage of the finished log for 24 to 48 hours ("curing") was necessary for adequate performance of fast compaction logs at room temperature. During this "curing" time, additional bonding or micro-orientation of particles apparently occurs which increases the strength of the log. Curing had no noticeable effect on logs compacted at 97°C however, indicating that such bonding processes are accelerated at high temperatures and requires no additional storage time.

In some 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. Storage of an inventory of 24-48 hours of mixed coal would incur a significant expense although lower than storage of the finished log. It was, therefore, necessary to isolate this effect.

Figure 1 shows the results of one of several experiments with tempering. In this case, a mold lubricant (molybdenum sulfide) was also used which far overwhelmed any effect of tempering. In this test the logs with shorter tempering times were processed while mold lubricant levels were high and therefore had low ejection pressures. As the experiment progressed, lubricant

levels presumably decreased which increased the ejection pressure. Thus this series shows an inverse effect of tempering.

Figure 2 shows another series of experiments without the confounding factor of mold lubricant. No consistent effect of tempering emerges. The effect of tempering, if it exists at all, is less than the normal variability observed in log production.

6. Preheating the Coal Outside the Mold

In laboratory compaction of coal logs, for convenience purposes the usual experimental procedure has been to heat the coal in the mold. The premixed powdered coal at room temperature (and sometimes up to 40°C) is charged to the mold. The mold is 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 (as measured with a thermocouple inserted 1/4 inch into the top layer of the coal). Compaction is then begun.

In a commercial-sized unit, coal would be preheated and charged at 97°C to the mold. The preheat portion of the compaction cycle would be eliminated. 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.

The visual quality of the logs as ejected from the mold was improved. There were few if any of the visible hairline surface cracks that were always found with the heated molds. In general, logs made from the preheated coal performed better than those from mold-heated coal. In Figure 3 the average weight loss for the preheated coal is far less than for mold heated primarily because the

preheated coal did not lose large chunks near the beginning of the test. The uniform attrition rates are about the same for both heating modes.

Figure 4 shows results of the same experiment but for a different batch of coal. Again the preheated coal averages less weight loss than the mold-heated but the difference is less dramatic than for the first batch. We believe that mixing difficulties contributed to the greater variability in the second batch.

Although it is not clear why the improved performance occurs with preheated coal, certainly the bonding force (friction, adhesion, etc.) is less between the coal and the interior of the mold. This observation is reinforced by measurements showing that the ejection pressures are lower with the preheated coal.

The net result of this work is that we can define a margin of assurance of quality for the commercial log.

FUTURE PLANS

The effects of piston face temperature on log performance, especially wear on the ends, will be investigated. Piston temperature throughout the compaction procedure (during heating of the coal mixture and compaction) will be taken for both heated and preheated compactions.

A large part of our effort in the next quarter will be to fill in answers to questions that currently exist such as comparison of log diameters and moisture levels in the 5-9% range.

Figure 1

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

Figure 2

Figure 3

Figure 4

Capsule Pipeline Research Center

Review of Studies on Lubricant Effects

Project Completion Report

Yin Li

July 27, 1995

Principal Investigator: Dr. Henry Liu
Research Associate: Yin Li
Research Assistant: Andrew Rockabrand .

Introduction:

In a previous study, the efficiency of mold lubrication on improving coal log quality was investigated. MAPCO coal was used as the testing material through out this study. A total of 42 logs was compacted under twelve treatments including two binder concentrations (0 and 3% Orimulsion), two temperatures (room temperature and 90C), and three mold surface conditions (unlubricated, SAE 40W motor oil lubricated, and calcium stearate lubricated).

All the logs made were tested for water absorption, weight loss wear resistance and tensile strength. Log density, moisture content, porosity and water holding capacity before and after water absorption were determined. The force displacement, transmitted force ratio, and ejection force were also analyzed.

