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Coal Log Pipeline Research at University of Missouri
4th Quarterly Report for 1995
10/1/95 - 12/30/95

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Project Sponsors:

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Coal Log Pipeline Consortium:
- Associated Electric Cooperative
- Mid American Pipeline Company
- Union Electric Company
- Williams Pipe Line Company
- Williams Technologies, Inc.
- Wilbros Butler Engineers

Small Business Participants:
- Bonnot Company
- COMPACTCONSULT, Inc.
- Gundlach Machine Company
- Nova Tech, Inc.
- Permalok, Inc.
- T. D. Williamson

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EXECUTIVE SUMMARY

During this quarter (10/1/95 - 12/30/95), major progress has been made in the following areas of coal log pipeline research, development and technology transfer:

1. Two revisions were made of the conceptual design of the coal log fabrication machine that can produce three 5.5-inch-diameter coal logs per minute. One revision was suggested by the consultant. It deals with adding two accumulators to absorb potential shock due to oil compressibility. The other revision is to use an alternate (better) framing system to support the machine. Many detailed shop (assembly) drawings were also prepared. Shop drawings will be completed in January. (Yuyi Lin).

2. Sent rotary press machine design to Automated Resources, Inc.--a company with extensive experience in rotary press--for review (Yuyi Lin).

3. Conducted an experiment on threshold binder (Orimulsion) concentration. It showed that for binder concentrations below 1%, the initial weight loss of coal logs (due to chipping of corner) is unaffected by the binder concentration unless the binder concentration is 1% or more. For binder levels above 0.25%, more binder causes less coal log wear after long time or large number of cycles of circulation through pipe. After 250 cycles in the pipe, binderless coal logs suffer approximately twice the wear of the logs with 1% binder (Yin Li).

4. Completed a theory for predicting the wall-resistance and lubricant effects on coal log compaction in mold. The theory was substantiated by experiments. Submitted a paper on this subject to POWDER TECHNOLOGY and the paper was accepted (Yin Li/Henry Liu).

5. Tested the effect of loading time, peak load time and unloading time on the abrasion resistance of large (5.3-inch-diameter) coal logs. It demonstrated that both long loading time and long peak load time contribute significantly to coal log quality (wear resistance). Unloading time, however, has less effect on coal log quality than loading and peak-loading times. This is due to the fact that after long loading and peak loading, there is not much excess water left in the log to affect the coal log quality. The result also showed that for compaction conducted with 2% binder, 10,000 psi compaction pressure, 30 sec. loading time, 0 sec. peak loading time and 20 sec. unloading time, initial water content of the coal mixture in the range of 20%-40% had little impact on the coal log quality (wear resistance). (John Wilson/Yungchin Ding)

6. Demonstrated that good-quality coal logs of Mettiki coal can be compacted rapidly (within 30 seconds) at 20,000 psi pressure and 97 °C with 2% binder (3% Orimulsion). Under the same rapid compaction, much better logs can be produced by raising temperature to 97 °C than at room temperature (Brett Gunnink)

7. Demonstrated that tempering has no effect on coal log quality when the log was compacted at 97 °C and uses only 0.5% binder (0.75% Orimulsion). Such logs have better quality than logs compacted under room temperature with 2% binder (3% Orimulsion). (Dick Luecke)

8. Saad Merayyan completed his M.S. thesis entitled "Wear of Coal Logs in Pipe." The research investigated the effect on coal log wear by several factors not studied or not satisfactorily studied by Cheng in his 1994 Ph.D. dissertation. These included the jet-pump effect, the diameter-ratio effect, the temperature effect, the velocity effect, the coal-type effect, the water pressure effect, the binder concentration effect and the coal log train effect--on wear of coal logs. It greatly expanded our knowledge on factors affecting coal log wear. (Thesis Adviser: Henry Liu)

9. Improved prediction of pressure drop in coal log pipeline. Student (Zhai) finished M.S. degree on this topic (Thesis Advisor: James Seaba).

10. Completed the installation of a capsule recirculating system for the automated HCP loop (Satish Nair).

11. Completed study on legal aspects of coal pipelines crossing railroads. Prepared a paper for ASCE Pipeline Crossing Conference. Revised manual of practice on legal issues (Peter Davis).

12. Completed planning and budgeting for next eight months. Documents sent to all sponsors for review (Henry Liu).

13. University President ordered an independent evaluation of the Center's economic model and the commercial potential of CLP. The evaluation was conducted by two reputable consulting firms--Foster Associates and J. D. Energy. The report confirmed the validity of the Center's economic model, and found many potential commercial applications of CLP, especially for relatively short distancess--within 100 miles.

FUTURE PLANS:

(NOTE: Future planning will closely follow the CPRC planning document prepared for the first eight months of 1996.)

1. Finish shop drawings for coal log machine based on hydraulic press to demonstrate producing three 5.5-inch diameter coal logs per minute. (Yuyi Lin)

2. Prepare and conduct bidding for the coal log machine. Select bids. (Lin/Liu/Committee)

3. Complete fast-track experiments on lubricant effect, slurry effect and large diameter effect on coal log wear. (Yin Li)

4. Complete first two scale-up tests as described in Task 4 of CPRC planning document. (Wilson/Ding)

5. Complete design and start construction of 6" pipe test loop at Rolla. (Wilson Ding)

6. Complete design of the 6" pipe test loop at Columbia needed for the proposed EPRI project. Select sites for the facility. (Liu/Marrero)

7. Test fast compaction of 1.9" logs with compaction time between 20-30 seconds. See Task 5 schedule in CPRC planning document. (Brett Gunnink)

8. Complete preliminary theoretical model for analyzing water movement through a coal log during compaction. Derive equations needed for prediction. See Task 6 of CPRC planning document.

9. Complete preliminary design of a coal heating system that heats the coal while being conveyed to the coal log compaction machine. Ask a vendor to provide an alternative heating system based on existing commercial equipment. Compare the two systems. Follow Task 8 of planning document. (Marrero/Burkett/Butler).

10. Complete derivation of equations for predicting capsule train behavior in pipe as described in Task 9 of planning document. (James Seaba)

11. Complete the first-quarter tasks specified in Task 10: Coal Log Behavior in Slopes and Bends. (Henry Liu)

12. Prepare 8"-pipe system for polymer drag-reduction test as described in Task 11 of planning document. (Marrero/Seaba)

13. Derive the equations needed for control of a complete HCP system using realistic boundary conditions. Check the correctness of the equation by using the model CLP system in Hydraulic lab. (Satish Nair)

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report
(Period Covered: 10/1/95-12/31/95)

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): Guoping Wen, Kang Xue,
Huachao Li (25%, new student)

Purpose of Study:

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

Work Accomplished During the Period:

I. Hydraulic-Press Machine

During last three months, efforts were focused on the revision and improvement of the design of the 300-ton hydraulic press machine for coal log production. The conceptual design of the machine has been sent to Mr. infield and the Erie Press for external expert review. Two graduate students worked on mold design, hydraulic system improvement, and alternative machine frame design.

A design automation tool has been developed. It integrates finite element analysis software with optimization software to produce optimized shape design for the compaction mold. The objective function to be minimized is a combination of weight and deformation. Controlling deformation of the mold is important, since the deformation affects the quality of compacted logs.

The improvement of the hydraulic oil reservoir and oil pump system is on quality and performance. We added two accumulators to absorb potential shock due to oil compressibility. We used regenerative circuits on both main cylinders to improve their speed.

So far we have considered three possible machine frame design alternatives. Each has its advantages and shortcomings. The last alternative presented using two thick steel plates is probably the strongest and least costly to manufacture.

The Capsule Pipeline Research Center has submitted a request to the College of Engineering to pay partially the manufacturing cost of this 300-ton press. We still waiting for the Dean's decision.

II. Rotary-Press Machine

During this period, the original plan of preparing detailed production drawings on the rotary press was changed. The main consideration is to focus efforts on the improvement and details of the 300-ton hydraulic press design. Also, expert suggestions can be incorporated into our detailed design, if the assembly drawings and reports can be reviewed and commented on first. Therefore, we sent the assembly drawing and the design report of the rotary press for expert review (Mr. Barney Wallace, Automation Resources, Inc.) and comments. A proposal for funding the construction of this machine is sent to NIST (National Institute of Standards and Technology). Without additional resources, the construction of this machine will not be done until next year, after the hydraulic-press machine has been tested.

Future Plans:

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

1. The control system design using a Programmable Logic Controller.

2. Select the data acquisition system for control and measurement.

3. Piston and mold-exit shape designs, which requires detailed modeling of the compaction process for the coal logs. This work is planned for Mr. Wen's Ph.D thesis topic. Finite element analysis will be used to design the best piston and mold-exit shapes. Based on our experience and information, piston and mold-exit shapes affect the capping phenomenon and the quality of the compacted logs.

4. Manufacturing and construction of the machine will follow the bid. We will provide the manufacturer any additional information as needed.

5. A support structure for the construction of the machine has been designed. It will be sent out for bid separately. Construction of this support structure will follow the bid.

Publications:

Lin, Y. Y., Wen, G. P. and **Xue, K.**, December 1995, "Machine for Rapid Production of Coal Logs: Design and Preliminary Tests," accepted for presentation and publication on the proceedings of *the 21st International Technical Conference on Coal Utilization & Fuel Systems* (12 pages).

