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Coal Log Pipeline Research at the University of Missouri

1st Quarterly Report for 1995

1/1/95 - 3/31/95

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National Science Foundation (IUCRC Program)
State of Missouri (Department of Economic Development)
U.S. Department of Energy (Pittsburgh Energy Technology Center)

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

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

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EXECUTIVE SUMMARY

During this 1st quarter of 1995, major progress has been made in the following areas of coal log pipeline R & D:

1. Completion of the first draft of the manual of practice. This will be a monumental document in the field of coal log pipeline and will facilitate utilization/commercialization of CLP.

2. Applied for two U.S. patents, one on the hot-water formed process, and the other on a process to improve the strength of binderless coal logs at room temperature. The process requires adjustment of the zeta potential and certain other factors.

3. Completed a survey of U.S. utilities and coal companies about potential sites for commercial demonstration of the coal log pipeline (CLP) technology. Eight companies submitted projects for considerations; three were selected for detailed analysis. One will be selected form the three as the demonstration project.

4. Collected all the information needed for revising the 1993 economic report; revised the computer program used in the 1993 report—made it more logical and more user friendly. Need more work to complete the report revision.

5. Conducted a detailed assessment of the coal log wear loss in pipe based on different processes. Selected 13 processes and compared their economics and maximum transportation distances. Four final processes were selected for detailed final economic analysis.

6. Reduced coal log compaction time from 5 minutes to 15 seconds approximately. Showed that through proper mixing of binder with coal and proper proportioning of water, the coal log compaction time can be greatly reduced without substantial weakening of the logs. Because the 15 seconds compaction time was limited by machine speed rather than the process, it is likely that satisfactory logs can be produced at compaction time much less than 15 second. This will be explored during the next quarter.

7. Demonstrated that better coal logs can be produced by lubricating the mold with calcium stearate or by conditioning the mold with MILITEC-1.

8. Found the reasons for coal log capping and developed strategies to prevent capping. Two of such strategies are currently being tested for their effectiveness.

9. Discovered that the strength and wear-resistance of coal logs can be increased substantially by adding as little as 0.4% fiber from waste paper.

10. Found that logs compacted at 97°C can be ejected at such temperature into a luke warm bath of water (at 45° C) without loss of strength. However, more rapid cooling or thermal shocks can damage to coal logs.

11. Submitted a proposal to DOE Pittsburgh Energy Technology Center on the planning and design of a large (8-inch-diameter 12-mile-long) pipeline test/demonstration loop.

12. Submitted an EPRI-TC proposal to more than 100 utilities that are EPRI members. The proposal is for running certain tests to pave the way for commercial demonstration of CLP.

13. Submitted a NICE^3 proposal to DOE on compacting coal fines into coal logs.

14. Completed the design of a machine that can mass produce coal logs of 7.5 inches diameter. Evaluated the costs of coal logs made by such machine at compaction time of 10 sec. and 30 sec.

15. Established contacts with companies that have experience in designing and fabricating fast compaction machines used for making tablets—the rotary press. Started to design a fast production coal log machine based on the rotary press concept.

MAJOR ACTIVITIES PLANNED FOR THE NEXT QUARTER INCLUDE:

1. Complete revision of the manual of practice. (CPRC Faculty)

2. Complete revision of the economic report. (Noble/Liu/Zuniga)

3. Negotiate/select a CLP demonstration project. (Liu/Marrero/CLP Consortium)

4. Evaluate, construct and test a 1.9-inch-diameter coal log rapid production system based on hydraulic press. (Dr. Lin)

5. Design and construct a 1.9-inch-diameter coal log rapid production system based on rotary press. (Dr. Lin)

6. Complete evaluation of the fiber effect on strengthening coal logs. Prepare a final report. (Gunnink)

7. Complete evaluation of zeta potential effect on strengthening coal logs. Prepare a final report. (Mr. Lin/Liu)

8. Complete evaluation of the hot-water-formed process in making coal logs. Focus attention on cooling time, cost of cooling, and commercial system design. (Gunnink)

9. Complete evaluation of lubricant effect on strengthening coal logs. Prepare a final report. (Li/Liu)

10. Complete evaluation of rapid compaction (10 to 30 seconds). Prepare a final report. (Luecke/Smith/Gunnink)

11. Complete evaluation of vacuuming effect on coal log production at room temperature. Prepare a final report. (Butler)

12. Complete evaluation of steam heating effect on coal log quality. Prepare a final report. (Butler)

13. Complete evaluation of particle size effect on coal log production using large mold. Prepare a final report. (Wilson/Ding)

14. Complete evaluation of coal log compaction speed effect using large mold. Prepare a report. (Wilson/Ding)

15. Complete evaluation of piston shape effect on elimination of capping and strengthening of coal logs. Prepare a report. (Smith)

16. Evaluate performance of coal logs made with controlled pressure applied to both pistons during ejection from mold. Prepare a report. (Smith)

17. Evaluate best method for mixing coal with binder in commercial coal log manufacturing. Prepare a report. (Burkett)

18. Evaluate best method to crush coal for commercial coal log manufacturing. (Burkett/Gundlach)

19. Assess equipment need for commercial coal log fabrication plant. (Burkett/Pro-Mark)

20. Complete testing and evaluation of coal log train separator. Prepare a final report. (Nair)

21. Complete design and construction of a coal log recirculation system in the automated CLP model. (Nair)

22. Design/select all components of an automated control system for an 8-inch-diameter-pipe pump-bypass. (Nair/Mistry/Nova Tech)

23. Complete assessment of pigging need for CLP. Prepare a report. (Liu/Nair/T.D. Williamson)

24. Test a special coal log detector. (Nair/T.D. Williamson)

25. Complete assessment of PERMALOK for possible use in CLP. (Liu/PERMALOK/Willbros Butler)

26. Assess best material and method for coal log pipeline internal lining. Evaluate cost and prepare a report. (Willbros Butler)

27. Test extrusion of coal fines. (Bonnot)

28. Prepare for a short course in CLP in July. (CPRC Faculty)

29. Publish 1995 Newsletter. (Liu)

30. Visit companies to boost CLP Consortium Membership. (Liu/Marrero)

31. Visit utility companies on the EPRI-TC proposal. (Liu/Marrero)

32. Revise and improve prospectus on Capsule Pipeline Company. (Liu)

33. Complete and submit proposal to Missouri Department of Economic Development to make CPRC a Missouri CAT (Center for Advanced Technology). (Liu/Marrero)

34. Prepare annual report to NSF and other sponsors. (Liu/Marrero)

INDIVIDUAL PROJECT REPORTS

(1/1/95 - 3/31/95)

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 1/1/95 to 3/31/95)

Project Title: Fast Compaction of MAPCO Coal Logs

Principal Investigator: Dr. Henry Liu

Research Associates: William Burkett and Rebecca Smith

Purpose of the Research:

The purpose of this study was to examine the effect of moisture content and compaction speed on the wear resistance of MAPCO coal logs. Compaction loading rates of six minutes, three minutes, one minute, 30 seconds, and 15 seconds were examined. Moisture contents of 23%, 20%, 17%, and 13% were examined for coal logs compacted at loading rates of 30 seconds and 15 seconds.

Work Accomplished During the Period:

Compaction Speed

All coal logs were compacted from MAPCO coal with 23% moisture (by total weight) and 2% asphalt (by dry coal weight). The compaction pressure was 20,000 psi and the temperature was 97°C. Only the loading time varied. The compaction process included loading and unloading at the same given rate. No hold period was used. One load was compacted at each loading times of six minutes, three minutes, and one minute. Three logs were compacted at a loading rate of 30 seconds.

Figure 1 presents the results of the circulation wear test. The log compacted at a loading time of three minutes performed the best with only 3.9% weight loss in 350 loops. In contrast, the logs compacted in a 30 second loading broke along circumferential cracks within 250 loops. A possible explanation for these results is given. Particles undergo different mechanisms of deformation at different loading rates. Faster loading causes particle fracture to dominate the mechanism of deformation. As particles fracture, surface area not coated by the asphalt binder is created, weakening the log. In addition, as compaction speed increases, less water is squeezed out of the log. Excessive moisture will prevent densification needed to produce a wear resistant coal log.

Considering these results, an investigation into the effect of moisture on the wear resistance of fast compacted coal logs was done.

Moisture

Compaction feed moisture content has an important effect on the quality of fast compacted coal logs. Water has two roles in the compaction feed. First, it is used to dilute the asphalt binder for mixing with the coal. Second, water provides some lubrication during compaction. Excessive moisture cannot be squeezed out of the log during compaction. Likewise, too little moisture results in poor mixing and insufficient lubrication.

All coal logs were compacted from MAPCO coal with 2% asphalt (by dry coal weight) and varying amounts of moisture. Compaction feed moistures of 23%, 20%, 17%, and 13% were used to compact coal logs. The compaction pressure was 20,000 psi, the temperature was 97°C, and loading and unloading times were each 30 seconds.

Figure 2 presents the results of the circulation wear tests. Each line is the average of three logs. The logs compacted with 17% moisture performed the best, with an average of 7% weight loss in 350 loops.

15 Second Compaction

Two logs were compacted in a 15 second loading, 2 second unloading process. The compaction feed contained 17% moisture and 2% asphalt. Figure 3 presents the results of the wear test in comparison to the 30 second compacted logs. The 15 second compacted logs lost an average of 8.5% weight in 350 cycles compared to 7% for the 30 second compacted logs. Because the 15 second and 30 second logs were compacted from two separate batches of compaction feed, batch effect may be responsible for the differences in circulation performance.

Future Plans:

Further tests with 15 second compaction are planned. Mixing and moisture content of the compaction feed are two variables which will be investigated. Addition of fibers to improve coal log wear resistance will also be tested.