The major results of the experiments were summarized below:

- 1) Calcium stearate is effective in increasing density, minimizing cracks and reducing the weight loss of the logs,

especially for binderless logs. The weight loss of the logs compacted with calcium stearate has a much smaller variation.

2) SAE 40W motor oil is effective on reducing wall friction. However, the excess oil left on the mold surface, particularly the lower half of the mold, squeezed into the surface particles and prevented strong bonds to form among those particles. As a result the strength of the log surface was reduced. For details, see the report titled "Lubricant Effects on Coal Log Compaction" (Li, January 1995).

The major drawback of lubrication is an extra cost to coal log fabrication. In order to explore the possibilities of reducing the lubrication cost, we selected several different solid lubricants based on the information from *Solid Lubricants and Self-Lubricating Solids* (Ed. by F. J. Clauss, Academic Press, 1972).

Rockabrand contacted several companies and asked for the price of each lubricant selected. Based on the information provided by these companies and some published references, we did the cost estimation for each lubricant. See report titled "Cost Estimation of Different Lubricants" (Li, March 1995).

In the above report, it is mentioned that the best way of reducing lubrication cost is to use solid-bounded lubricating film, such as MoS_2 . Because it is reported that the endurance life of resin-bounded MoS_2 is 9,860,000 cycles at 35,000 psi.

This will not only reduce the cost but also cut the time required for re-lubricating the mold.

In order to test the efficiency of MoS_2 , another set of experiments were designed to compare the surface conditioning with Militec-1, MoS_2 and chrome-plating in enhancing coal log quality and reduction of wall friction.

Experiments

1. Variable Test Conditions

- 1). Binder concentration: 0 and 3% Orimulsion (water included)
- 2). Temperature: Room temperature (RT) and 90°C
- 3). Lubrication of mold: No lubricant (NL), MoS_2 dry film lubricated (MO), chrome-plated (CR), and Millitec (MI)

2. Fixed Test Parameters

- 1). Coal type: MAPCO
- 2). Particle size distribution: -30 mesh (please see Table 1 for detail)
- 3). Initial moisture content: 20% by weight
- 4). Peak Pressure: 20,000 psi
- 5). Loading speed: 8,000 lb/min (see Figure 1)
- 6). Compaction mold: Two single-piece molds with tapered exit (1°) and 1.91" in diameter were used in the

experiments (Figure 2).

i. One was a unchrome-plated, stainless steel mold which was used for the control, MoS₂ dry film, and Militec-1 experiments.

ii. The other one was a chrome-plated mold with the same mold inner diameter. This mold was used for the chrome-plated mold experiments.

7). Piston type: flat ended

8). Mixing: a mixer (about 5 min)

9). Wear test velocity (V_L): 85% lift-off velocity

Table 1. Coal particle size distribution

Particle size (mesh.)	Percentage
30 - 60	45.2
60 - 120	23.5
120 - 200	19.6
Pan	11.7

The experimental design is presented in Table 2.

Table 2. Design of experiments

Surface condition	Temperature of Mold	Amount of Orimulsion
Unlubricated	90°C	3%
Unlubricated	90°C	0%
Unlubricated	Room Temperature	3%
Unlubricated	Room Temperature	0%
MoS ₂ lubricated	Room Temperature	3%
MoS ₂ lubricated	Room Temperature	2%
MoS ₂ lubricated	Room Temperature	1%
MoS ₂ lubricated	Room Temperature	0%
Chrome-plated	90°C	3%
Chrome-plated	90°C	0%
Chrome-plated	Room Temperature	3%
Chrome-plated	Room Temperature	0%
Militec-1 treated	90°C	3%
Militec-1 treated	90°C	0%
Militec-1 treated	Room Temperature	3%
Militec-1 treated	Room Temperature	0%

Results and Discussion

After compaction the logs were ejected immediately. After ejection they were placed in 500 psi water for one hour to saturate. The saturated logs were then stored for about one day prior to circulation in a 2in, 75 foot long steel pipe at 85% lift-off velocity for 350 cycles or more.