Lin, Y. Y., Wen, G. P. and **Li, H. C.**, December 1995, "Integrating Finite Element Analysis and Shape Optimization into High Pressure Compaction Mold Design Process," submitted to the *1996 ASME Design Technical Conference* (21 pages).

Lin, Y. Y. and **Xue, K.**, December 1995, "Support Structure Design for the 300-Ton Compaction Machine," *CPRC Internal Report* (7 pages).

Lin, Y. Y., Wen, G. P., December 1995, "Revision and Details of 300-Ton Compaction Machine Design," *CPRC Internal Report* (30 pages).

Deng, Q. W. and **Lin, Y. Y.**, December 1995, "Modeling of RAM Extrusion Process and Optimal Die Design,"submitted to *the 1996 ASME Design Technical Conference* and *Journal of Mechanical Design.* (22 pages) This paper is partially based on Deng's MS Thesis with extension on optimal shape design for extrusion die. (Dr. H. Liu is Deng's Thesis adviser; Yuyi Lin served on his committee and worked with him on optimization of the die).

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 10/1/95-12/31/95)

Project Title: Fast-track experiments related to coal log compaction
Principal Investigator: Yin Li, Research Associate
Co-Investigator: Henry Liu, Director, CPRC
Research Assistants: Bainin Tao
Purpose of Study:

1. Threshold Binder Concentration Determination
Binder is important to coal log quality and fabrication cost. The purpose of this study is to find out the lowest binder concentration that produces acceptable coal logs with and without lubrication.

2. Economic Analysis of Using Solid Lubricants in Commercial Coal Log Compaction
To investigate the cost of MoS_2 used in large volume, the lubricant application methods, the equipment needed for lubrication and the cost of using MoS_2 in commercial coal log manufacturing.

Work Accomplished during the Period:

Threshold binder concentration

A total of 24 logs was compacted using an unlubricated, stainless steel mold and tested for water absorption and wear resistance. Detailed analysis on log dimension, moisture content, density, porosity and weight loss were conducted.

The following major conclusions have been reached:

1). When binder concentration was < 1%, there was no improvement of **initial** weight loss during circulation due to increased binder. With 1% binder, however, the initial weight loss was reduced by about 50% (Fig. 1).

2). For all binder levels that were above 0.25%, the improvement of log wear resistance due to increasing binder concentration was apparent when the logs were circulated beyond 150 cycles (Fig. 1). With 1% binder, weight loss due to wear was approximately half of that without binder.

3). For logs compacted at room temperature, expansion or volume increase during water absorption tests was significantly affected by the binder addition. Generally, log expansion decreased with increasing binder concentration (Fig. 2).

4). Moisture contents of the logs before and after water absorption were also a function of binder concentration. An increase in binder concentration linearly reduced the moisture content of the logs due to increased volume reduction and water displacement during compaction. During water absorption test, the moisture content of the logs increased about 4% and was independent of the binder concentration (Fig. 3).

5). Binder concentration did not show any significant effect on log density which can be explained by the increased water displacement and the decreased log volume during compaction due to increasing of binder concentration.

Economic analysis of solid lubricants

Lubricant application methods have been reviewed. The most common methods are summarized as:

1. Resin-Bonded Coatings

Resin-bonded solid films represent the largest and most commercial significant class of solid film lubricant products.

2. Burnishing

Burnished coatings of MoS_2 obtained by mechanically rubbing the solid particles on the surface of a part are commonly used in bearing and other sliding applications.

3. Mechanical impingement

Impingement techniques were developed which in effect blast the substrate surface with a solid lubricant. Impingement films usually incorporate a low concentration of a proprietary inorganic binder system to enhance adhesion of the substrate.

Calcium stearate power costs around $0.54/lb and MoS_2 powder costs around $5/lb. MoS_2 is much more efficient on improving log wear. MoS_2 can be used in dry-film form which is reported to have much longer endurance life than powders. This study has not been completed yet.

Future Plan: During the next quarter, the final part of the binder threshold study will be completed. Coal logs with 0 to 1% binder will be compacted in the same mold but with MoS_2 lubrication. A study on piston lubricating effects will also be started. The purpose of this study is to test the effect of lubricating piston ends with calcium stearate and MoS_2 on coal log quality. Previous experimental results of 1.75″ and 1.91″ molds showed significant improvement of log wear resistance due to an increase of log diameter ratio from 0.85 to 0.9. A new mold with a diameter of 2.0″ is being fabricated which can be used to make logs with 0.95 diameter ratio. A preliminary study on mold diameter and log diameter ratio effects on coal log wear resistance will be conducted.

References:

1. Bhushan, B. and Gupta, B. K. 1991. *Handbook of Tribology*, McGraw-Hill, Inc.
2. Booser, E. R. 1994. *Handbook of Lubrication and Tribology*, vol. III, CRC Press, Inc.
3. Booser, E. R. 1984. *Handbook of Lubrication and Tribology*, vol. II, CRC Press, Inc.

Publication:

Li, Y., Liu, H., and Rockabrand, A. 1995. Friction and lubrication of coal log compaction. Submitted to *Powder Technology*.

CPRC Reports:

1. Li, Y., Liu, H. and Rockabrand, A. Experimental studies on lubricant effects. Revised December 1995.
2. Li., Y., Liu, H. and Tao, B. Threshold binder concentration. Progress Report I, Jan. 1996.

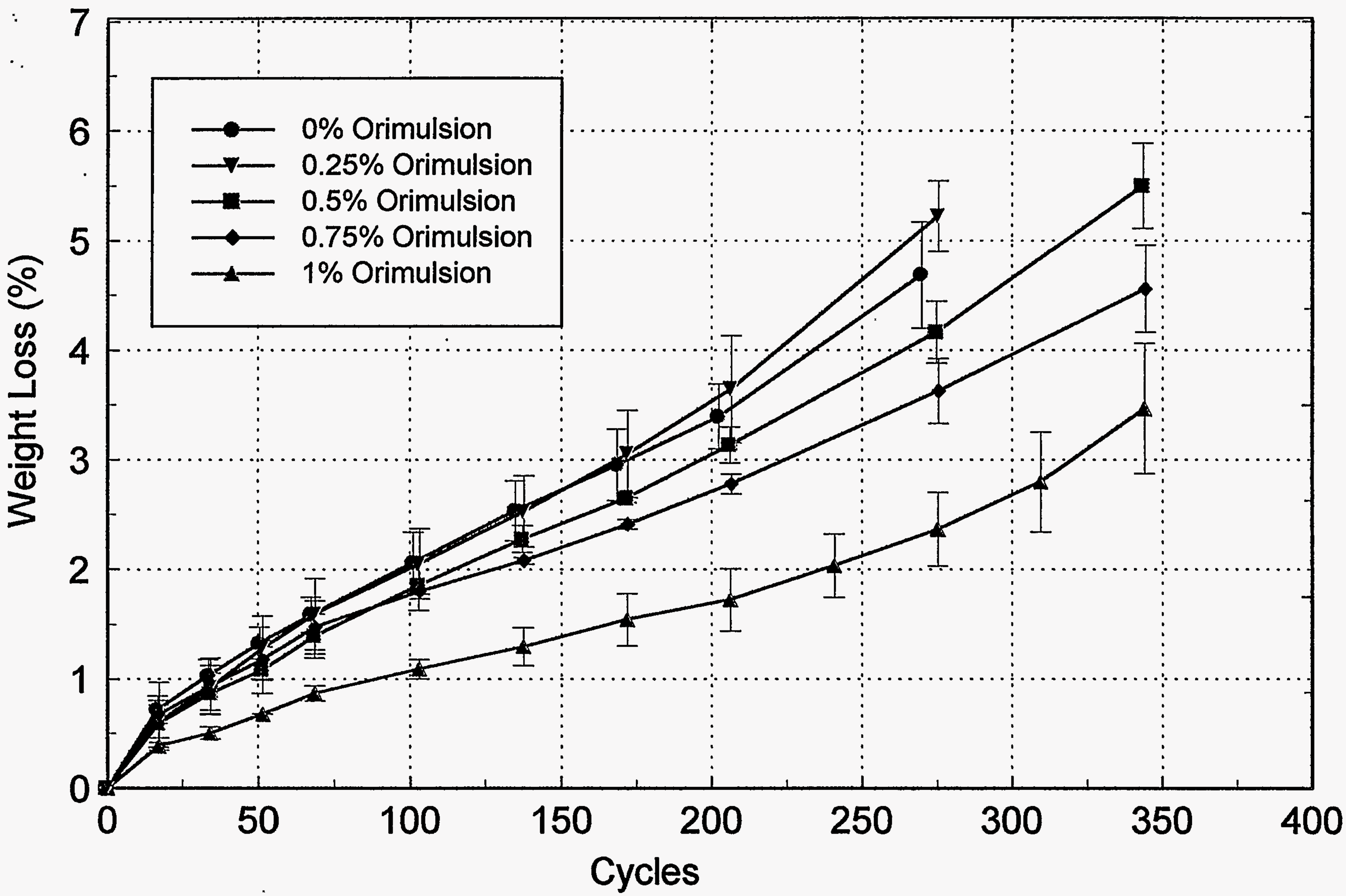


Figure 1. Weight loss of coal logs compacted in a unlubricated, stainless steel mold at different binder concentrations