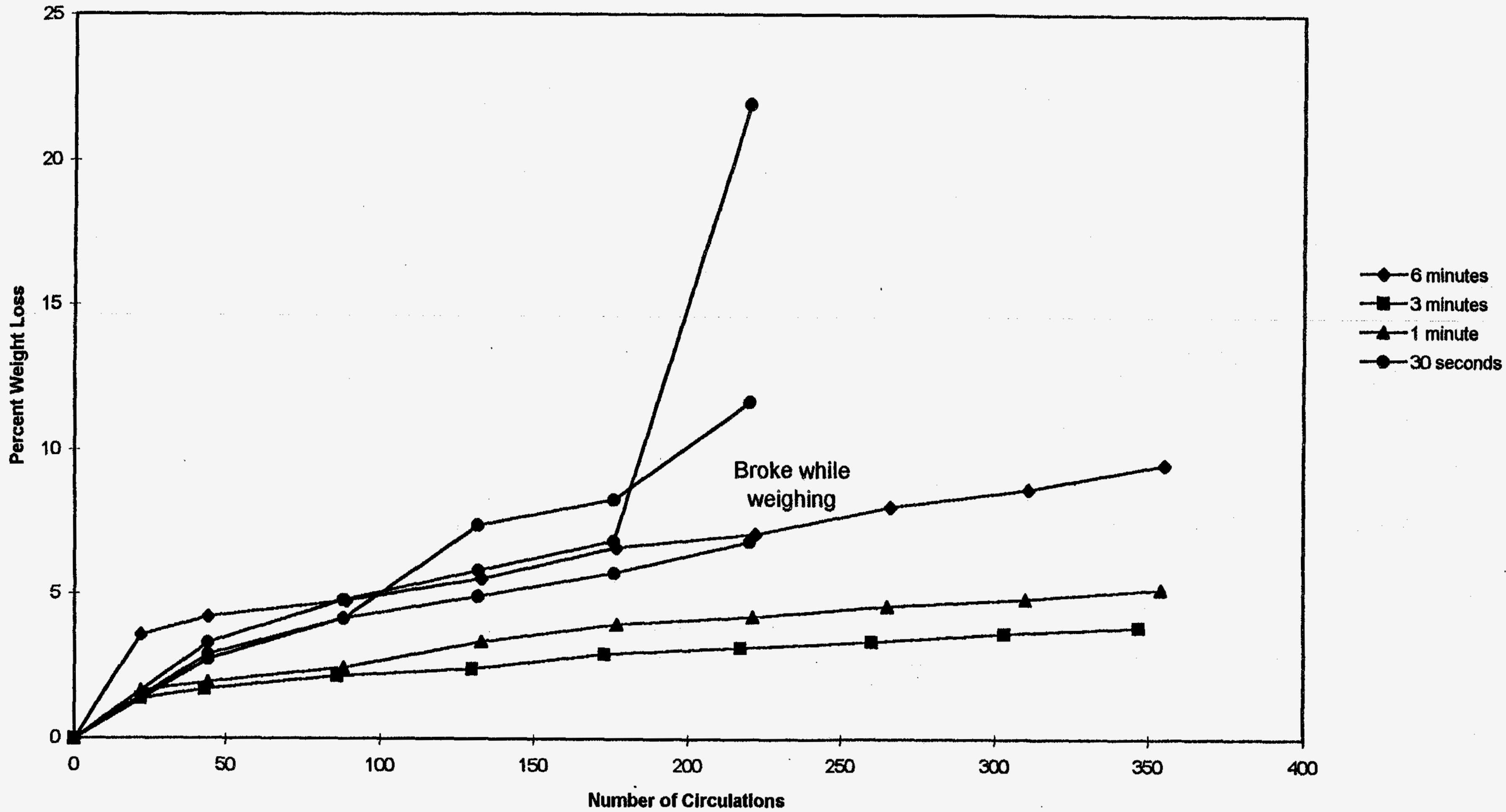


Figure 1: Wear Test Results for Coal Logs Compacted at Different Loading Rates

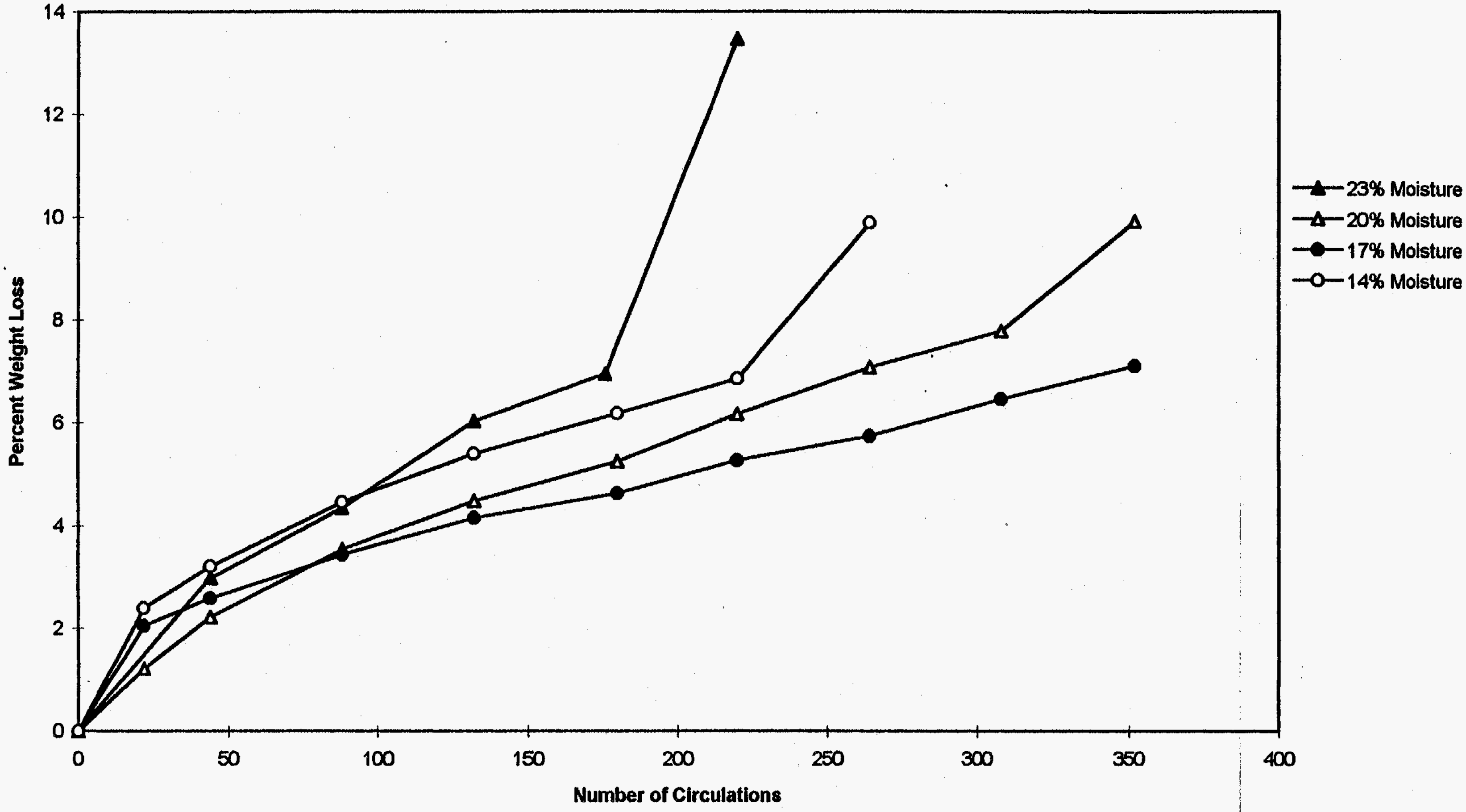


Figure 2: Average Wear Test Results for Coal Logs Compacted with Different Moisture Contents

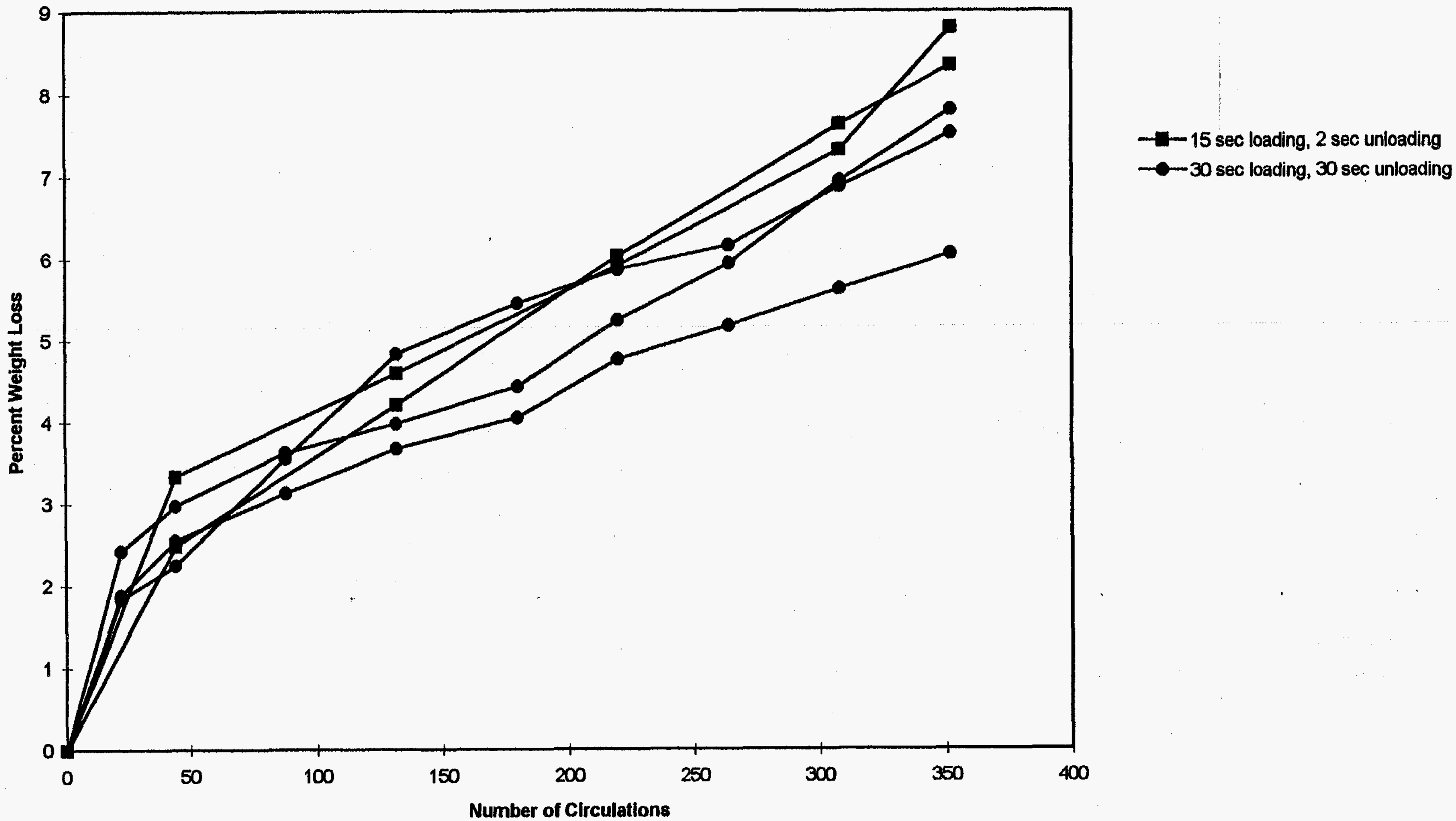


Figure 3: Comparison of Wear Test Results for Logs Compacted in 15 seconds and 30 second Loading Time

CAPSULE PIPELINE RESEARCH CENTER QUARTERLY REPORT

(Period Covered: 1-1-95 to 3-31-95]

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 produce coal logs using a reduced compaction time.

The compaction procedure in making coal logs as previously developed requires maintaining elevated pressure on the log in the mold for an extended period (5 to 10 min.). This hold time has a significant effect on CLP economics. This experimental program has had the objective of reducing the length of time required for compaction of the log.

The Compaction Cycle

A graph of the "slow" compaction cycle is shown in Figure 1. This cycle includes 3 minutes of loading and unloading and 5 minutes of holding at maximum pressure. Logs manufactured using this compaction cycle were acceptable by the tests being used for the 2 inch diameter logs.

The "fast" compaction cycle shown in Figure 2 represents about the shortest time that the log can be compacted using the equipment currently available. The shortest compaction time is about 10-15 seconds for the first stroke, and 5 - 10 seconds for each additional stroke. Typical loading times varied from 20 to 30 seconds while the unloading times varied from 8-14 seconds. The total cycle time for a single cycle compaction varied from 30 to 40 seconds. The maximum pressure attained was 20,000 psi.

For some experiments, multiple strokes were used as depicted in Figure 2. It was found, however, in early work, that multiple strokes did not improve log performance. Hence the data reported below is all from logs made using just a single compaction stroke. For the single stroke compaction, the last two pulses in Figure 2 are omitted.

It is important to note in the compaction cycle patterns shown in Figure 2, that the largest fraction of the compaction time is below 6000 psi pressure (approximately 65-70%). Since we believe that very little of the log strength is formed below 6000 psi, probably this part of the compaction cycle could be modified or speeded up without a significant effect on the results.

Rapid Compaction and Coal Log Performance

A large number of variables have been explored. In the following, standard conditions are summarized along with ranges of variables tested.

1. Compaction time to 20,000 psi - "slow" - 11 minutes; "fast" - 35 - 40 seconds.

2. Binder concentration from orimulsion - asphalt concentrations based on dry weight of coal are 2.2% and 0.5 %.

3. Initial Moisture 19%, 15%, 9%, 6.5-8.0%

4. Temperature - room temperature and 97°C

5. Ejected from mold rapidly (into 50°C water for high temperature compaction).

6. Cure or no cure, i.e., storing of finished log in at room conditions for a certain time.

7. Tempering or no tempering, i.e., storing of the mixed coal, water and binder before compaction.

8. Metiki (MAPCO) coal ground in the hammer mill and then sifted through 30 mesh screens.

9. Test criteria for all logs was performance in the 2 inch steel pipeline.

10. Circulated at 85% lift-off and 100% lift-off.

11. Single piece stainless steel mold with flat pistons.

Results

a. Compaction Temperature

In scouting experiment, the logs were compacted with the "fast" or "slow" method at room temperature. These logs contained 2.2% binder and were circulated at lift-off velocity. Those logs which were circulated without curing for at least 24 hours, showed large weight loss and/or broke after relatively few circulation cycles.

A few logs compacted "fast" at room temperature and several logs compacted with the "slow" method, which were then "cured" for 24 to 48 hours did not break until more than 250 circulation cycles. Weight losses were about 10% for this circulation time. It was believed that at lower circulation velocities, lower weight loss would occur but the principal aim of these experiments was to compare "fast" and "slow" compaction.

As a result of these experiments, interest was shifted to the higher temperature compactions. All of the other experiments reported here were conducted at compaction mold and coal temperatures of 97°C.

b. Lower Asphalt Concentrations

Binder concentration is an important economic factor in coal log manufacture. In these experiments lower binder concentrations are explored. The binder concentration was reduced from 2% to 0.5% (asphalt concentration based on dry weights).

Coal logs were mixed with 30% initial moisture. Excess moisture was then evaporated in the oven leaving 19% moisture the initial mix. Logs were tested in the steel pipeline with water at lift-off velocity. The top of the log inside the mold was always the front of the log in the pipeline. This end was also always against a moving piston. Also these logs were ejected from the mold after compaction at faster speeds than those from previous experiments

Figure 3 shows a comparison between "fast" and "slow" compacted logs produced with one or two moving pistons. All logs eventually experienced a break of the back of the log except one "slow" log. The "slow" logs did somewhat better than "fast" logs at all stages of the test except at initial times. Fast logs produced with one moving piston seemed to perform better than those produced with two moving pistons.