The results of unlubricated, molybdenum disulfide dry film lubricated and the chrome plated molds were reported by Rockabrand (Reports on June 9 and July 10, 1995). The followings are more detailed discussion of the results.

1. Results of unlubricated mold

A total of twelve logs were made with the unlubricated stainless steel mold (three 90°C logs with 3% Orimulsion, three 90°C logs with 0% Orimulsion, three room-temperature logs with 3% Orimulsion, and three room-temperature logs with 0% Orimulsion). The results of the wear tests are given in Figure 3. All of the 90°C logs passed the criteria of 3% weight loss up to 350 cycles. The difference between the 90°C-3% Orimulsion logs and the 90°C-0% Orimulsion logs is not significant. Room temperature logs with 0% Orimulsion were the worst (>5% weight loss up to 350 cycles). However, the weight loss of the room temperature logs with 3% Orimulsion was slightly over 3% up to 350 cycles. It seems that at room temperature, the effect of binder on improving log

quality is very evident but at 90°C the significance of binder was reduced considerably.

2. Results of chrome plated mold

Another twelve logs were made with a chrome-plated mold (the conditions were the same as above). The weight loss results are given in Figure 4. Again, the room temperature binderless logs were the worst ones. All the other three types of logs passed the weight loss criteria. Different from the unlubricated mold, the progress of log quality by using binder at both room temperature and 90°C is obvious with a chrome-plated mold.

3. Comparison of surface treatments

Figure 5 is the comparison of the weight losses of the logs made by the chrome-plated and unlubricated stainless steel molds (90°C and 3% Orimulsion). The difference between these two conditions was very small but after 150 cycles the variation of the logs made with the chrome-plated mold became smaller than that of the unlubricated mold.

Figure 6 is the comparison of the room-temperature logs containing 0% Orimulsion made by MoS₂ lubricated, chrome plated, and unlubricated molds. The unlubricated stainless steel mold is the best within this group but none of the logs passed the weight loss criteria. The results for this set of logs are unexpected.

More information, such as density, porosity, water absorption, etc is needed to explain the results.

Figure 7 is the comparison of the weight losses of the logs made with chrome plated and unlubricated molds (90°C and 0% Orimulsion). The difference in results between the treatments was very small. Again after 150 cycles the variation of the logs made with the chrome-plated mold became smaller than that of unlubricated mold.

Figure 8 is the comparison of the room-temperature logs with 3% Orimulsion made with MoS₂ lubricated, chrome plated, and unlubricated molds. The logs produced with MoS₂ lubricated mold was considerably better than the other two treatments (about 1.4% weight loss up to 350 cycles). The other two treatments showed very similar weight loss pattern and they were very close to the weight loss criteria.

4. Effects of MoS₂ lubrication at different binder content

The comparison of the effects of MoS₂ at different binder concentrations is given in Figure 9. The logs made with 1, 2 and 3% Orimulsion performed very similarly and their weight losses were all lower than 2% up to 350 cycles. The logs made with 0% Orimulsion did not pass the weight loss criteria (6% loss up to 300 cycles). What is the lowest binder concentration that gives acceptable logs still needs to be answered (0.5%, 0.1%... ?).

Based on above results, it is expected that the surface chemistry of the coal is affected by the binder concentration. There must be a threshold value that changes the surface condition to a favorable level for compaction. Above this threshold, the log quality becomes insensitive to binder addition.

5. Friction forces and transmitted forces

From previous discussion, we have known that the room-temperature logs with 3% Orimulsion made by a MoS_2 lubricated mold are significantly better than those made with chrome plated and unlubricated molds (Figure 8). In order to understand the reasons, the total friction forces generated under these conditions were calculated and compared in Figure 10. Apparently, the friction force generated (when the applied force $> 125\text{kN}$) by the unlubricated mold is the largest. The friction force of the chrome plated mold ranked the second.