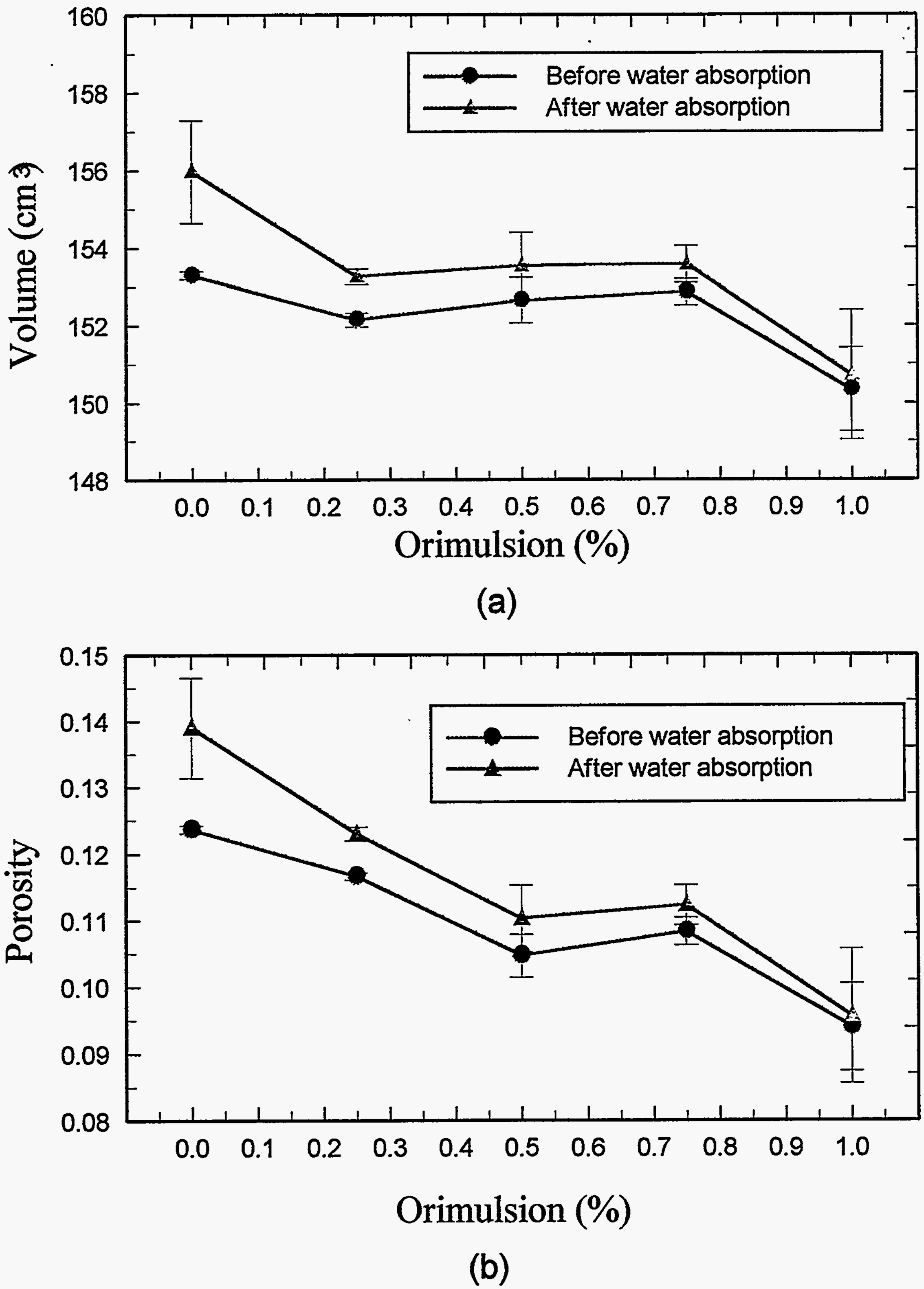


Figure 2. Volume and porosity of coal logs compacted in an unlubricated, stainless steel mold at different binder concentrations

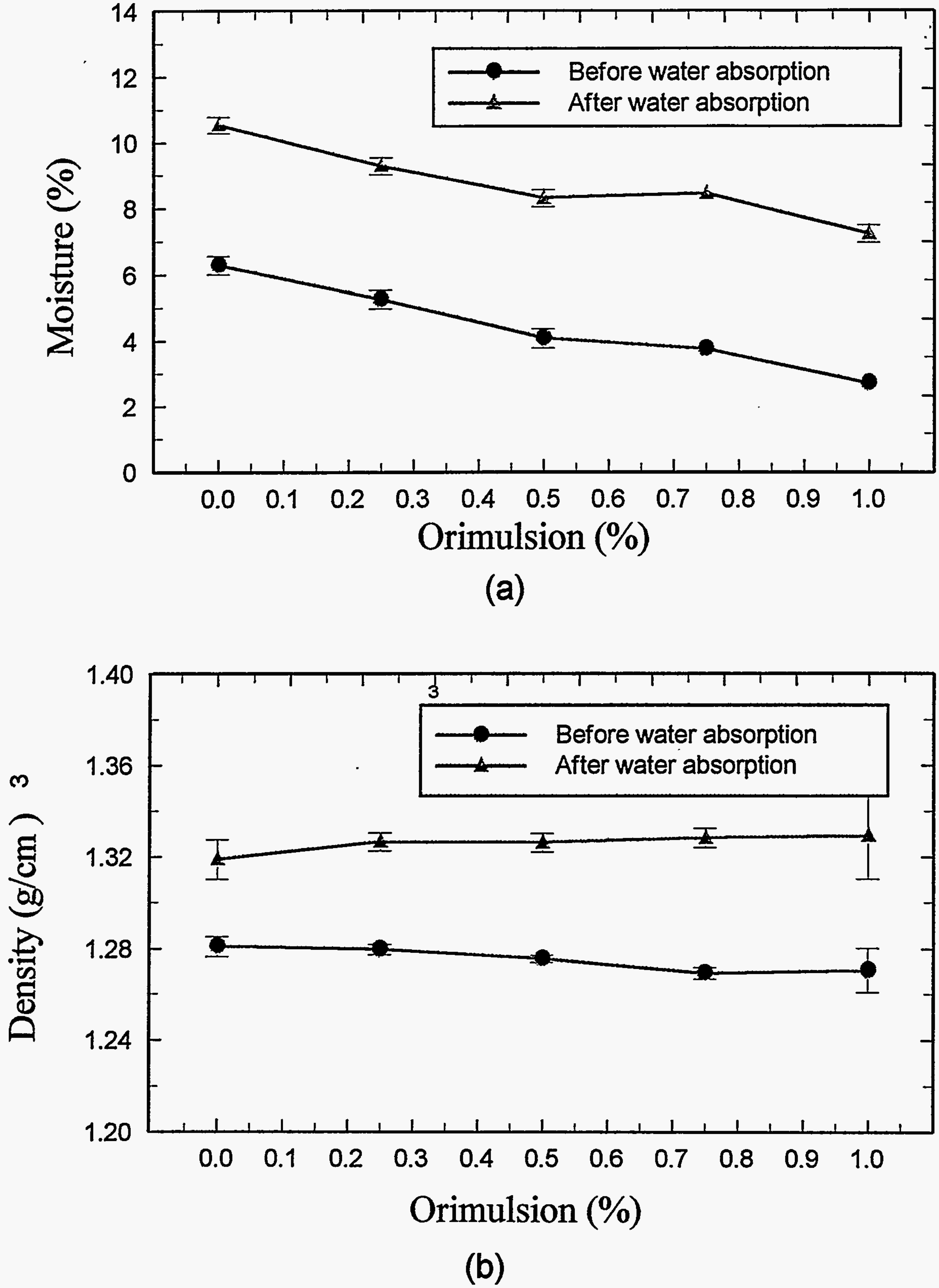


Figure 3. Moisture and density of coal logs compacted in an unlubricated, stainless steel mold at different binder concentrations

4th Quarterly Report

Coal Log Pipeline Project

Oct. 1 - Dec. 31 1995

Project Title: Coal Log Fabrication Using Hydrophobic Binders

Project Investigator: Dr. John W. Wilson

Research Assistant Professor: Dr. Yungchin Ding

Graduate Research Assistant: Bing Zhao and Brent Ward

OVERVIEW

In the current large coal log fabrication process, coal log manufacturing speed (rate) is considered to be one of the most important factors to the commercialization of the Coal Log Pipeline System. The rate of coal log fabrication depends mainly upon the requisite time period to form a single coal log, and the time interval between any two coal logs formed consecutively. However, the time required between the formation of two coal logs relies on the design of a special coal log fabrication machine. When considering the time needed to produce a single coal log, it is obvious that the shorter the fabrication time, the faster the fabrication speed, and the higher the coal log productivity.

In the coal log compaction process, the fabrication time required to form a single coal log is the combination of loading time (rate), peak loading time, and unloading time (rate). Fast compaction can be described as producing a satisfactory coal log by reducing each part of the fabrication process as short as possible, with the use of currently available equipment and test conditions. The investigation of fast compaction of commercial size coal logs was studied during this reporting period, and durability tests of coal logs fabricated by fast compaction were also carried out to evaluate the effect of fast compaction on the performance of the coal logs manufactured.