These "fast" logs represent the most economically favorable conditions that had been achieved to that time. All subsequent experiments were made with the economically sensitive conditions of low binder concentrations and 97°C and no cure.

c. Comparison of "Fast" and "Slow" Compaction at 97°C Without Cure Time

In these experiments, three logs were made using "fast" and three with "slow" compaction. All logs showed patterns of circumferential cracks after being removed from the mold. This, however, may be due primarily to the interior mold surface or mold design. Because of density differences, the "fast" compacted logs had an aspect ratio of 1.8 while the "slow" logs had an aspect ratio of 1.6. There was no cure time for any of these logs.; the initial moisture concentration had been 19%.

Figure 4 shows the results from the circulation test. Logs were circulated in water moving at lift-off velocity. The top of the log (coming out of the mold) was the front end in the circulation test. These logs show a quick initial jump in weight loss. The logs may not have experienced as much weight loss if the ends had been beveled.

Two of the "fast" logs had the entire back end ("cap") break off causing 16% weight loss at 40 circulation cycles. This same capping also occurred for two of the "slow" logs causing high weight loss at 250 circulation cycles. The longest lasting "fast" log had the back two-third of it break at 200 circulation cycles. It is at this point in all the logs that the largest circumferential crack arises. The "slow" log that performed the best in the pipeline experienced 7% weight loss at 400 circulation cycles. It may be significant that this log was also the only log made with only one moving piston.

d. Initial Moisture

During rapid compaction, it was believed that insufficient flow time for removal of excess initial moisture from the mold may prevent maximum compaction strength of the log. In these experiments, the effect of initial moisture level in the coal was explored.

A large batch of coal was mixed with 28% initial moisture and 0.5% binder. High moisture allows better mixing of asphalt. The excess moisture is evaporated in the oven immediately before compaction; this drying time was about 2 hours. Three logs with 9% initial moisture were made within 4-8 hours of production of the mix. After 2-3 days, three logs were made with 9% initial moisture and two with 15% initial moisture were made 2-3 days later.

Figure 5 shows the results of the tests of the coal logs in the steel circulation loop. For logs whose coal had been tempered for 2-3 days, the lower moisture content logs performed better. Logs with 9% initial moisture had weight percentage losses of 6.5-7.5% in 350 circulation cycles while those with 15% initial moisture experienced 14.5-15% weight loss in 350 circulation cycles. Logs made from coal that had been tempered 4-8 hours broke within 125-275 circulation cycles.

e. Tempering

In the previous experiments, there were indications that retention of the mixed coal, moisture and binder might have a beneficial effect on the coal log performance. To examine this effect, seven coal logs were compacted from the same mixed batch of ground coal. A lower initial moisture content has been used in these tests than previous.

A large batch of coal was mixed with 28% initial moisture and 0.5% binder. Excess moisture is evaporated in the oven immediately after mixing leaving the coal with 8% moisture. Two logs were made within four hours of initial mixing. Logs were then compacted a half, one, two, three, and four days later.

Figure 6 shows the results of the circulation test for the coal logs. The first three logs produced from this batch had the back end of the log break off during circulation relatively quick (at 125-200 circulation cycles). Logs produced after 1-4 days of tempering performed better in the loop. The best log was that produced after four days of tempering and had 6.1% weight loss after 350 circulation cycles.

Although the best log had the longest tempering time, the data indicate that, after one day of tempering, increases with tempering time have little effect on log performance.

Summary of Results

The principal conclusions from this work are:

1. Satisfactory logs can be made using a fast compaction cycle. There is some benefit from the longer hold at pressure in the compaction cycle, but the benefit is small.

2. Satisfactory logs can be made using 0.5% binder based on dry weights.

3. The "fast" compaction cycle described here can probably be shortened considerably because much of the compaction time occurs below 6000 psi.

4. Logs made from Metiki coal at room temperature must be "cured" for 24 to 72 hours.

5. The best results are obtained when the initial moisture in the coal is about the same as in the final log. Mixing, however, is very important and is best accomplished at higher moisture levels. In these experiments, mixing was conducted at high moistures followed by air drying.

6. Mold design is very important and is not totally defined at this time. A number of features have not been completely investigated such as interior chrome plating, taper, etc.

7. "Tempering" or storage of mixed feed for one day before compaction marginally improves the strength of the log. This effect, however, is much less than the effect of "curing" for logs made at room temperature.

All logs in the last series of experiments were compacted under the same conditions which are currently considered optimal as derived from the work described here:

1. "Fast" compaction (40 second cycle)
2. 0.5% binder by dry weight.
3. Single piece (stainless steel) mold, flat pistons.
4. 8% initial moisture
5. Coal heated in mold to 97 °C.
6. Ejected hot into 50 °C water.
7. No cure.
8. Mapco coal through 30 mesh, hammer mill
9. Circulated at 85% lift-off velocity.

Future Work

Further development is required for coal log manufacture. More economical compaction conditions will improve the success prospects for the pipeline. A better understanding of factors is also needed to improve log performance. The status at present is that we know how to make a satisfactory small log at satisfactory economic conditions but significant improvements in both log performance and economic margins would be welcome.

The compaction equipment used in these experiments places mechanical limits on our ability to explore some conditions such as faster compaction time. There are, however, a few areas that we currently see the need to explore:

1. Better mold surface such as chrome plating.

2. Some changes in mold design such as tapering.

3. Exploration of factors involved in tempering such as mixing time, temperature and moisture.

4. Confirmation of some previous results from this new baseline. These might include circulation conditions in the test pipeline, moisture levels, particle size distributions and mold temperatures.