In order to see how effective each treatment is in transmitting force to the bottom piston, the transmitted force ratio (transmitted force/applied force) was calculated for each case and plotted vs applied force (Figure 11). The profile of the transmitted force ratio of the MoS_2 lubricated mold showed a very interesting pattern that is different from the other two. At a low compaction force, the transmitted force ratio is very low but increases continuously through out the rest of the compaction

period. The highest transmitted force is 70% of the applied force which indicates a 30% loss of applied force at the peak load due to friction. This pattern is very favorable to produce strong bindings because towards the end of loading period, coal particles are in more compact form (excess water and air are removed) and contact area among particles are formed. If enough energy is provided at this stage, strong binding among particles can be developed.

The transmitted force ratios of the chrome plated and unlubricated molds had the same pattern. Started from a very low value, the transmitted force ratios then reached to their peak value very rapidly. After reaching the peak value, they decreased though out the rest of the process. At the peak load of the compaction, the transmitted force of the chrome plated mold was 58% of the applied force (42% loss due to friction). For the unlubricated mold, only 50% applied force was transmitted to the bottom piston (50% loss due to friction).

6. Existing problems with molybdenum disulfide dry film

It was pointed out by Rockabrand (Report on June 9, 1995), however, that molybdenum disulfide dry film lasted only for four to five logs. This number is much lower than the endurance life expected. A few possible factors may affect the endurance life of molybdenum disulfide dry film are listed below:

1) Effect of acidic conditions

MAPCO coal is very acidic. Although MoS_2 is resistant to most of acids, it is not clear that if the MoS_2 film used on this study would be affected by the acids produced by MAPCO coal or not.

2) Surface condition (roughness and pre-treatment)

The surface roughness and pre-treatment prior to molybdenum disulfide dry film application are reported to have an important effect on the endurance life. At this moment we are not clear if the surface conditions satisfy the requirement or not. It is also noticed that the surface roughness of the mold for MoS_2 treatment is different from that of the chrome-plated mold.

3) Film thickness

The optimum thickness for MoS_2 film is application dependent. Either too thin or too thick will affect its performance.

4) Reaction of sulfur in the coal with the mold

The mechanism of MoS_2 film bonding the mold surface involves the reaction between sulfur and the metal surface. Since coal contents sulfur, it is not clear that if this will affect the bonding of the film or not.

Conclusions

1. With a unlubricated mold, Orimulsion has a profound effect on improving the log quality at room temperature but under 90°C the significance of the binder was reduced considerably.
2. Under all the conditions tested (room temperature and 90°C, 0 and 3% Orimulsion), chrome-plated mold did not show any significant benefit on reducing weight loss of the logs.
3. Under room temperature and with the presence of Orimulsion, MoS₂ dry film lubrication showed substantial improvement on wear resistance of coal logs. Compared with the unlubricated and chrome plated molds, the weight loss of MoS₂ dry film lubricated logs was 50% lower (about 1.4% loss up to 350 cycles). An existing problem with MoS₂ dry film is the endurance life. Studies should be conducted on how to solve this problem.
4. When the applied force is larger than 150 kN, the unlubricated mold generated the highest friction force and the molybdenum disulfide dry film lubricated mold had the lowest friction force. When the applied force reached the peak load, the transmitted force ratio is 0.7 for the MoS₂ dry film lubricated mold, 0.58 for the chrome-plated mold, and only 0.5 for the unlubricated mold.