In addition to coal log durability tests, another factor to be considered in coal log fast compaction is the effect of the moisture content of the coal-binder mixtures before compaction. The influence of the amount of water added to prepare coal-water mixtures, on the final coal log moisture content, was also investigated when the fast compaction method of making coal logs was carried out.

PROGRESS TO DATE

Influence of Loading Rate on the Durability of Coal Logs

The compaction machine used to fabricate large coal logs is a 200 ton (400,000 lb) capacity Baldwin hydraulic press. Due to the manual control of this machine, the loading operation is technically limited. The normal loading rate used in the previous tests on coal logs was within the range of 2,500 to 3,500 lb/s for large (5.3" in diam.) coal log compaction, with the maximum compaction pressures being 10,000 psi. In order to study the influence of loading rate on the performance of coal logs, higher loading rates were applied during the coal log compaction operation, as shown in Table 1. The minimum loading time used in these tests was 15 sec., which is also the fastest loading rate the uniaxial press can provide.

Table 1 Influence of Loading Rate on Coal Log Durability

Log No.	Load Time, s	Load Rate, lb/s	Weight Loss, %
1	15	14667	7.8
2	30	7333	4.3
3	45	4889	3.8
4	60	3667	2.3

In this study, the coal logs tested were all made under the same conditions, i.e., 2% Orimulsion binder; 10,000 psi compaction pressure; 0 sec. peak loading time; 20 sec. unloading time; and a 5 min. tumbling test. Figure 1 shows the influence of the various loading rates on the abrasive resistance of coal logs after the tumbling tests. It can be seen from Figure 1 that the effect of loading rate on the weight loss of coal logs becomes less significant when the loading rate is lower than 7333 lb/s.

Influence of Peak Load Time on Coal Log Durability

During the fast coal log compaction tests, it was found that the control of the peak loading time was much easier than the control of the loading and unloading rates, when using the Baldwin hydraulic press.

Table 2 shows the weight loss of coal logs that were fabricated under various peak loading periods.

Table 2 Influence of Peak Load Time on Coal Log Durability

Log No.	Peak Load Time, s	Weight Loss, %
1	0	6.3
2	15	3.5
3	30	2.7
4	45	2.4
5	60	1.8
6	300	0.8

All coal logs tested in this study were made under the following conditions: 1.5% Orimulsion binder; 10,000 psi compaction pressure; 30 sec. loading time; 20 sec. unloading time; and a 5 min. tumbling test. The percentage weight loss of the coal logs shown in Table 2 decreased, that is, the durability of coal logs increased as the peak loading time increased from 0 to 300 sec. (5 min.). These test results are also graphically shown in Figure 3. The most notable increase in durability of the logs occurs when the peak compaction time increases from 0 to 15 sec. The reason for the increase in coal log durability along with the increase of peak loading time stems from the fact that the water within the coal log mixture requires time to exit the coal log. With increased peak compaction time, less water is retained within the coal log and, hence particle bonding is increased and a more durable log is produced.

Influence of Unloading Rate on Coal Log Durability

In the previous tests, the coal log unloading rates used were within the ranges of 4,000 to 5,000 lb/s. During the current fast compaction tests, the coal log unloading rate was increased to 22,000 lb/sec. to evaluate its influence on the performance of coal logs. Table 3 and Figure 3 show the durability test results of coal logs that were made at various unloading rates. The test conditions used in this study were: 2% Orimulsion binder; 10,000 psi compaction pressure; 30 sec. loading time; and 30 sec. peak loading time.

Table 3 Influence of Loading Rate on Coal Log Durability

Log No.	Unloading Time, s	Unloading Rate, lb/s	Weight Loss, % 5 min.	10 min.	20 min.
1	10	22,000	4.4	5.8	9.9
2	20	11,000	1.8	4.1	7.3
3	30	7,333	0.8	2.3	3.5
4	40	5,500	0.5	2.1	2.9

As it can be seen in Figure 3, it is obvious that the abrasive resistance of coal logs decreased as the unloading rate increased from 10 to 40 sec. However, there was only about 4% difference in weight loss between the fastest and slowest unloading rates, after the 5 and 10 min. tumbling tests. These test results suggest that the fast unloading of coal logs can be achieved with limited damage to the coal logs.

Influence of Fast Compaction on Coal Log Moisture Content

According to previous studies, the addition of 25 to 35% of water to the coal is good practice for the normal coal log compaction process, since it makes the mixing of coal particles with binder easier than at lower moisture contents. However, the amount of water added to the coal sample may be critical when the fast compaction process is carried out. That is, the water that exists in the coal-binder mixture must be expelled during the limited short compaction period in order to obtain satisfactory binding strength between the coal particles. Table 4 shows the moisture content of coal logs that were made with coal-binder mixtures of various moisture contents. The test conditions for these coal logs tested were: 2% binder concentration, 10,000 psi compaction pressure, 30 sec. loading time, 0 sec. peak loading time and 20 sec. unloading time. The test results indicate that the moisture content of a coal-binder mixture of up to 40% has no significant effect on the final moisture content of a coal log. Even though the coal log tumbling (5 min.) weight loss results fluctuated, all coal logs tested had a weight loss of less than 4%.

Table 4 Moisture Content of Coal Logs

Log No.	Water Percent, %	Log Weight After Made, g	Log Weight After Dried, g	Moisture Content,%
1	20	3671	3418	6.89
2	25	3774	3526	6.31
3	30	3660	3407	6.91
4	35	3617	3366	6.94
5	40	3719	3457	7.04

CONCLUSION

1. The fast compaction of commercial size coal logs is technically feasible. Based on a good machine design, the selection of the fabrication period and the relative wear resistance of coal logs will mainly depend upon the coal log traveling distance and the throughput of the pipeline.

2. The amount of water added to facilitate the mixing of coal particles and binder may have to be limited in order to prepare 20 to 40 percent moisture content of coal-binder mixtures. Under these conditions, satisfactory coal logs can still be produced using a fast compaction process.

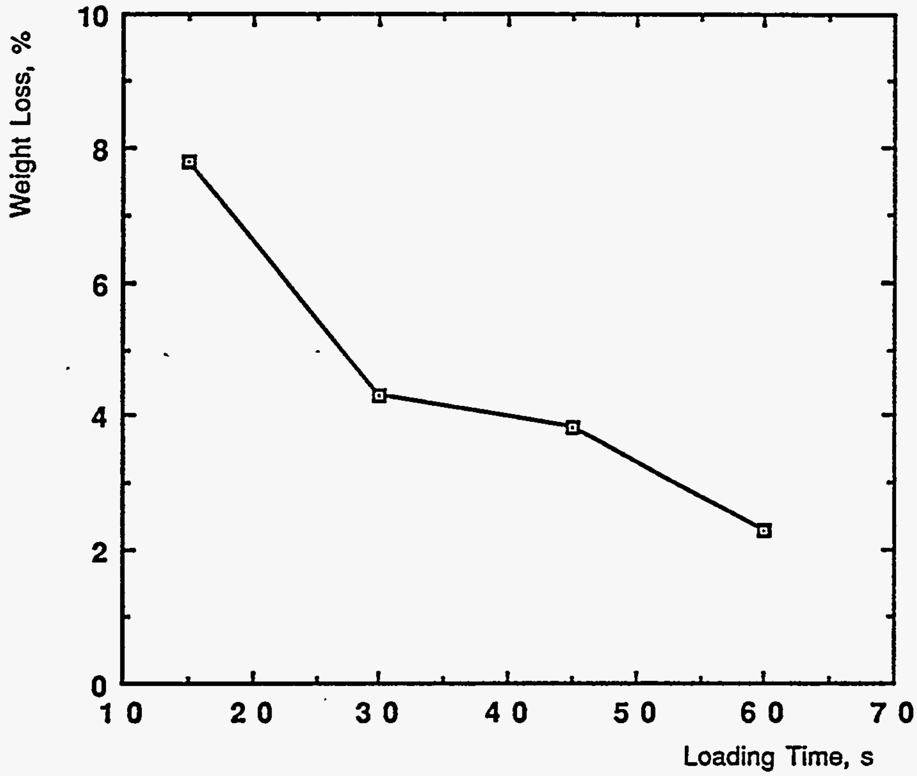


Figure 1 Influence of Loading Time on Coal Log Durability

Conditions: -6M x 0
2.0 % of Orimulsion binder;
10,000 psi of compaction pressure;
0 sec. of peak load time;
20 sec. of unloading time;
5 min. of tumbling test.