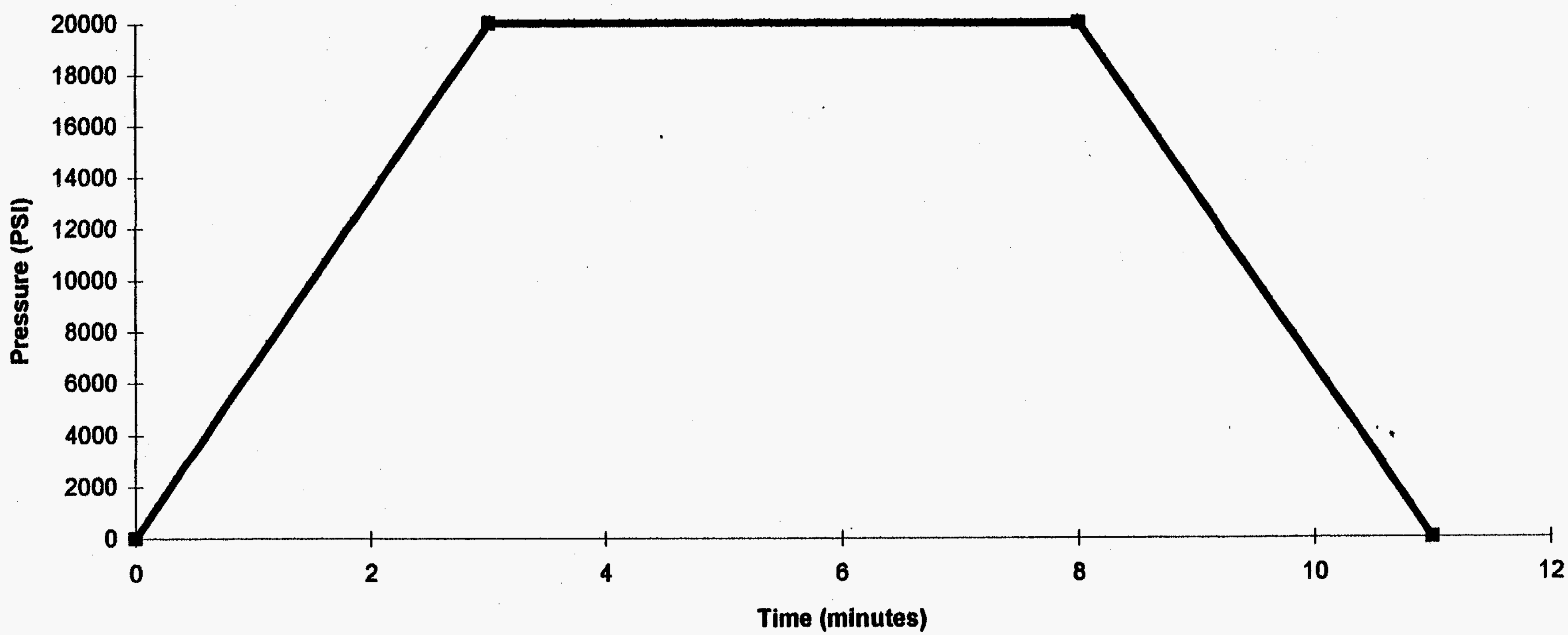


Figure 1: Compaction Curve

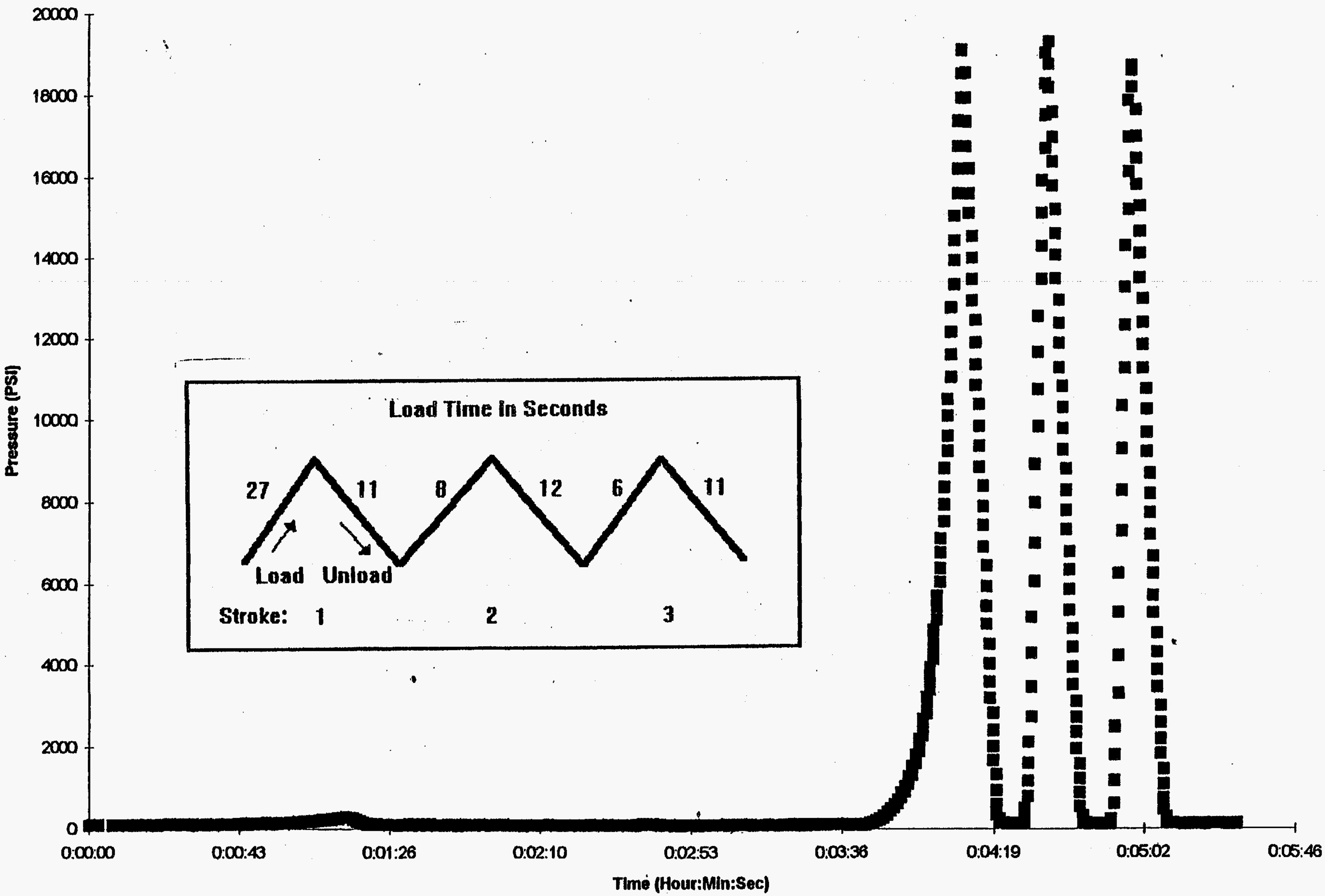


Figure 2: compaction curve

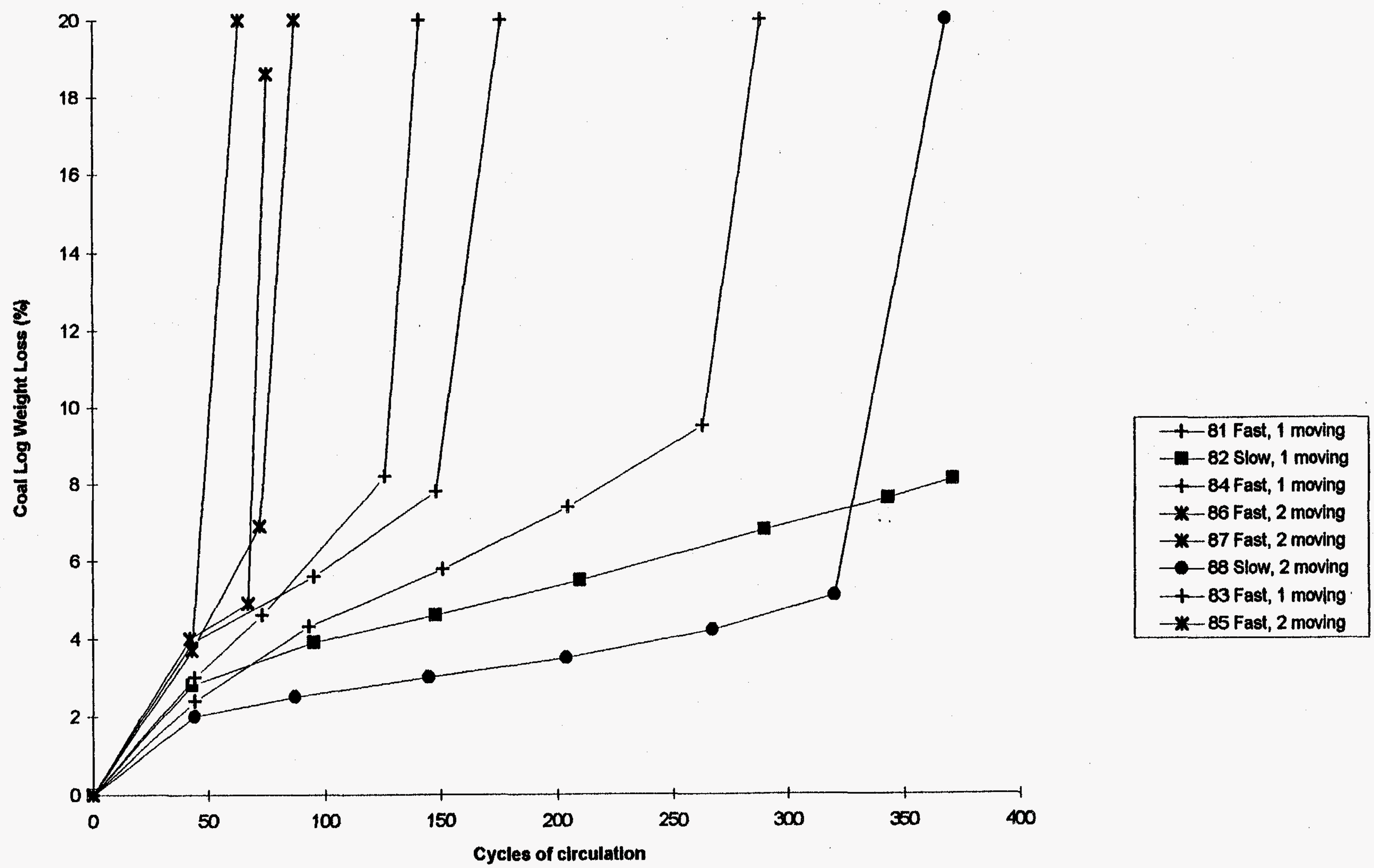
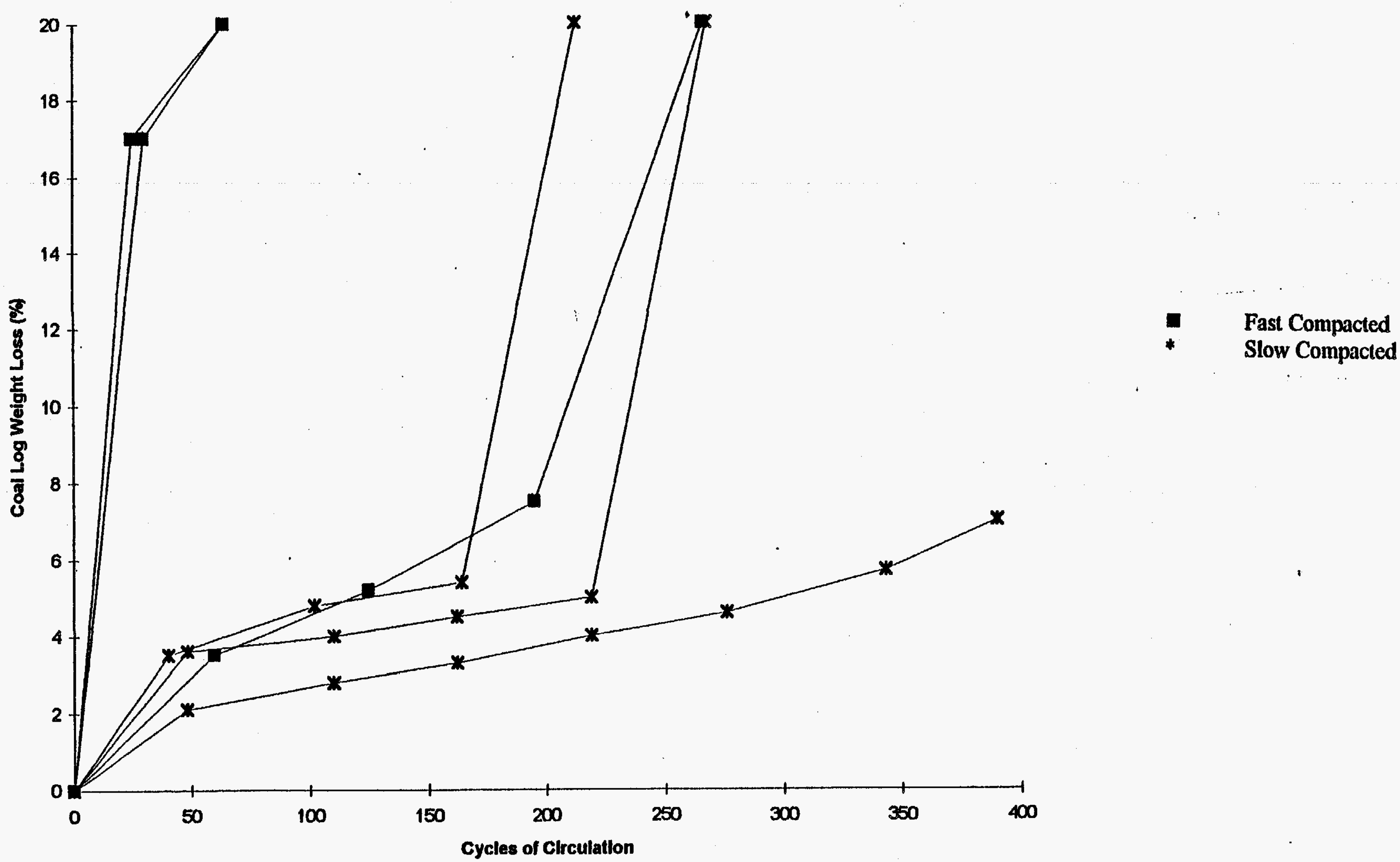


Figure 3: One moving piston vs. two moving pistons, slow vs. fast compaction


Coal Log Weight Loss (%)
Cycles of Circulation
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200
250
300
350
400
Fast Compacted
Slow Compacted