Figure 1. Typical coal log compaction and ejection load patterns

Figure 2. Compaction mold used with a tapered exit (dimensions are in inch)

Figure 3 . Coal logs compacted with unlubricated mold

Figure 4 . Coal logs compacted with chrome-plated mold

Figure 5. Comparison of logs made in molds of different surfaces.
(90°C, 3% Orimulsion, 1.91" mold, 20,000 psi)

Figure 6. Comparison of logs made in molds of different surfaces.
(Room temperature, 0% Orimulsion, 1.91" mold, 20,000 psi)

Figure 7. Comparison of logs made in molds of different surfaces.
(90°C, 0% Orimulsion, 1.91" mold, 20,000 psi)

Figure 8. Comparison of logs made in molds of different surfaces.
(Room temperature, 3% Orimulsion, 1.91" mold, 20,000 psi)

Figure 9. Comparison of MoS_2 effect with different binder concentrations.
(Room temperature, 1.91" mold, 20,000 psi)

Figure 10. Comparison of total friction force with different surfaces.
(Room temperature, 3% Orimulsion, 1.91" mold, 20,000 psi)

Figure 11. Comparison of transmitted force ratio with different surfaces.
(Room temperature, 3% Orimulsion, 1.91" mold, 20,000 psi)

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 4/1/95 to 6/30/95)

Project Title: Effect of compaction preload on MAPCO coal logs

Principal Investigator: Dr. Henry Liu

Research Associate: Yu Lin

Purpose of the Research:

The purpose of this research is to examine the effect of preload on the quality of MAPCO coal logs compacted with fast double-sided method.

Preload is an important step in laboratory scale for coal log double-sided compaction. Prior to compaction the mold rests on two supporting blocks and the coal is filled in the mold. After giving a preload, the coal is slightly compressed and the blocks can be removed, and the mold becomes floating during compaction.

Experiments and Methods

The coal used in the research was ground by a hammer mill and screened through a 30 mesh USA sieve. Water and Orimulsion were added to the coal (2800 g for making 15 logs) in one batch to produce a mixture of 7.5% (by total weight) moisture and 2% (by dry coal weight) asphalt. The coal mixture tempered for 24 hours before compaction of the first log.

All coal logs were compacted in the No.5 mild steel, single-piece, taper-ended mold (1.91 in bore diameter). The bore was chrome-plated and unlubricated. Both pistons were flat-ended. The top piston was mild steel, while the bottom piston was stainless steel.

Three preload magnitudes (0 lb or no-preload, 500 lb, and 2500 lb) and two preload speeds (slow and fast) were studied. For slow preload, turn small pressure knob 1/2 turn and start compaction machine preload to either 500 lb or 2500 lb. For fast preload, press "Down" button to move beam down and preload to either 500 lb and 2500 lb. Total five cases, no-preload (0 lb preload), 500 lb-slow preload, 500 lb-fast preload, 2500 lb-slow preload, and 2500 lb-fast preload have been investigated in this experiments.

After preload, press "Up" button releasing pressure and removing the supporting blocks, then start fast compaction by turn the small pressure knob 1 and 1/2 turns. The peak load was 15714 psi (45,000 lb), and the peak load was immediately released. Figure 1(A) shows the set up of the mold for preload. The height of supporting blocks is 70 cm. The height of coal filled in mold before preload was 148 cm. Figure 1(B) shows the set up of the mold for no-preload (0 lb-preload). For keeping the same height of coal (148 cm) in mold before preload the mold was hanged by two chains 70 cm above the press table.

1. Preliminary Test

One hundred ninety grams of the coal mixture were placed in the mold. The coal and mold were heated together to 97°C for 20 minutes before preload and compaction. After compaction the logs were ejected out of the mold immediately. Four logs were compacted with four preload cases, no-preload, 500 lb-slow preload, 500 lb-fast preload, and 2500 lb-fast preload in this preliminary test.

2. Modified Test

One hundred ninety grams of the coal mixture were placed in the mold. The coal and mold were heated together to 97°C for 15 minutes. Total 10 logs were made with five different preload cases in this test. For each case two logs were made (not enough coal left in the same batch for making 3 logs due to the first 4 logs were broken in preliminary test).

After compaction the coal logs were cooled to 75°C in mold by a fan then fast ejected out of the mold. After physical measurements of the coal logs were recorded, the logs were placed in 500 psi water absorption for one hour. Each coal log then sat in atmosphere water 12 to 18 hours before the circulation wear test. All coal logs were circulated in steel loop at 0.85 lift-off velocity for 100 minutes.