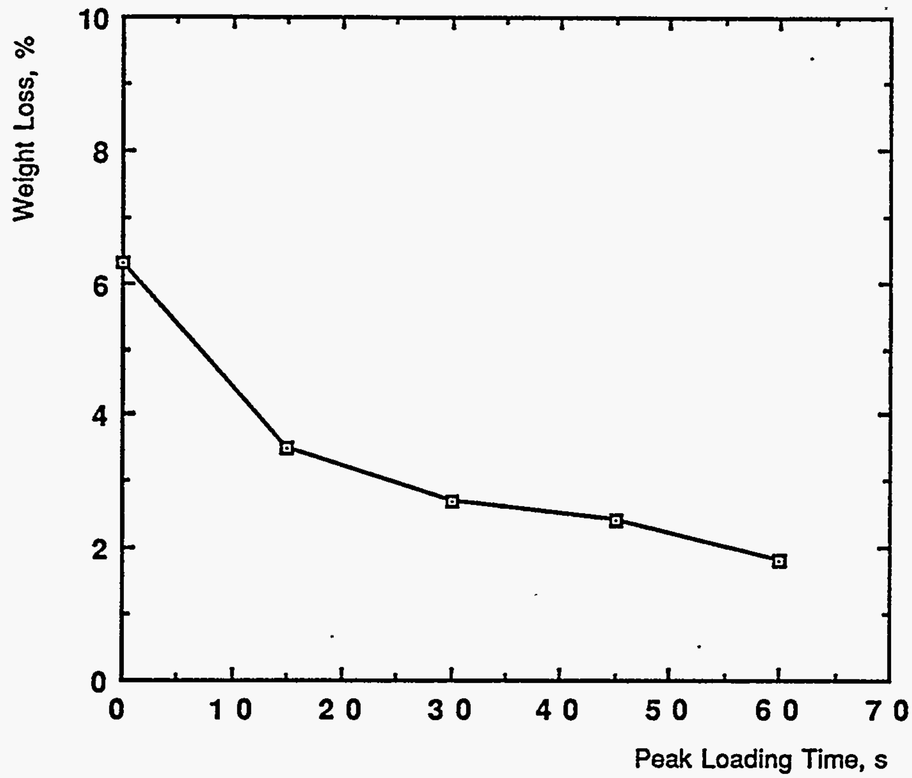


Figure. 2 Influence of Peak Load Time on Coal Log Durability

Conditions:
- -6M x 0
- 1.5 % of Orimulsion binder;
- 10,000 psi of compaction pressure;
- 30 sec. of loading time;
- 20 sec. of unloading time;
- 5 min. of tumbling test.

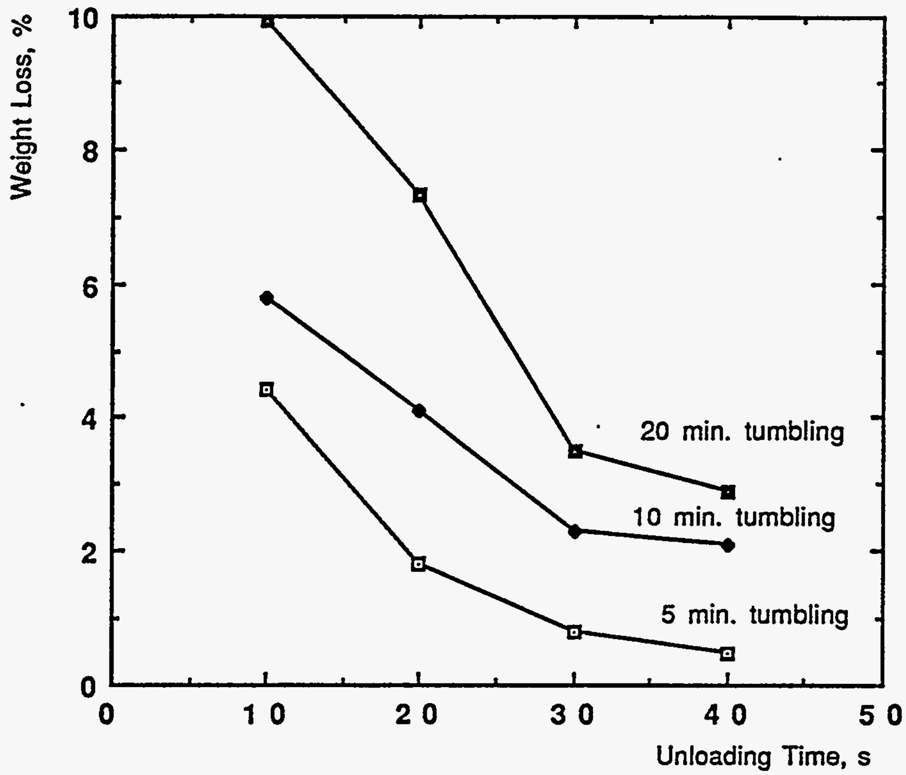


Figure 4. Influence of Unloading Time on Coal Log Durability

Conditions: -6M x 0
2.0 % of Orimulsion Binder;
10,000 psi of compaction pressure;
30 sec. of loading time;
30 sec. of peak load time.

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 9/30/95/ to 12/31/95)

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

Compaction of the coal log constitutes one of the major costs factors for the CPL. This step includes several processing steps such as pulverizing, control of moisture and temperature and the addition of other materials such as binders. However the major element of compaction economics is the investment necessary to compact huge amounts of coal. In earlier work, a smooth rate of increase in compaction pressure had been found to produce logs of the desired quality. The compaction cycle time for this procedure, however, would require a large investment in compaction machinery and would be prohibitively expensive.

In this work, the compaction time required for coal logs was reduced. Early in the program it was learned 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, the last of operating conditions were defined for a compaction cycle of 30 to 40 seconds that yields logs from Metiki coal which give satisfactory performance in the test pipeline loop. The crucial factors involved temperature, initial moisture, particle size and sufficient mixing which, along with lower lift-off velocities for logs that fill a larger inside fraction of the diameter of the pipeline, allow standard logs to pass circulation test criteria. Other important compaction parameters are in Table 1. The high process temperature of 90-97°C was necessary to avoid a one to two day storage ("curing") time required when the compaction is conducted at room temperature.

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.

A major effort in this quarter was work on the thesis of the graduate student on this project who will present his thesis defense early in the coming semester.

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.

INTRODUCTION

One of the major cost components of the CLP is compaction of the log. Compaction cycle time has a large influence on the economics of log manufacture because of the investment required for compaction machinery. 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.). Economically it was highly desirable to reduce the length of the cycle for compaction of the log.

The previous standard "slow" compaction cycle included a minimum of 3 minutes of loading and unloading and 5 minutes of holding at maximum pressure for a total of about 11 minutes. The new, "fast" compaction cycle represents about the shortest time that the 1.9 inch diameter test coal logs can be compacted using the experimental equipment currently available. The "fast" compaction cycle has a typical loading time of 30-40 seconds, no holding time at pressure, and is unloaded in 0-1 seconds.

It seems likely that, with different compaction 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.**

Early investigations showed that Western (sub-bituminous) coal responded well to reduced compaction time. Eastern (bituminous) coal, however, required extensive investigation to determine satisfactory conditions.

2. **Compaction Temperature**

Both room temperature and 97°C were explored. In economic comparison of compaction temperatures, 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 compaction 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 in the compacted log 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 with 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 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, improved 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 87°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 as possible 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, some type of 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 also 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).

In several experiments with tempering, no consistent effect was found. The effect of tempering, if it exists at all, is less than the normal variability observed in log production. The results of these tests in Figure 1 show the lack of correlation of circulation performance with tempering. This figure also demonstrates that 7 of the 8 test logs passed the nominal circulation criteria of 3% loss in 350 cycles and the other was only slightly higher at about 3.3%. Note that these results were not optimized; for example these logs had sharp rather than beveled edges.

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

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 <u>always</u> found in logs from heated molds. In general, logs made from the preheated coal performed better than those from mold-heated coal. The average weight loss for the preheated coal was significantly less than for mold heated primarily because the preheated coal did not lose large chunks near the beginning of the test. The attrition rates are slightly higher for the preheated coal.

Although is not clear <u>why</u> the improved performance occurs with preheated coal, certainly is related to bonding forces (friction, adhesion, etc.) between the coal and the interior of the mold. Ejection pressures were lower with the externally preheated coal. In limited tests with lower piston (ram) temperatures, no effect on log quality was found.

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

FUTURE PLAN

The case for production of satisfactory coal logs using a 30 to 40 second compaction cycle has been established. Economic studies indicate that even further reduction in compaction cycle time is desirable and even necessary. The data produced here suggest that more rapid compaction cycles are feasible from the point of view of the quality of the log that is produced. However the physical limits have been reached for the compaction equipment used in this work. A change of equipment is required. A different group is pursuing development of equipment and procedures for more rapid compaction. Our efforts have been on finishing the thesis and technical paper describing the details of this work.