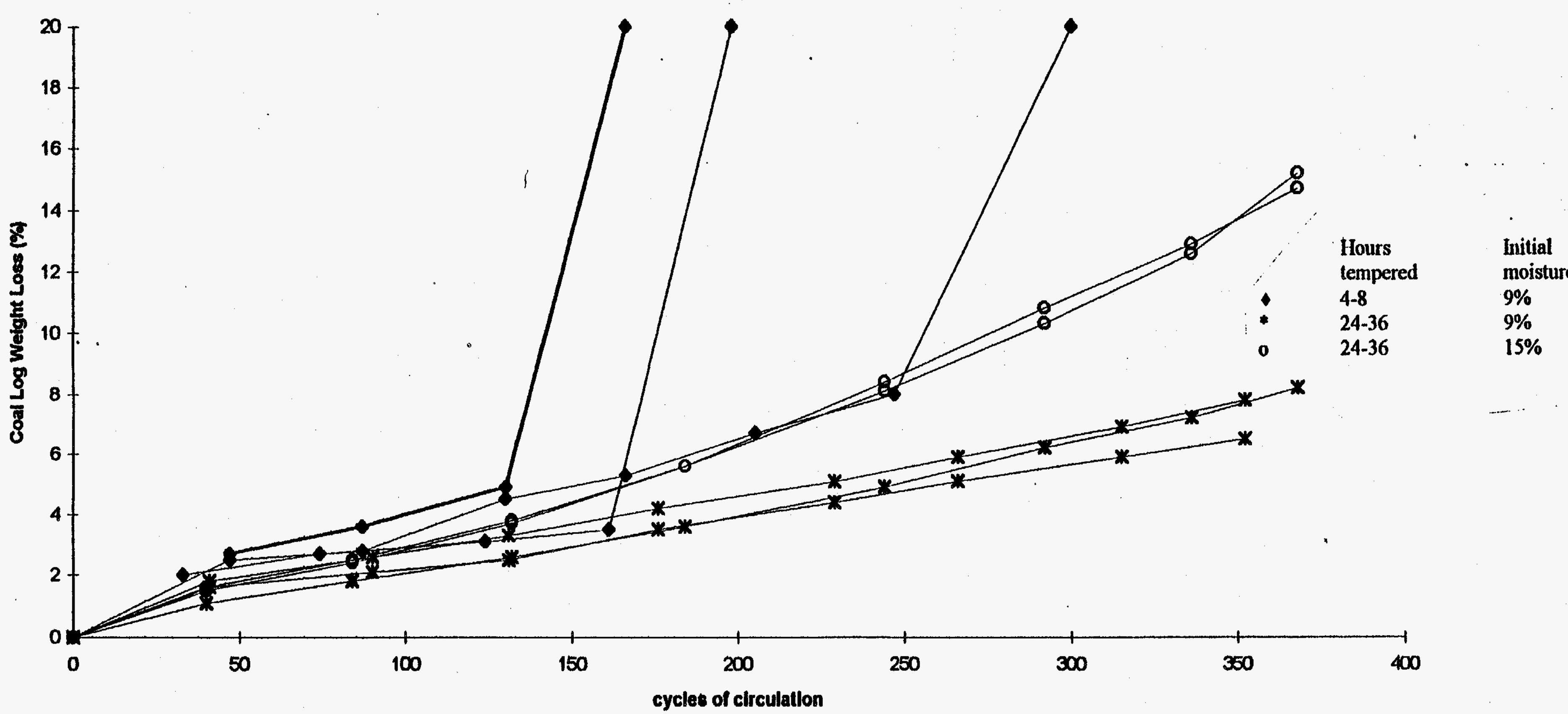


Figure 5: Fast compacted logs. 9% vs. 15% initial moisture

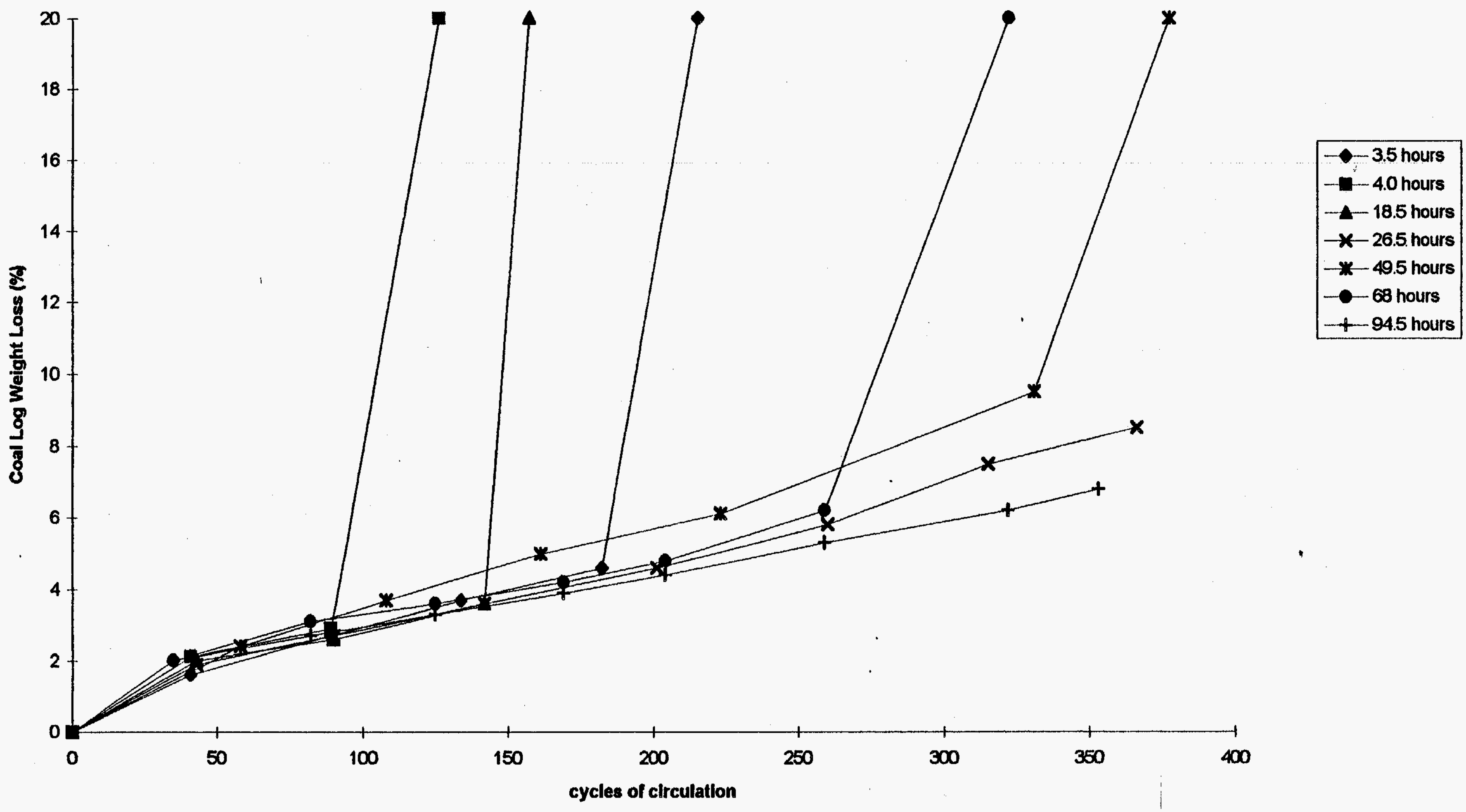


Figure 6: Log tempering time and circulation performance

CAPSULE PIPELING RESEARCH CENTER

Quartely Report
(Period Covered: 1/1/95 to 3/31/95)

Project Title: Effect of Cooling on Coal Log Quality

Principal Investigator: Dr.Henry Liu

Research Associate: Rebecca J. Smith

Research Assistant: Yu Lin

Work Accomplished:

Introduction

Coal log compaction with binder at 97°C produces strong logs. Much circulation wear test data have been collected by C.C. Cheng for Powder River Basin - North Antelope coal logs compacted at 97°C and cooled in the mold to 34°C. These coal logs passed the circulation wear test and have been the most successful to date. Cooling coal logs in the mold is not an efficient way to maximize mold use. The purpose of this study is to investigate the effect of cooling on the coal log quality. Coal logs cooled in compaction mold, air, and water were made.

Experiments

1. *For PRB coal*

The coal used in this experiment was PRB coal from the North Antelope mine in the Powder River Basin of Wyoming. The coal was ground by a ball mill, screened and remixed to give the maximum-density size distribution given in Table 1. Because the coal logs were compacted over a two day period, two separate batches were prepared to minimize the tempering effect. The two batches of compaction feed mixture were mixed for the 12 coal logs compacted. They contained 38% moisture (by total weight) and 3.3% emulsion (2% bitumen by dry coal weight). The emulsion used was SS-1H, an asphalt emulsion containing 60% asphalt and 40% water.

2. *For MAPCO coal*

The MAPCO coal was from the Mettiki mine in Maryland. The coal was ground by a hammer mill and screened through a 30-mesh seive. Water, coal, and binder were mixed and allowed to equilibrate for one hour prior to compaction. Because the coal logs were compacted over a week period, four separate batches were prepared to minimize the tempering effect. The four separate batches (three coal logs per batch) of compaction feed were mixed. The compaction feed contained 21% moisture. The amount of asphalt binder (water not included) was 2% by dry coal weight. The asphalt added was in the form of Orimulsion, an emulsion containing 70% asphalt and 30% water. For each 100 g of dry coal, 2.86 g of Orimulsion (2.00 g asphalt and 0.86 g water) was added.

3. *For both PRB and MAPCO coals*

All coal logs were compacted in the stainless steel single-piece mold at a pressure of 20,000 psi and a temperature of 97°C. The empty mold was preheated 15 minutes before addition of the compaction feed. Both stainless steel pistons had flat ends. The loading and unloading rates were 120 lb/sec. The peak pressure was maintained for five minutes. The logs were ejected at a speed of 2.5 in/min.

Four types of coal log cooling were examined. The first cooling method involved cooling the mold to 34°C with a blowing fan before coal-log ejection. For the second method, the coal logs were ejected at 97°C immediately after compaction, then cooled to 34°C standing in still air. For the third method the coal logs were first ejected at 97°C into a warm water bath (approximately 46°C). Then the logs and the water were cooled to 34°C. In the last method, the coal logs were ejected at 97°C into a room-temperature (approximately 22°C) water bath and immediately placed in the 500 psi water absorption test.

After the one-hour, 500-psi water absorption test, the logs compacted with PRB coal were immersed in atmospheric pressure water for approximately 24 hours before the circulation wear test, but the logs compacted with MAPCO coal were subjected to circulation wear test immediately. The water velocity in the pipeline was the lift-off velocity determined from Liu's equation. The ranges of velocity were 5.80-6.10 ft/s for PRB coal logs, and 6.20-6.50 ft/s for MAPCO coal logs.

Results and Discussion

1. For PRB coal

Table 2 lists the pre-water absorption, post-water absorption, and pre-circulation densities of the tested coal logs. The pre-water absorption data were taken at 34°C. The post-water absorption data was taken immediately after the 500 psi water absorption test. The logs then sat in atmospheric-pressure water for approximately 24 hours before the circulation test. The densities were calculated again immediately before circulation. The highest average pre-water absorption density, 1.245 g/cm^3, was measured for those logs cooled in the warm water, and the lowest, 1.151 g/cm^3 was measured for those logs cooled in still air. For post-water absorption and pre-circulation, the highest densities were measured for those logs cooled in the mold, and the lowest were measured for those logs ejected into the cool water. Their average post-water absorption densities were 1.295 and 1.268 g/cm^3, and average pre-circulation densities were 1.286 and 1.260 g/cm^3, respectively.

Table 3 lists the average weight and dimensions of the coal logs with different cooling methods. As compaction pressure was released, the coal logs expanded. The average volume of the logs cooled in the mold was 113.25 cm^3 before water absorption. This was about 4.16% less than the average of the logs cooled in air. The expansion of coal logs cooled in the mold was inhibited by the mold walls and the pistons. Only the top piston was moveable. As the log cools, it expanded against the top piston, and a circumferential crack was formed near the top two millimeters of the log-- the capping phenomenon. No other circumferential cracks were visible on the log surface.

In contrast, coal logs ejected immediately out of the mold and cooled in air or water could expand unhindered. The relaxation of the logs were usually not uniform. The logs cooled in air had visible cracks after ejection from the mold. These cracks widened as the log surface cooled. In addition, the logs continued to lose moisture as they cooled in air. The logs cooled in water also had visible circumferential cracks, but the cracks were not as severe as those in the air cooled logs.

After water absorption, the weight gains of the coal logs cooled in the mold and those in air were 7.25% and 12.5%, respectively. This indicates that there were more pore volume and cracks in the logs cooled in air.

Cooling rate may also be a factor affecting the quality of the coal logs due to the different stress distribution in the logs cooled with different cooling methods. Both those logs cooled in the mold and those in warm water, required approximately 30 minutes to reach 34°C. In contrast, the logs cooled in air reached 34°C in 10 minutes. The temperature of the logs ejected into cool water was not monitored. These logs were immediately placed into 500 psi water absorption chamber. The temperature of the cool water was 19°C, slightly below the room temperature of 22°C.

After 500-psi water absorption, all logs were put in atmospheric water for soaking for 24 hours. Their densities decreased due to further expansion of the logs. The densities of logs cooled in air decreased 1.50%, and those cooled in mold or in water only decreased about 0.70%. The density data indicate that the method of cooling had a obvious effect on coal log density due to different expansions.

Figure 1 shows the relations between average weight loss of the logs and circulation cycles in the wear test. Each line is based on the average of three logs cooled by the same method. After circulating 45 cycles, the average weight losses of logs were 1.77%, 2.69%, 3.11%, and 3.97% for logs cooled in warm water, in cool water, in the mold and in air, respectively. After 75 cycles, the logs cooled in air and in cool water broke. The logs cooled in warm water and in mold had weight losses of 5.68% and 8.89%, respectively, after circulating 330 cycles in the pipeline. Figures 2 to 5 show the weight loss of each coal log. The logs cooled in air and in cool water usually broke after circulation of 50 to 100 cycles. This caused the weight loss to increase sharply. In this study, it is interesting that the logs cooled in warm water were more wear resistant than those logs cooled in the mold. The mechanism and reason are not currently understood.

2. For MAPCO coal

Table 4 lists the post-cooling and post-water absorption densities of tested coal logs. The post-cooling data were taken immediately after each log reached 34°C. The logs were then subjected to 500-psi water absorption for one hour followed immediately by circulation wear test. The highest pre-water absorption densities were measured for those logs cooled in the warm water, 1.286 g/cm^3. The lowest density was 1.260 g/cm^3, for the logs cooled in air. The highest post-water absorption densities were measured for those coal logs cooled in the mold. Their average density was 1.327 g/cm^3. The logs cooled in air had slightly lower densities, average density was 1.320 g/cm^3. The coal logs cooled in warm water and in cool water had almost the same average post-water absorption densities 1.304 and 1.308 g/cm^3. The coal logs cooled in cool water had a large range of densities, 1.298 to 1.323 g/cm^3. This indicates that the quality of the logs cooled in cool water is unstable.

Table 5 lists the average weight and dimensions of the coal logs with different cooling methods. The volumes of the logs cooled in the mold and air were 113.14 cm^3 and 115.35 cm^3, respectively. The volume of logs cooled in air increased 2.0% more than those cooled in the mold. This was due to the inhibited relaxation and expansion of the logs by the mold. According to the data in Table 5, the volumes of the coal logs cooled in the mold and warm water almost did not change after water absorption. The volumes of the logs cooled in air and cool water reduced 1.06% after water absorption. The weight gains of the coal logs cooled in the mold and air were 3.4% and 4.4%, respectively. This indicates that the logs cooled in air have more pore volume or cracks.

Figure 6 shows the relations between weight loss of the coal logs and circulation cycles in the wear test. Each line is based on the average of three coal logs cooled by the same method. The coal logs cooled in the mold were the most wear resistant with only an average weight loss of 5.5% after 350 cycles. Figures 7 to 10 show the weight loss of each individual coal log. Especially noteworthy is the high capping tendency for all logs except those cooled in the mold. Figure 8 shows that all three coal logs cooled in air lost both a bottom and a top cap. Bottom caps were lost on each log cooled in warm water, and two also lost a top cap. Coal logs cooled in cold water did not lose any top caps, but two did lose bottom caps. The capping mechanism is not clearly understood. Elimination of the capping problem could reduce circulation weight loss by as much as six weight percent.

Conclusion

1. Cooling method has an obvious effect on the quality of compacted coal logs. The optimum cooling method is dependent on the type of coal.

2. For PRB coal, the coal logs cooled in warm water performed well, for MAPCO coal, the coal logs cooled in mold were better than those cooled in air or water.

3. Rapid cooling in either air or water seems detrimental to the quality of coal logs.

4. Capping was observed only for MAPCO coal logs and influenced by the cooling method to a certain degree. Cooling in mold can reduce capping.