Results and Discussions

1. Preliminary Test

All four logs were broken during ejected out of the mold. When the logs entered in bevel section of the mold their bottom ends (1-2 cm thick) broke and fell down, then accompanied by a string of popping sound and hot airstream, a series of thin coal pieces

continuously broke and fell down. Finally the top ends fell down with a thickness of 1-2 cm. This phenomenon was observed for the first time in the fabrication of coal logs. The coal pieces-broken in middle section of the logs accompanied popping sound may be due to the explosion of high pressure hot air or steam compressed in cracks or between two layers in coal logs. During fast compaction, the hot air and the water vapor (may be formed at the temperature closed to 100°C) were not squeezed out the mold and they were forced towards to and compressed in middle of the logs. When the logs entered in low pressure bevel section of the mold during ejection the compressed hot air or steam quickly expanded causing many coal pieces broken in the middle of the logs and producing popping sound..

2. Modified Test

After modifying the compaction method used in preliminary test by reducing the heating time to 15 minutes from 20 minutes and cooling the logs to 75°C from 97°C in the mold before ejection, ten logs were successfully made in the modified test. These measures may reduce the amount of water vapor by reducing heating time and lowered the pressure of hot air or steam compressed in cracks or between tow layers of the logs by cooling the logs to 75°C.

Figure 2 shows the whole compaction processes of the coal logs (including preload) in the experiments. The average preload times and compaction times were 0 and 51.15 seconds for no-preload, 53.07 and 28.81 seconds for 500 lb-slow preload, 60.51 and 25.10 seconds for 2500 lb-slow preload, 3.88 and 25.55 seconds for 500 lb-fast preload, and 4.83 and 19.95 seconds for 2500 lb-fast preload, respectively. The slow preload took much more time than fast preload (about 12-13 times). The compaction time for high preload was shorter than that for low preload.

Table 1 lists the physical properties of the ten logs. The logs compacted with no-preload and 500 lb-slow preload had the highest average density, 1.293 g/cm³. The logs with 500 lb-fast preload had the lowest average density, 1.282 g/cm³. After 500 psi water absorption for one hour the water gain of the logs with no-preload was the lowest, 3.32%, and the logs with 500lb-fast preload had the highest water gain, 3.50%. Based on the test

data, the logs with no-preload or with slow preload or low preload had higher density and lower water gain than those with fast preload or high preload.

Table 1 Properties of coal logs

Log No.	Preload way	Weight (g)	Diameter (cm)	Length (cm)	Density (g/cm ³)	Ejection force (lb)	Water gain (%)
1	No	188.3	4.880	7.795	1.292	2880	3.24
2	No	188.5	4.881	7.797	1.293	2950	3.39
3	500lb,S	188.4	4.881	7.796	1.292	2950	3.39
4	500lb,S	188.4	4.879	7.795	1.293	3000	3.28
5	500lb,F	188.5	4.893	7.825	1.282	2950	3.50
6	500lb,F	188.7	4.897	7.830	1.281	3000	3.50
7	2500lb,S	188.3	4.881	7.940	1.287	2940	3.35
8	2500lb,S	188.4	4.881	7.882	1.288	3200	3.34
9	2500lb,F	188.3	4.889	7.824	1.283	2950	3.40
10	2500lb,F	188.4	4.888	7.823	1.284	3000	3.38

Figure 3 shows the relations between weight loss of coal logs and cycles of circulation in wear test. The average weight losses of the logs after circulating 360 cycles were 2.11% for no-preload, 2.47% for 500 lb-slow preload, 2.85% for 2500 lb-slow preload, 3.24% for 500 lb-fast preload, and 3.461% for 2500 lb-fast preload. Obviously, the logs with no-preload had the best wear-resistance, and with slow preload and low preload were more wear-resistant than those with high and fast preload.