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

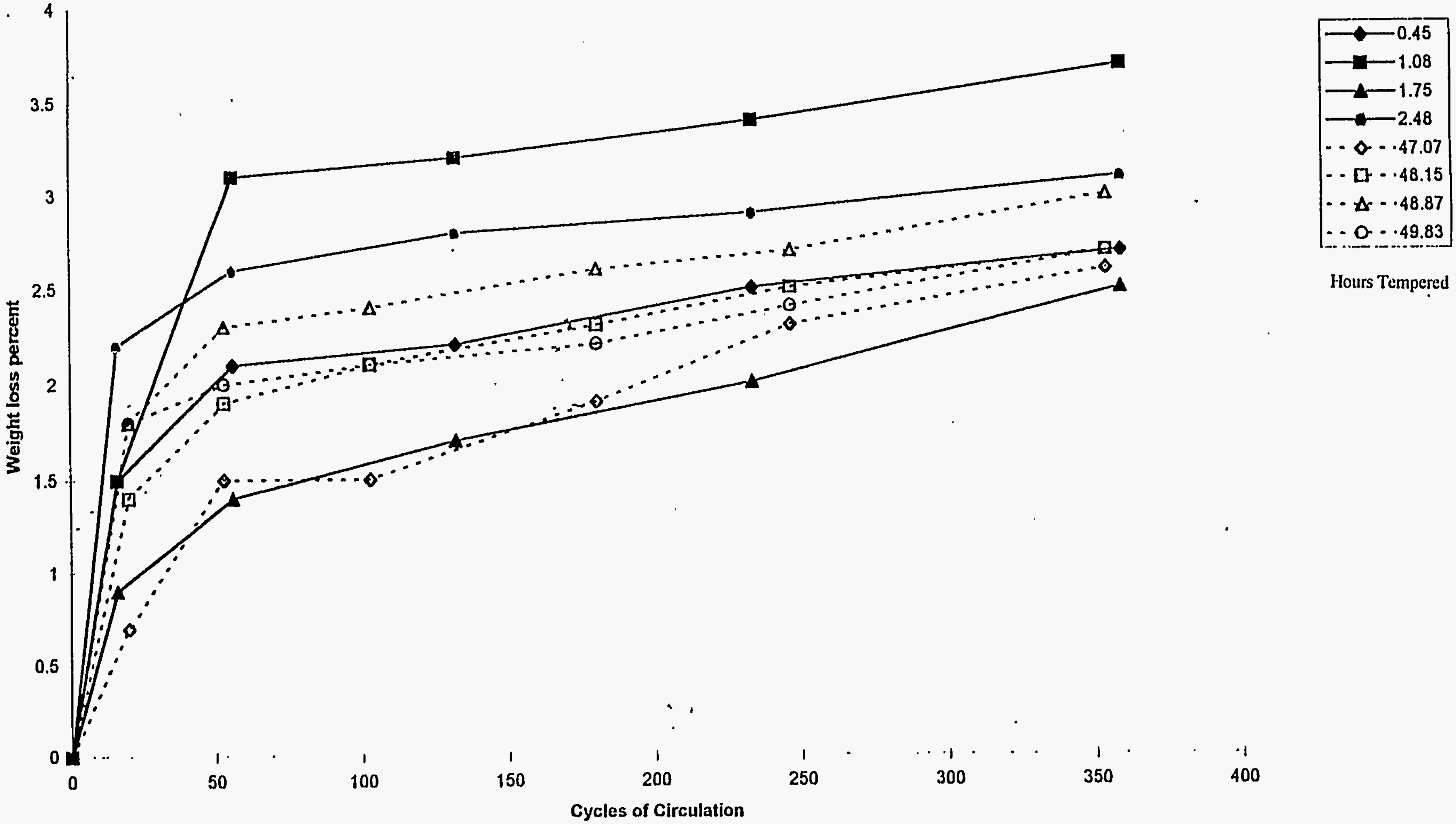


Figure 1

CAPSULE PIPELINE RESEARCH CENTER

Progress Report

(Period Covered: 10/01/95--12/31/95)

Project Title: <u>**Fast Coal Log Compaction**</u>

Principal Investigator: Dr. Brett W. Gunnink, Associate Professor of Civil Engineering

Graduate Student Assistant: Kai Jiang

Purpose of the Research: To reduce the compaction cycle of coal logs to less than 30 seconds.

Work Accomplished During the Period:

- **Introduction**

To make the coal log pipeline technology fully developed and speed up its commercialization procession, it is very important to decrease the compaction time required for coal logs. A program was carried out to reduce the compaction cycle to less than 30 seconds. Using the satisfactory conditions for faster compaction such as initial moisture, particle size, amount of binder and so on, defined by former researchers in the center, coal logs made with a cycle time of 25 seconds showed out promising results. To overcome the physical capability limit of the present compaction equipment, we are now adjusting a programmable 300kip machine to be ready for a less-than-10-second compaction. All the efforts indicate that it is feasible to reduce the compaction cycle to a much shorter time, not only from the point of view of the coal log strength, but from the experiment facilities aspect as well.

This report compares coal logs made at room temperature to those at 97°C with a compaction cycle of 25 seconds.

Also attached is the check list of the 300kip machine, which is a must for operation.

- **Fast Compaction at Room Temperature**

  First, coal logs were made at room temperature. The process parameters are shown in Table 1. And the circulation result is plotted in Figure 1.

- **Fast Compaction at 97°C**

  To compare the results with room temperature compaction, coal logs were made under 97°C. The process parameters are shown in Table 2. Circulation result is plotted in Figure 2 and Figure 3.

  - Note

    Due to miscalculation, the logs mistakenly ran under the lift-off velocity instead of 0.85*lift-off velocity during the first 5 minutes of circulation. Therefore, considerable loss occurred to the bottom of the logs during the first 20 cycles. This is shown in Figure 2.

    A make-up justification based on average loss after that is approximately evaluated. And the result is shown in Figure 3.

- **Discussion**
  - The fast compaction process less than 30 seconds can be used to make coal logs with good circulation test performance.
  - Coal compacts made at 97°C are much stronger and perform significantly better in laboratory scale pipeline circulation tests than compacts made at room temperature.
  - Coal compacts made at 97°C are susceptible to circumferential cracking and ejection loss.
  - Ejection procession of 97°C compaction, which is always accompanied by big noise and vibration, is longer and needs higher pressure than that of room temperature compaction.

Table 1. Fast Coal Log Compaction Parameters (at room temperature)

Coal	Grind air dry Metiki coal, through -30mesh
Mold	No. 5 (Single-Piece, 1.91" inside diameter, 9" length, 1° taper in bottom 3", chrome plated)
Binder	3gms Orimulsion(70% Bitumen+30% water) per 100gms dry coal
Moisture	8% moisture prior to making coal logs (set time=1hr)
L/D	1.68 (200gms mixed coal per log)
Preload	2,500lb
Compaction Style	Floating Mold
Compaction Pressure	20,000psi (57,000lb)
Compaction Temperature	Room Temperature
Compaction Time	25 second loading, 0-1second unloading, No hold time at pressure
Ejection from the mold	Ejected as quickly as possible
Water Absorption	1 hour at 500psi
Circulation Test	332 cycles @ 85% of calculated liftoff velocity

Table 2. Fast Coal Log Compaction Parameters (at 97°C)

Coal	Grind air dry Metiki coal, through -30mesh
Mold	No. 5 (Single-Piece, 1.91" inside diameter, 9" length, 1° taper in bottom 3", chrome plated)
Binder	3gms Orimulsion(70% Bitumen+30% water) per 100gms dry coal
Moisture	8% moisture prior to making coal logs (set time=1hr)
L/D	1.68 (200gms mixed coal per log)
Preload	2,500lb
Compaction Style	Floating Mold
Compaction Pressure	20,000psi (57,000lb)
Compaction Temperature	97°C
Compaction Time	25 second loading, 0-1second unloading, No hold time at pressure
Ejection from the mold	Ejected hot as quickly as possible
Water Absorption	1 hour at 500psi
Circulation Test	350 cycles @ 85% of calculated liftoff velocity