Table 1 Particle Size Distribution of PRB Coal Used in the Test

Passing Through Sieve (mesh)	Retained on Sieve (mesh)	Weight Percent Coal (%)
30	50	29.35
50	100	20.61
100	200	14.77
200	Pan	35.27

Table 2 Density of Coal Logs with Different Cooling Methods (PRB coal)

Log No	Cooling Method	Density (g/cm^3)		
		Pre-Absorption	Post-Absorption	Pre-Circulation
1	in mold	1.220	1.304	1.291
2	in mold	1.204	1.297	1.285
3	in mold	1.208	1.285	1.281
4	in air	1.154	1.278	1.264
5	in air	1.157	1.293	1.266
6	in air	1.143	1.278	1.263
7	in warm water	1.245	1.282	1.276
8	in warm water	1.238	1.286	1.266
9	in warm water	1.251	1.279	1.277
10	in cool water		1.269	1.260
11	in cool water		1.269	1.261
12	in cool water		1.267	1.258

Table 3 Average Weight and Dimensions of Coal Logs with Different Cooling Methods (PRB coal)

Cooling Method	Pre-Water Absorption				Post-Water Absorption			
	Weight (g)	Diameter (cm)	Length (cm)	Volume (cm^3)	Weight (g)	Diameter (cm)	Length (cm)	Volume (cm^3)
in mold	139.40	4.473	7.328	113.25	149.50	4.472	7.347	115.34
in air	136.10	4.492	7.447	117.96	153.23	4.508	7.481	119.34
in w-water	148.53	4.507	7.479	119.25	153.13	4.503	7.498	119.34
in c-water					150.16	4.511	7.429	118.57

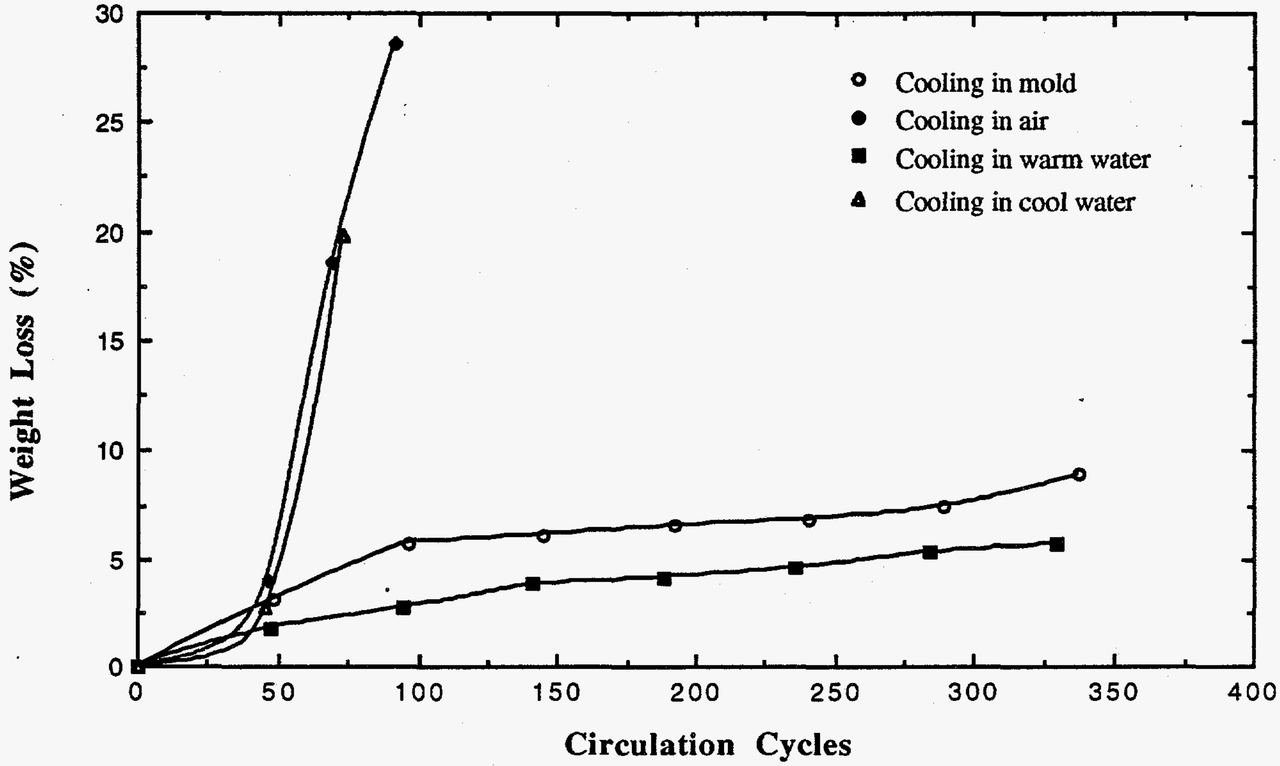


Fig. 1 Effect of Cooling on Weight Loss of PRB Coal Logs in Pipepline (Average of 3 logs for each line)

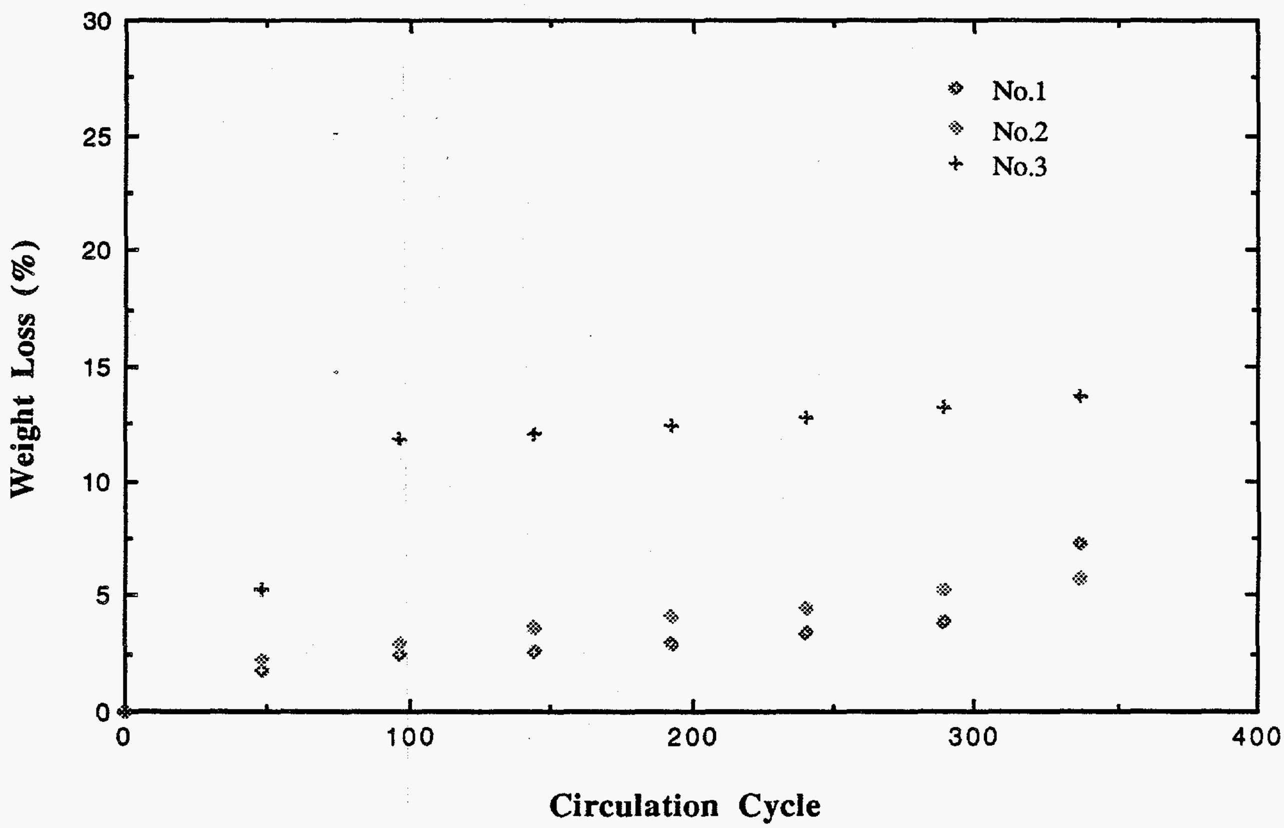


Fig.2 PRB Coal Log Weight Loss in Pipeline (Cooling in Mold)

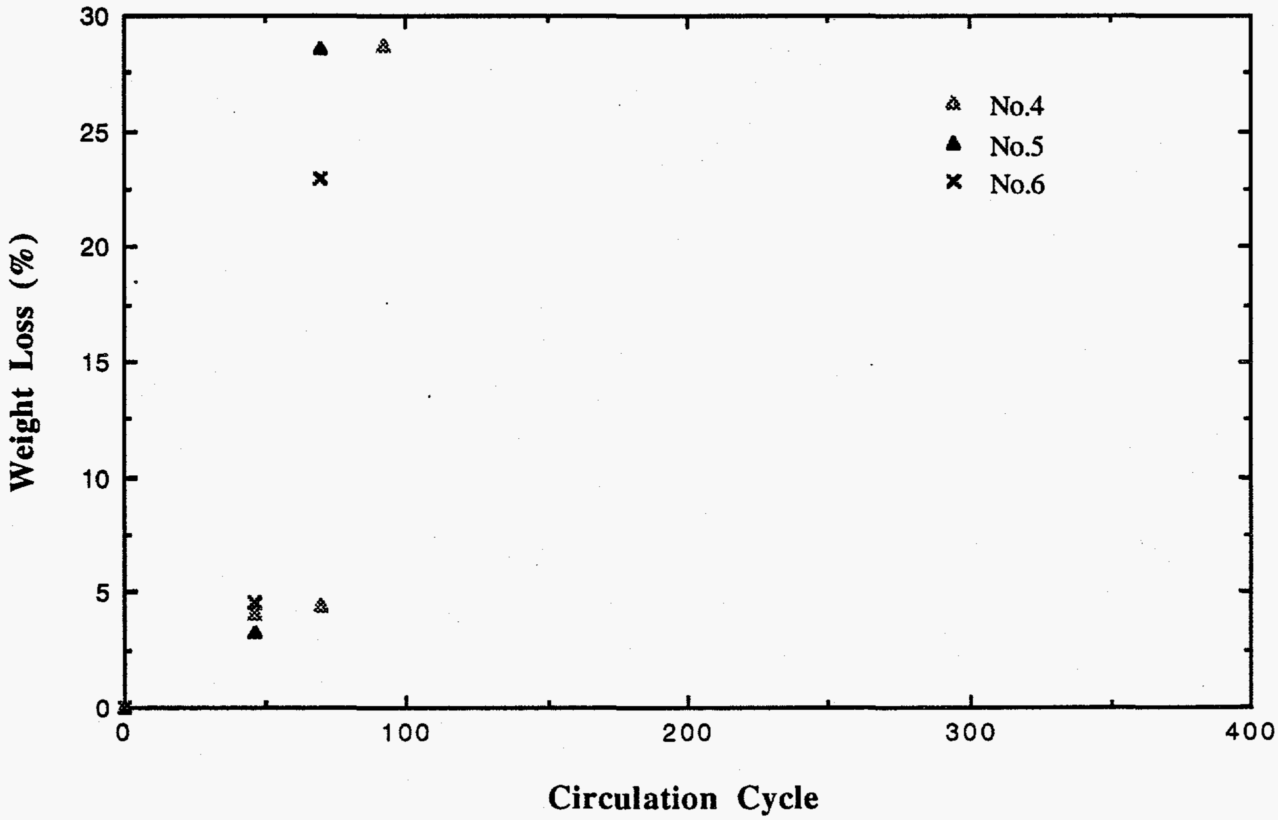


Fig.3 PRB Coal Log Weight Loss in Pipeline (Cooling in Air)