Figure 4 shows the relations between compaction time (excluding preload time) and the weight loss of coal logs after circulating 360 cycles. The average weight loss of the logs with no-preload and 51.5 seconds of compaction was 2.11%. The average weight loss of the logs with 2500 lb-fast preload and 20.1 seconds of compaction was 3.46%. In general, with increase of the compaction time the weight loss of the logs decreased. This may be due to that more air in coal was squeezed out the mold and the coal particles

arranged more tightly in long compaction than in short compaction. This led to a high density and good wear-resistance.

Figure 5 shows the relations between average weight loss of the logs after circulating 360 cycles and displacement of top piston after preload. The displacement of top piston with no-preload was 0, the average weight loss of the logs was the lowest, 2.11% after 360 cycles of circulation. The displacement of top piston during preload increased with the preload speeds and the preload magnitudes. When the displacement of top piston increased the weight loss of coal logs increased, too. This can be explained by the reverse direction of pressure gradient in coal during preload and compaction. The reverse pressure gradient caused a formation of discontinuous planes or cracks in coal logs. This in turn led to more weight loss in wear tests.

Conclusion

1. In fast-high temperature compaction with immediate ejection such as the method in the preliminary test, high pressure hot air and steam compressed and gathered in cracks or between two coal layers at the middle section of the logs usually caused a series of coal pieces broken during ejection.

2. Preload has a effect on the quality of MAPCO coal logs in fast double-sided compaction due to the reverse of pressure gradient in the low section of the logs during preload and compaction.

3. In fast double-sided compaction for making good coal logs, no-preload is the best, slow preload and low preload are better than fast preload and high preload due to the increase of compaction time contributing to more air squeezed out of the mold, and the reduction of the displacement of top piston after preload contributing to the increase of the uniform degree between layers in the logs.

Fig. 1(a) Set up of compaction mold for preload compaction (double-sided)

Fig. 1(b) Set up of compaction mold for no preload compaction (double-sided)

Fig. 2 Compaction processes in preload test (double-sided)

Fig. 3 Relations between weight loss of coal logs and cycles of circulation

Fig. 4 Relations between compaction time and weight loss of coal logs after circulating 360 cycles

Fig. 5 Relations between average weight loss of logs after circulating 360 cycles and displacement of top piston after preload

Capsule Pipeline Research Center (CPRC)

Quarterly Report

(Period Covered: 4/1/95-6/30/95)

Project Title: Polymer Drag Reduction in 8" Hydraulic Capsule Pipeline

Principal Investigators: James Seaba, Assistant Professor of Mechanical Engineering
Henry Liu, Professor of Civil Engineering
Thomas Marrero, Associate Professor of Chemical Engineering

Post Doctoral Fellow: None

Research Assistant: Clark Darrah

Work Accomplished During the Period:

The project was started in the middle of this period by Clark Darrah under the supervision of professors Seaba and Liu. A review of literature on the use of polymers as drag reducing agents, specifically polyethylene oxide (PEO), was completed by Darrah. This project is a continuation of a study done by the CPRC in 1994. In the original study, it was determined that a concentration of 25 ppm of PEO in a 2" plexiglass pipeline resulted in a 75% reduction in drag. The current study is to determine the drag reduction in an 8" steel pipeline and eventually form a model for predicting drag reduction for any size pipe.

For the experiment, a remote facility with a 430 foot long test loop is being used. This facility needed considerable repair and maintenance. There was extensive damage to the plumbing during the winter. The plumbing has been fixed; and measures have been taken to insure that there will be no future cold weather damage.

Theoretical predictions of the pressure gradient and friction factors for the pipe without drag reduction were calculated. These results agreed with the rough measurements obtained while operating the pipeline at various velocities. The computer data acquisition hardware and associated measuring devices are currently back ordered at the factory.