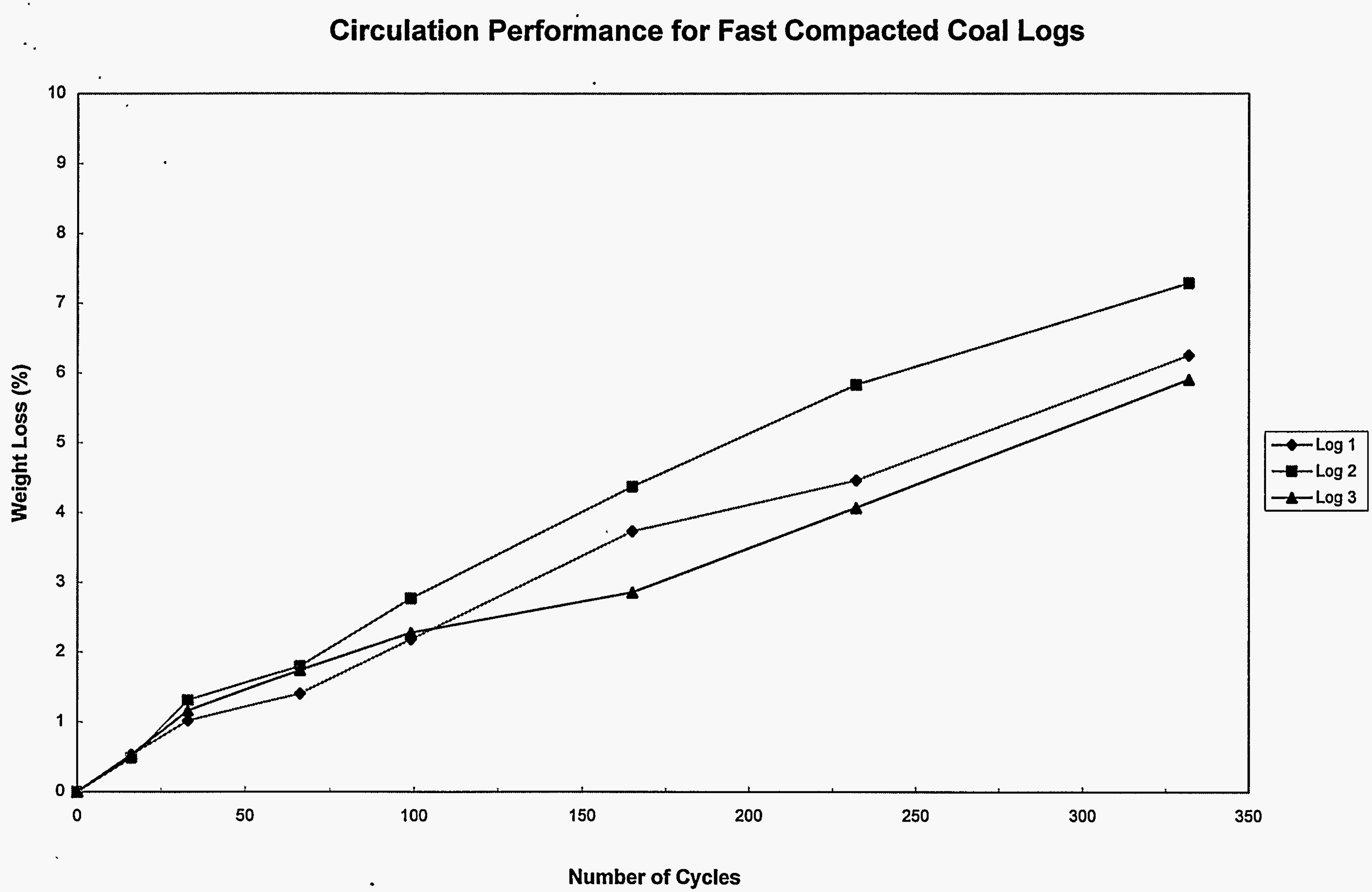
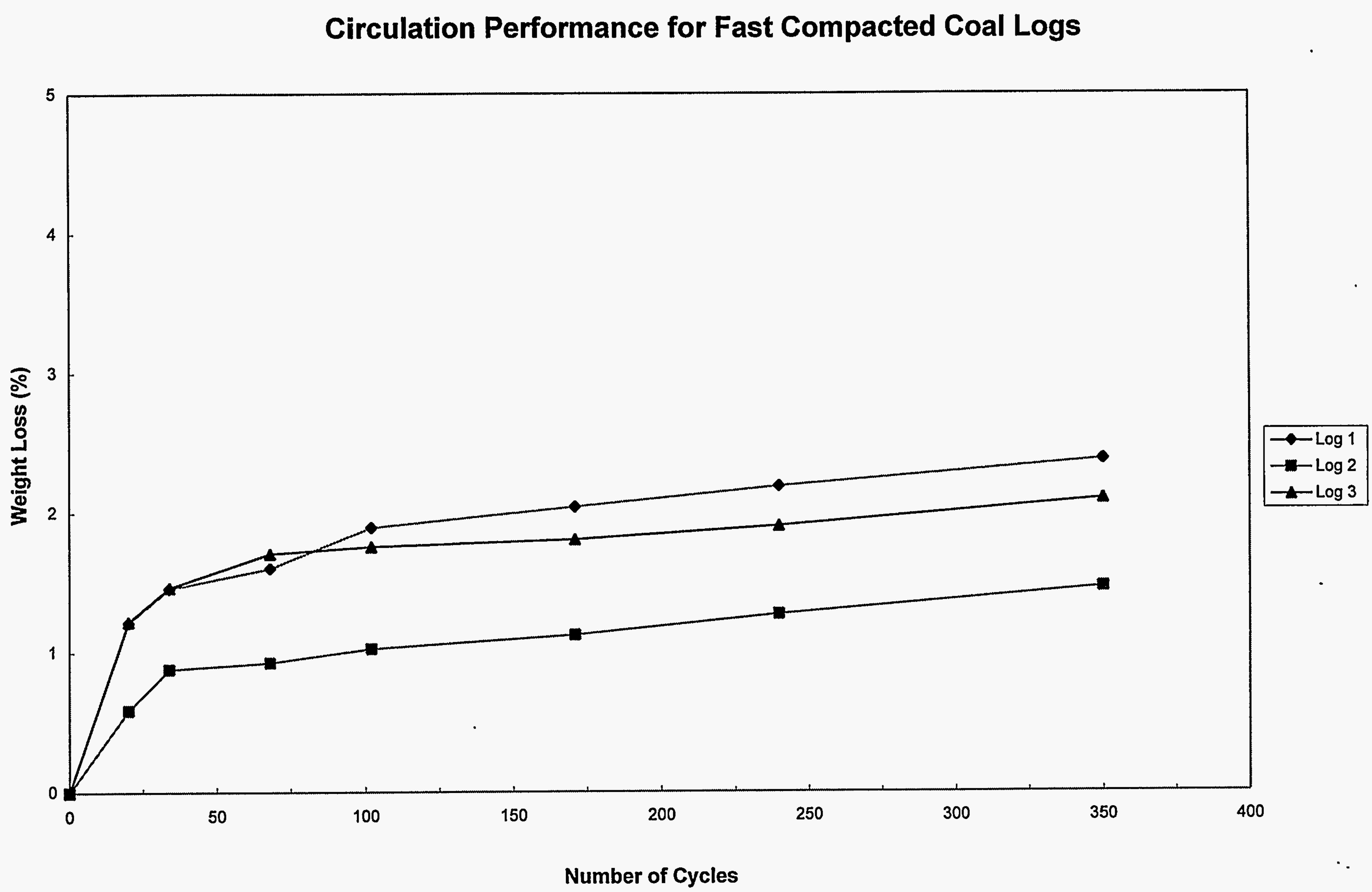

Circulation Performance for Fast Compacted Coal Logs
Weight Loss (%)
Number of Cycles
0
1
2
3
4
5
6
7
8
9
10
0
50
100
150
200
250
300
350
Log 1
Log 2
Log 3

Figure 1



Circulation Performance for Fast Compacted Coal Logs
Weight Loss (%)
0
1
2
3
4
5
0
50
100
150
200
250
300
350
400
Number of Cycles
Log 1
Log 2
Log 3

Figure 2

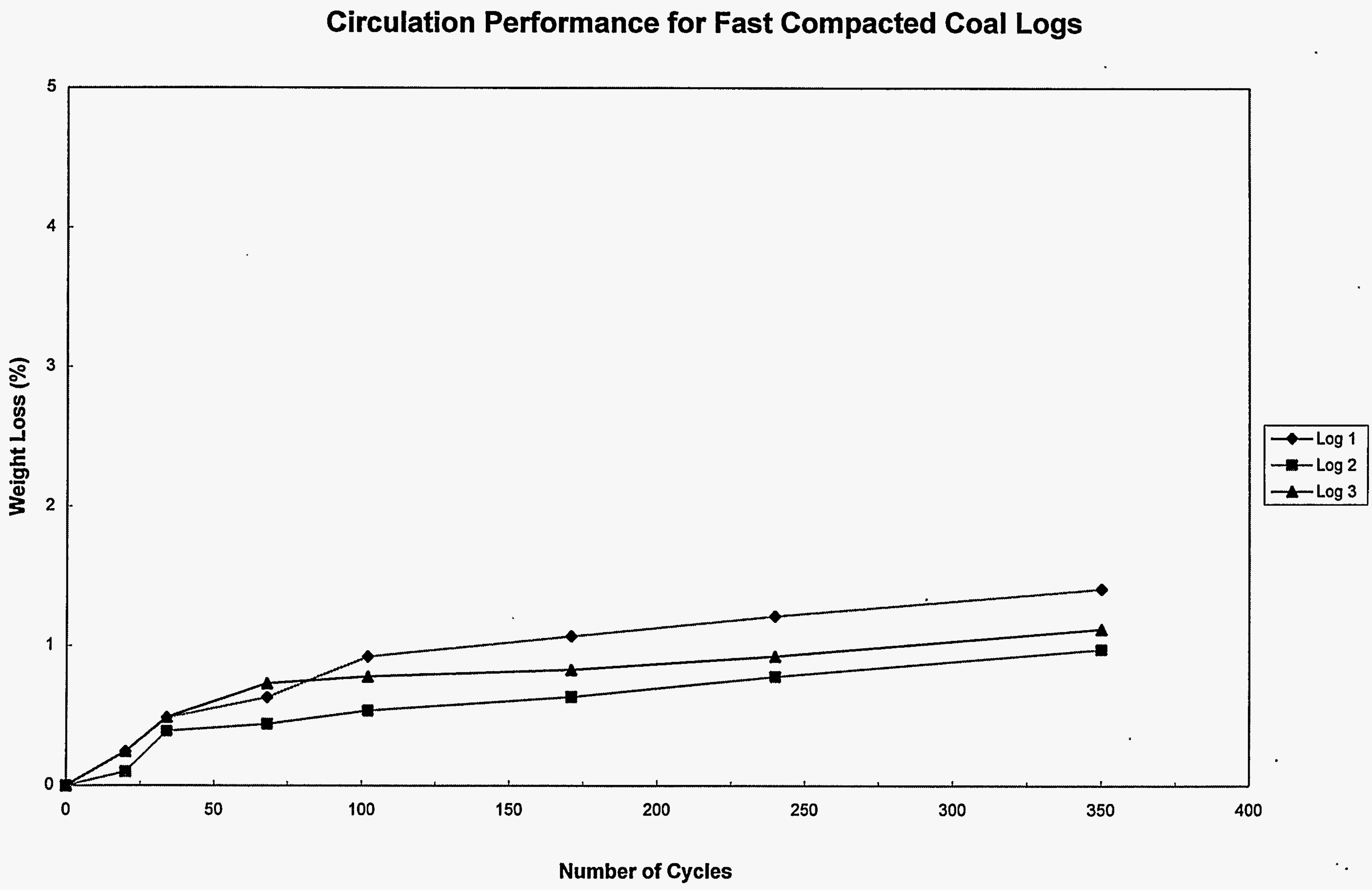

Circulation Performance for Fast Compacted Coal Logs
Weight Loss (%)
0
1
2
3
4
5
0
50
100
150
200
250
300
350
400
Number of Cycles
Log 1
Log 2
Log 3