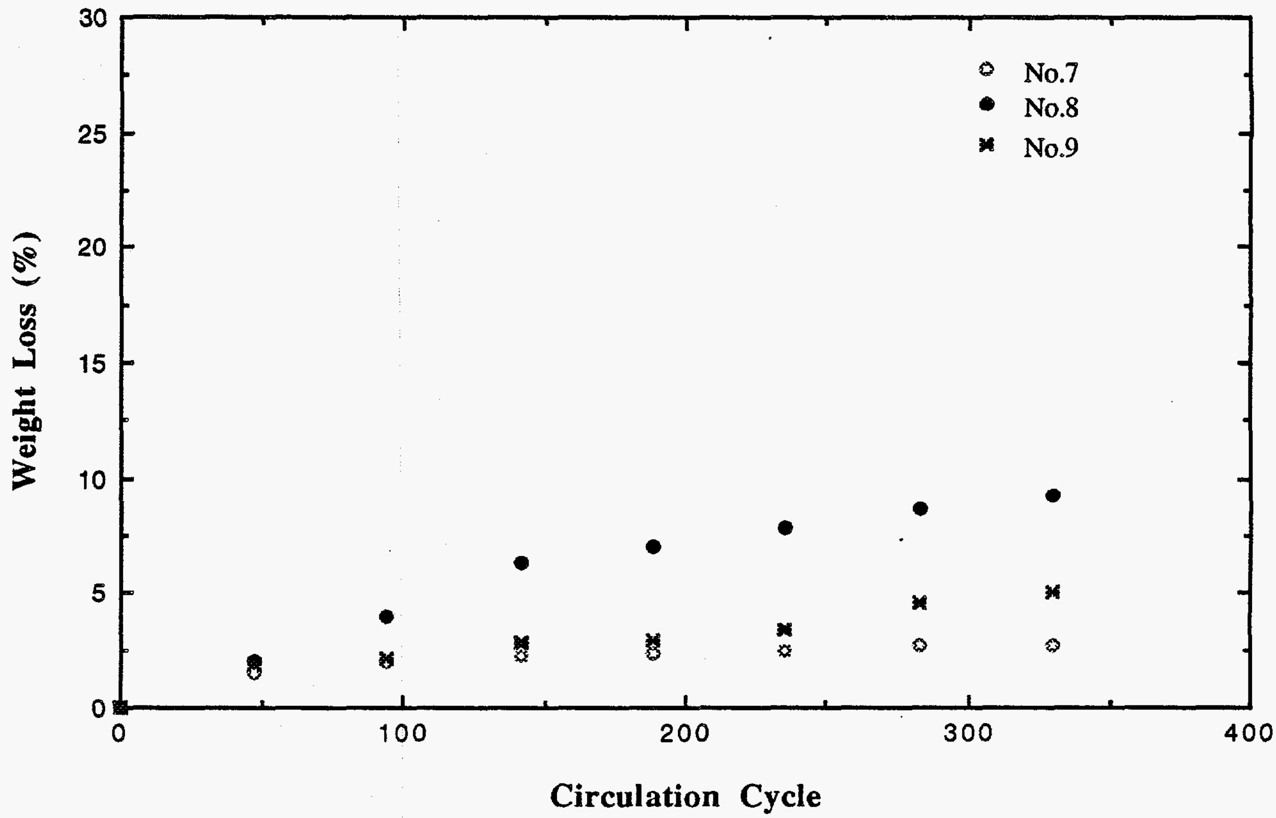


Fig.4 PRB Coal Log Weight Loss in Pipeline (Cooling in Warm Water

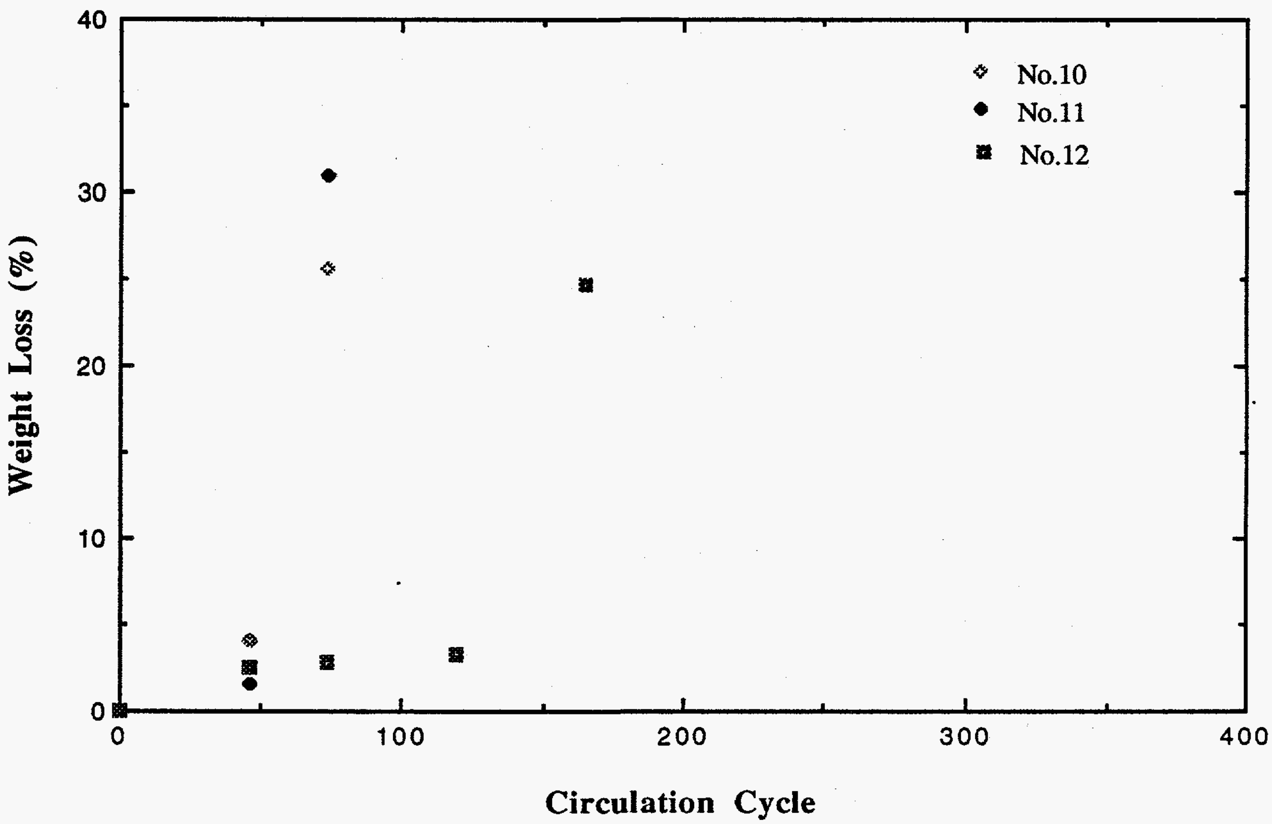


Fig.5 PRB Coal Log Weight Loss in Pipeline (Cooling in Cool Water)

Table 4 Density of Coal Logs with Different Cooling Methods (MAPCO coal)

Log No	Cooling Method	Density (g/cm^3)	
		Pre-absorption	Post-Absorption
13	in mold	1.282	1.326
14	in mold	1.288	1.329
15	in mold	1.277	1.326
16	in air	1.258	1.319
17	in air	1.261	1.320
18	in air	1.261	1.320
19	in warm water	1.276	1.306
20	in warm water	1.293	1.300
21	in warm water	1.290	1.305
22	in cool water	1.278	1.323
23	in cool water	1.249	1.298
24	in cool water	1.260	1.303

Table 5 Average Weight and Dimensions of Coal Logs with Different Cooling Methods (MAPCO coal)

Cooling Method	Pre-water Absorption				Post-water Absorption			
	Weight (g)	Diameter (cm)	Length (cm)	Volume (cm^3)	Weight (g)	Diameter (cm)	Length (cm)	Volume (cm^3)
in mold	145.16	4.475	7.197	113.14	150.23	4.476	7.196	113.17
in air	145.40	4.475	7.338	115.35	151.80	4.471	7.283	114.29
in w-water	149.57	4.496	7.326	116.25	151.77	4.498	7.328	116.38
in c-water	146.90	4.495	7.332	116.29	152.00	4.488	7.326	115.84

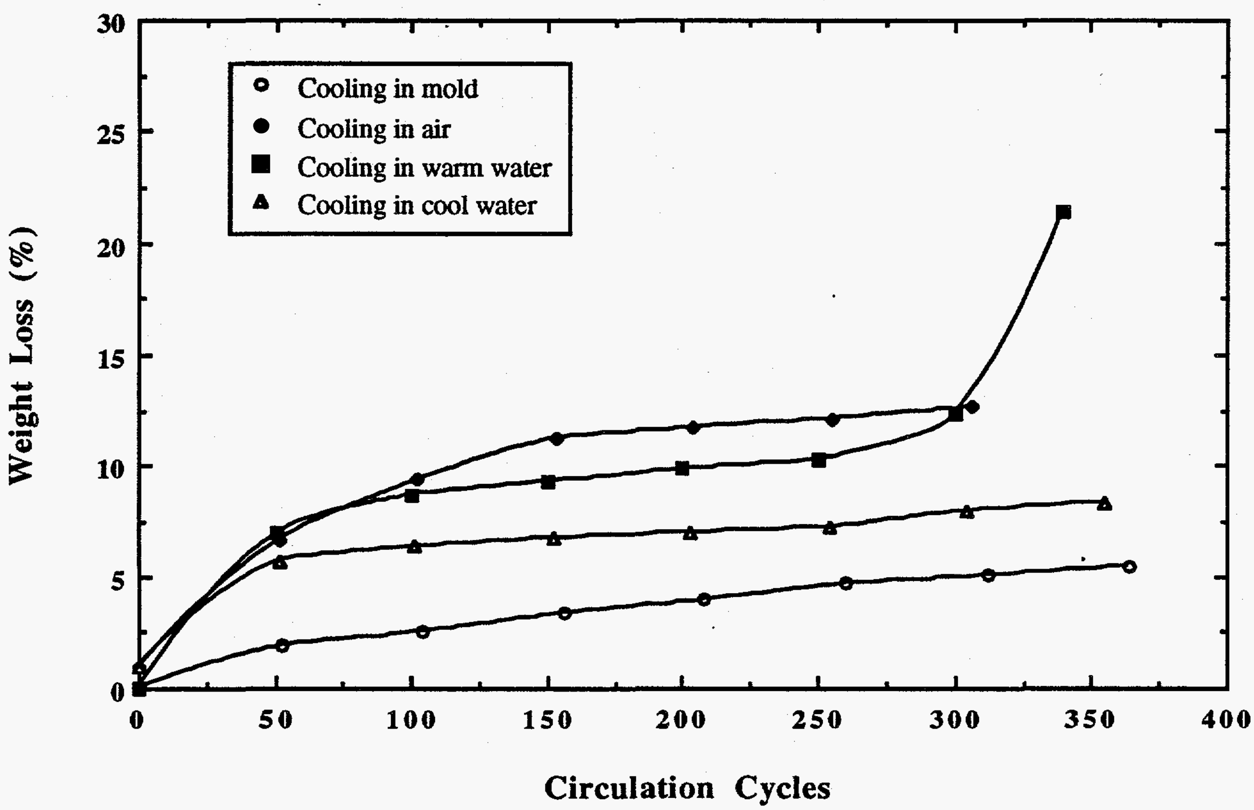


Fig. 6 Effect of Cooling on Weight Loss of MAPCO Coal Logs in Pipeline (Average of 3 logs for each line)

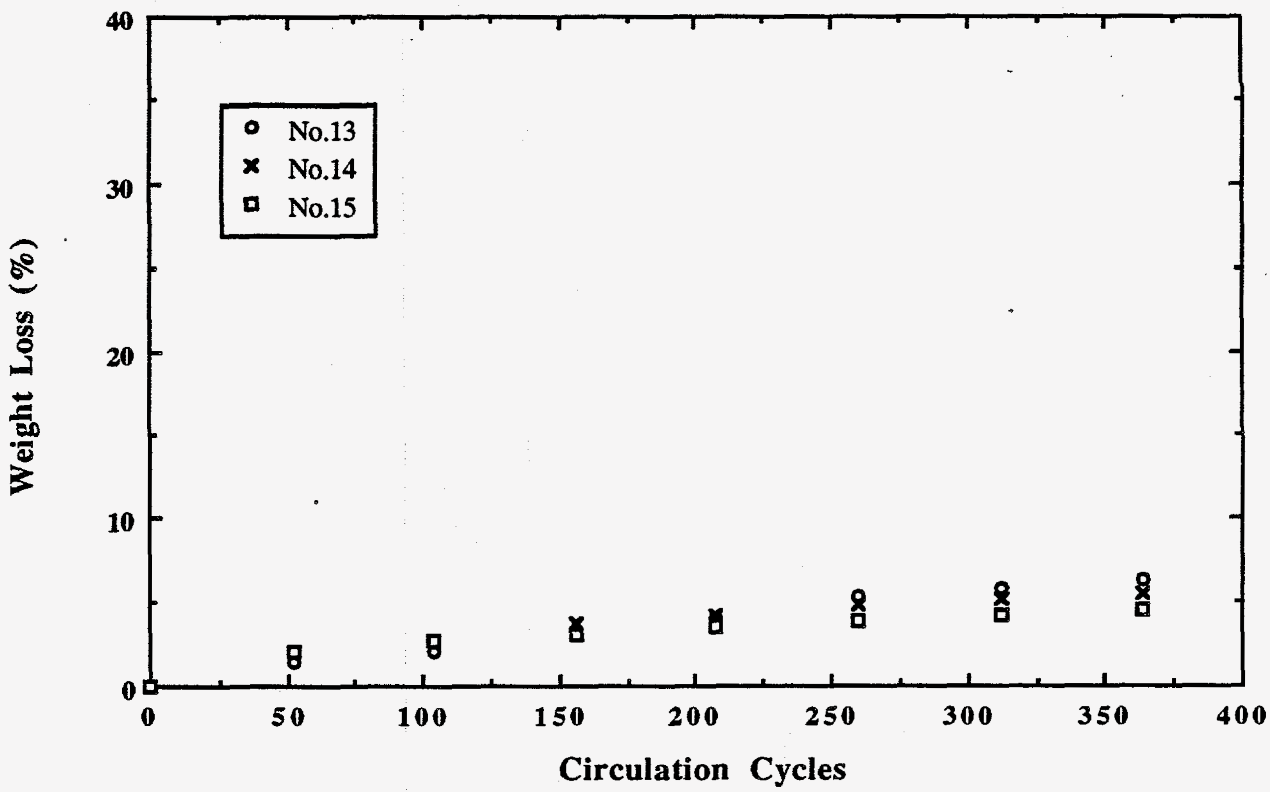


Fig. 7 MAPCO Coal Log Weight Loss in Pipeline (Cooling in Mold)