As for the polymer, its properties have been study. In the previous study with the 2" pipeline, the polymer was added by injecting a small volume of concentrated PEO into the system. It is more difficult to do this with the 8" pipeline because of the much large volume of water involved. PEO in larger concentrations (in the 1,000 to 10,000 ppm range) quickly increases in viscosity until it becomes a non-Newtonian fluid. Thus different methods for injecting the concentrated polymer into the pipeline have been explored, as well as various mixing techniques.

Two methods of injecting the concentrate have been proposed. The main differences are in the location on the test loop where the polymer will be injected and the concentration. One method involves the use of a cavity pump, obtained for the 5-mile test run last year in Kansas. It can

displace a viscous solution into the pipeline at a high pressure. Hence the polymer could be injected into the pipeline just downstream of the jet pumps to avoid the shear degradation caused by the pumps. This method appears to be ideal for long pipelines such as in industry. However, there are several disadvantages of this injection method for the test loop. The cavity pump can only displace two gallons per minute. For testing purposes, all of the polymer needs to be injected within one cycle through the loop. The concentration of PEO needed to accomplish this, +20,000 ppm, is too high; the mixture becomes a non-Newtonian fluid.

To be able to utilize this injection method, either a new displacement pump would have to be obtained or the polymer would need to be mixed in a slurry form, with several solvents. The cavity pump was originally obtained for use with a slurry form of PEO. However, the study with the 2" pipeline used a PEO and water mixture instead of slurry. To maintain consistency between the two studies, a slurry concentration of PEO cannot be used.

A second method of injecting the polymer was developed to accommodate the test facilities that will be used. Approximately 70 gallons of 1000 ppm concentration of PEO would be injected into the pipeline just upstream of the jet pumps. Using a tank placed above the pipe, gravity and the suction produced by the jet pumps would drain the polymer into the pipeline.

The main problem with this method is the immediate shear degradation of the polymer caused by the jet pumps. This would not occur in an industrial coal log pipeline. However, the jet pumps would help evenly disburse the PEO in the pipeline. The mixing of the lower concentration of PEO would be easier and of better quality than the high concentration needed for the first method.

Future Plan:

The possible injection methods for the polymer will be further evaluated. The fabrication of either system will be fairly simple. A decision on which system will be made very soon.

Once the needed data acquisition hardware arrives, experimentation can begin. Some time though will be required to setup and calibrate the equipment. There will be four experimental conditions studied:

- 1). Water only
- 2). Water and capsules
- 3). Water and polymer
- 4). Water, capsules and polymer

The data collection should commence by the end of the next period, as long as the data acquisition hardware arrives. A final report will be prepared by the end of the year.

Capsule Pipeline Research Center

Quarterly Report

for

Individual Projects

(Period Covered: 4/1/95-7/31/95)

Project Title: Unsteady Flow in Coal Log Pipeline

P.I.: Dr. Charles Lenau, Professor of Civil Engineering

Post Doctoral Fellow : Jianping Wu

Purpose of Studies: (1) To develop a methodology for analyzing unsteady flow and hydraulic transients generated by the operation of coal log pipelines. (2) To develop a methodology for the hydraulic design of pump bypass and an injector systems.

Work Accomplished During the Period:

A paper has been written and submitted for presentation at the 8th International Symposium on Freight Pipelines at Pittsburgh, Pa. to be held in Sept. 95. The title is "Hydraulic Design of Coal Log Pipeline Injection System". This paper gives the various possible configuration of an injection system depending upon the coal log feed rate.

Some progress has been made in modeling a gravity feed injection lock. A simple design criteria has been found to determine the maximum coal log feed rate.

The second draft of Chapters. 3 and 4 in The *Manual of Practice* has been completed.

Work To Be Accomplished Next Period:

Some additional design criteria concerning details of injection system will be investigated.

Reference:

Capsule Pipeline Research Center, *Coal Log Pipeline (CLP) Manual of Practice*, 2 nd. draft, March 1, 1995.