Figure 3

Check List

- **Function Generator**
  - Select Local
  - Select Dual Slope and Ramp
  - BREAKPOINT on 70 Local Normal
  - Rate 1 on 230 seconds
  - Rate 2 on 15 seconds
  - Output zero on
- **XDCR1**
  - LVDT Cable connected
  - Select Coarse
  - Zero on 513
  - Cal Factor on 268
  - Verify signal coming out
- **XDCR2**
  - Load Cell Cable connected
  - Select *1
  - Zero on 629
  - Excitation on 355
  - Verify signal coming out
- **SERVO CONTROLLER**
  - ΔP on 6
  - Rate on 6
  - Gain on 4
- **FDBK SELECT on XDCR2**
- **LIMIT DETECT**
  - UPPER on +190
  - LOWER on -1000
- **Select INTLK XDCR2**
- **Set point around 500**
- **Span on 190**
- **Check DC error on XDCR2**
- **Check Data Acquisition System**
- **Check Specimen**
  - Chains
  - Eyehooks
  - Mold alignment
- **Turn on Hydra Low then High**
- **Use Setpoint control moving the lower table upward very slowly till around 8 inches to start the experiment**
- **Push start on Function Generator**

Capsule Pipeline Research Center
Quarterly Report
(period covered: 10/1/95 to 12/31/95)

Project Title: Coal Log Train Transport

Principal Investigator: Dr. James Seaba, MAE Dept.

Research Assistants: Wenwei Xu (CE)
Dong-Qing Zhai (MAE)

Purpose:

To experimentally and numerically study the fluid mechanics of capsule train transport in a pipeline. Specifically, the pressure drop, capsule velocities, clearance between pipe and capsule, and capsule-capsule interaction during transport are correlated to water velocity, capsule aspect ratio and diameter ratio.

Work Accomplished During this Period:

D.Q. Zhai completed her M.S. Thesis entitled, "Computational Analysis of Capsule Transport in Pipe." The equations for the numerical model are derived and presented in this thesis. Fig. 1 compares the total pressure drop to bulk fluid velocity for 8 capsules in a train. The model agrees with the experimental data in regime I for all experimental data available which includes Fig. 1 (0 to 0.3 m/s in Fig. 1). Fig. 1 also shows that the model is in close agreement over regimes II to IV. However, Regimes II to IV generally do not agree as well as Regime I. More data is required to fully assess this model.

W. Xu has designed a new data acquisition program to collect pressure and electromike data in the 2-inch pipeline. In addition, new pressure transducers were put in place to assess the pressure drop across the capsule train. Accurate measurements in regime I are very difficult due to the low pressure drop. However, current measurements are repeatable and agree with the model.

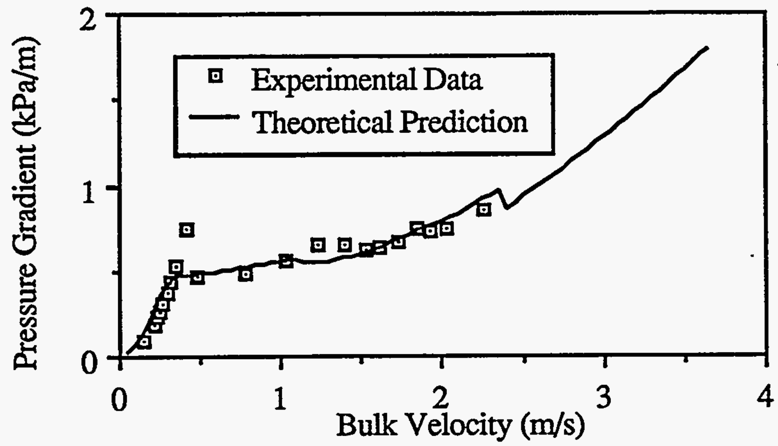


Figure 1 Capsule transport in water using 8 capsules, k=0.707, a=2.

Future Work

The measurement of capsule and static pressure drops in the 2-inch pipeline over all capsule flow regimes (1 to 4) will be completed by April 1996. This will also include electromike measurements which determine the orientation of the capsules in the pipeline. The results will be compared to the capsule train transport model. The model will continue to be developed by Dr. Seaba.

Capsule Pipeline Research Center

Quarterly Report

(Period Covered: 10-1-95 to 12-31-95)

Project Title: **Legal Aspects of CLP**

P.I.: Dr. Peter N. Davis, Isidor Loeb Professor of Law

Research Ass'ts: none

Purpose of Study: To explore legal issues involved in commercialization of CLP, including eminent domain powers for right-of-way and water rights acquisition, nature of water rights acquired by voluntary transfer, right to cross railroads, conversion of existing pipelines, pipeline waste disposal, environmental assessment, etc.

Work Accomplished During the Period:

Research conducted during the period:

(1) *Coal pipelines crossing railroads.* Additional research on common law of rights to intersecting transportation line rights-of-way, and updated list of state statutes granting eminent domain authority to coal pipelines. Completed. [Peter Davis]

Publication work:

(1) *Coal Pipelines Crossing Railroads: Legal Issues.* Preparation of paper, co-authored with Dr. Henry Liu, on rights and powers of coal pipelines to cross railroad rights-of-way without the consent of the railroad owner. This article discusses both common law rights and powers and state statutes granting the power of eminent domain to coal pipelines. This article will be published in the paers of the ASCE Pipeline Crossings Specialty Conference in March 1996. Completed. [Peter Davis]

Work Proposed for Next Quarter:

Research work:

none.

I will be stationed in London, England, from January through May 1996 on a teaching assignment at our law school's study abroad program.

Publication work:

(1) *Manual of Practice: Legal Aspects -- Preliminary Draft.* If time permits before leaving the United States on January 8, 1996, I will complete preparation of third draft of the legal chapter for the Manual of Practice. Some of the work will be taken from the pipeline crossings paper, above. [Peter Davis]

Work Left for Summer 1996:

Research work:

(1) *Proposed federal property rights statute.* Summary of statute which defines compensable takings under environmental statutes and the Endangered Species Act. [Peter Davis]

(2) *Is pipeline water diversion a "beneficial use" under prior appropriation law?* [Peter Davis]

(3) *State waste discharge regulation.* Summary. [Peter Davis]

(4) *State wetlands disturbance regulation.* Summary. [Peter Davis]

(5) *Endangered Species Act.* Summary. [Peter Davis]

(6) *State environmental impact report requirements.* Summary. [Peter Davis]

(7) *Model remedial legislation.* Finish drafting remedial legislation to enhance viability of coal pipeline projects. In progress. [Peter Davis]

(8) *Platte Pipeline easements in northern Missouri.* Determine easement language used in sample recorded easements for Platte Pipeline in some northern Missouri county. [not yet assigned]

Publication work:

(1) *Manual of Practice: Legal Aspects -- Final Draft.* Complete preparation of third draft of the legal chapter for the Manual of Practice. [Peter Davis]

(2) *Law review articles.* Continue preparation of one or two law review articles on right-of-way and water rights issues based on Florida conference paper by Davis, Cress & Sullivan, *Legal Aspect of Coal Pipelines in the United States -- Preliminary Findings* (Apr. 1993), on the Pipelines Crossings Conference Paper by Davis & Liu, *Coal Pipelines Crossing Railroads: Legal Issues* (Mar. 1996), and on the *Manual of Practice: Legal Aspects -- Final Draft.* The Manual of Practice manuscript will be used as the basic text for these articles. [Peter Davis]

Key Results of Recent Work:

Coal Pipelines Crossing Railroads: Legal Issues. The list of states conferring eminent domain authority to coal pipelines was revised upward. Eighteen states confer general eminent domain authority on coal pipelines. Twelve of those states expressly authorize coal pipelines to cross railroads. They are Alabama, Iowa, Louisiana, Montana, New Jersey, North Dakota, Oklahoma, South Carolina, South Dakota, Texas, Virginia, and West Virginia. (Details of the corrections are outlined in the 3d Quarter Report.) Remedial legislation is needed in the other states.

Publications:

none.

Unpublished Research Reports:

none.

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