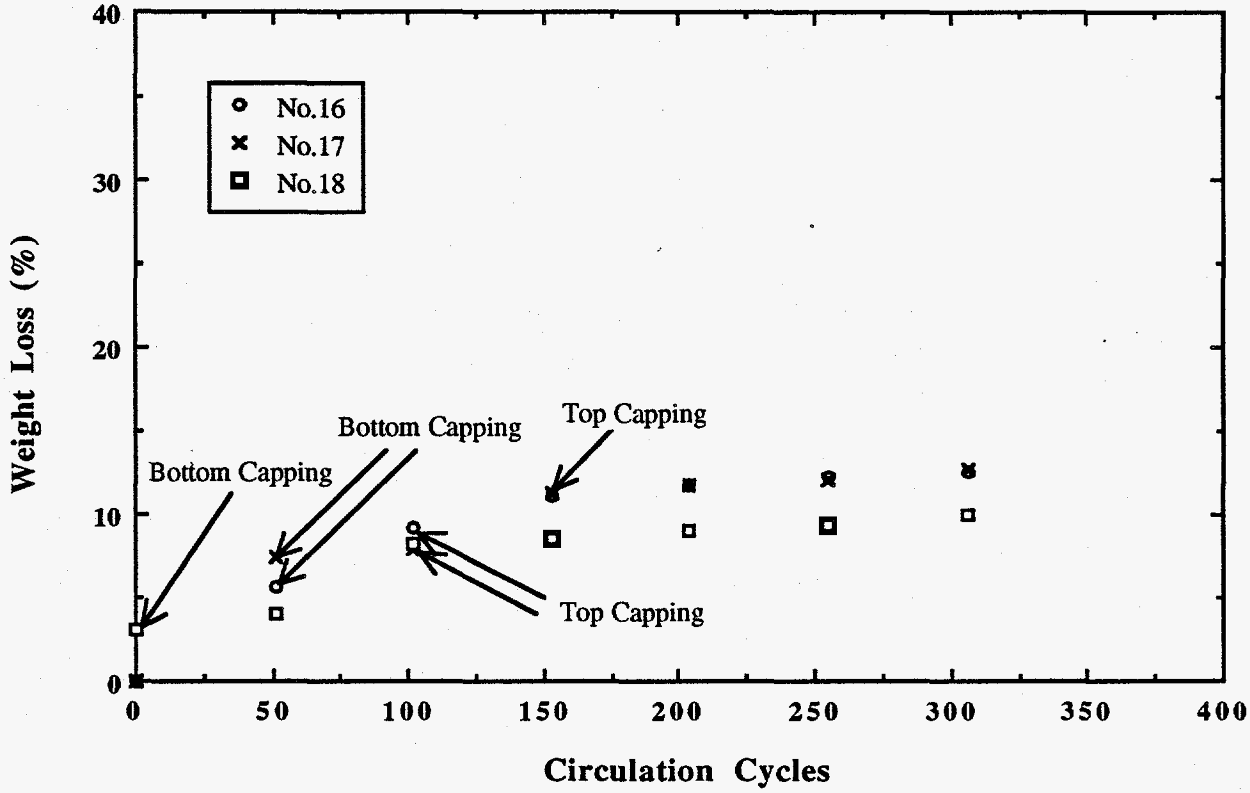


Fig. 8 MAPCO Coal Log Weight Loss in Pipeline (Cooling in Air)

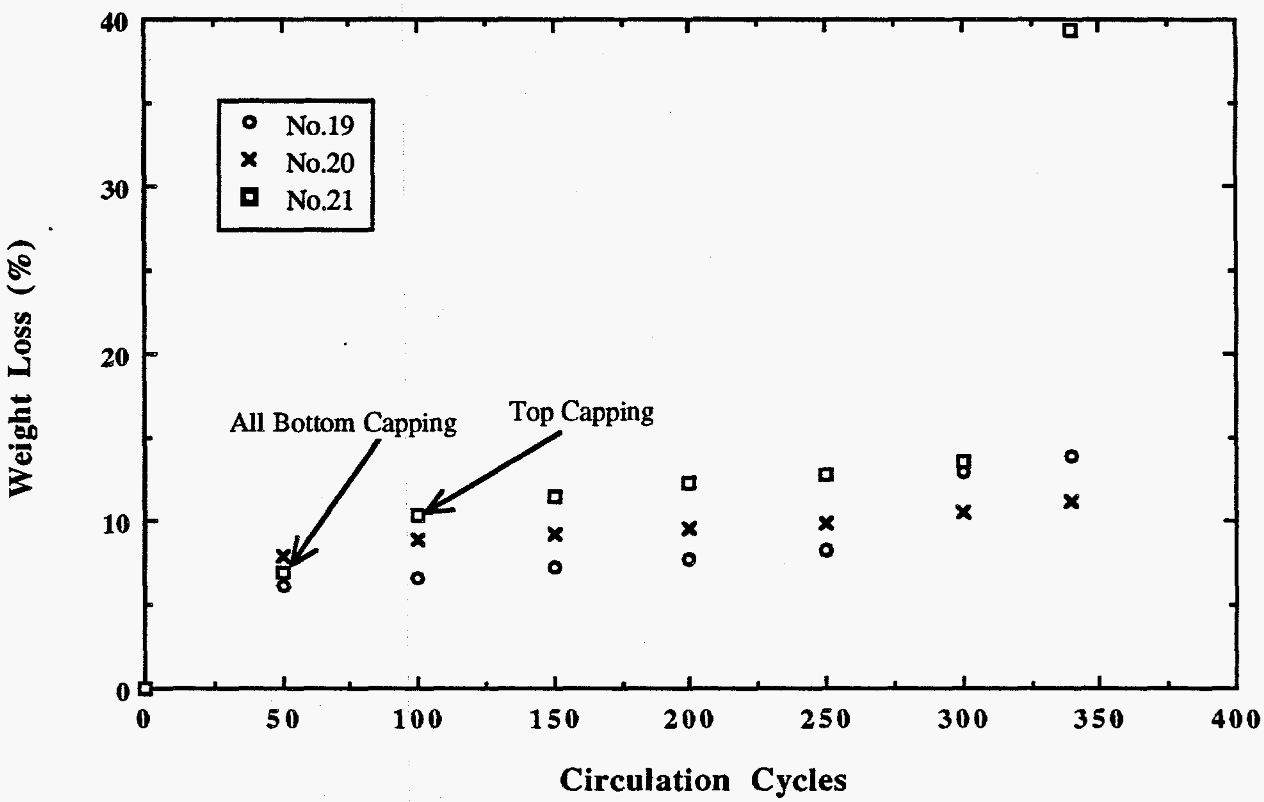


Fig.9 MAPCO Coal Log Weight Loss in Pipeline (Cooling in Warm Wate

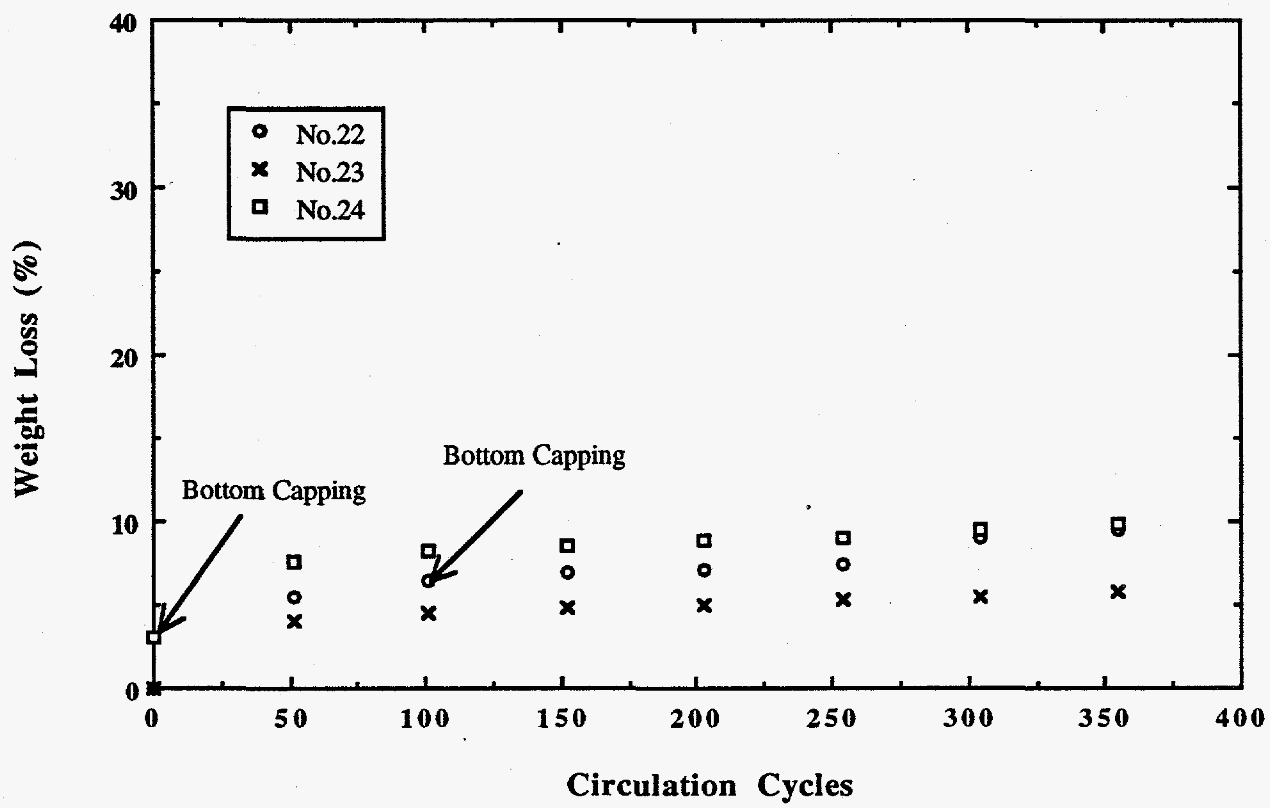


Fig. 10 MAPCO Coal Log Weight Loss in Pipeline (Cooling in Cool Water)

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TO: Coal Log Fabrication Group Faculty and Students

FROM: Henry Liu

DATE: February 10, 1995

SUBJECT: Coal Log Capping

Coal-log capping is a problem that we must solve before we can make good coal logs, especially with MAPCO (Bituminous) Coal in small (1.73-inch) mold.

The attached paper by Robert Thompson published in CERAMIC BULLETING seems to explain the phenomenon of capping very well. You need to read it and apply to your work.

As you can see from the paper, capping is a tensile-stress-induced failure caused mainly by the elastic expansion of the coal log after the log has been compacted in the mold and the piston is removed. Without piston pushing and with wall friction preventing the wall surface of the log to slide, the center portion of the coal-log end bulges out, creating a concave surface of maximum tensile stress--see Fig. 1. If the tensile stress in this concave surface exceeds the tensile strength of the log, cracks will develop along this maximum tensile stress surface. Hereafter, I shall refer to this type of failure as "**bulging failure**."

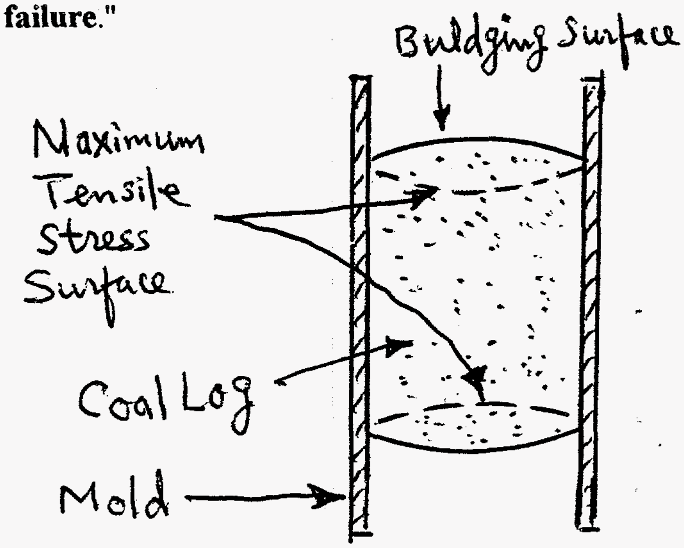

Fig.1 Coal Log in Mold after Compaction

I believe that the foregoing theory explains most but not all of what we have observed in our laboratory. Sometimes a large adhesive force is formed between the piston and the log. As the piston is retrieved, it pulls the log with it and causes another tensile stress in the log. The maximum tensile strength surface caused by piston adhesion alone should be parallel to the piston surface, approximately. With this force alone, it would cause a disk type capping. This type of failure is referred to herein as "**piston-adhesion failure**."

Generally, both the "**bulging failure**" and the "**piston-adhesion failure**" exist simultaneous, causing the log to cap in a shape different from either a simple lense (for bulging failure) or a simple disc (for piston-adhesion failure). The combined effects create a complex shape depending on the relative tensile strength induced by each of the two causes, and materials inhomogeneity.

A third type of failure is due to piston clamping action caused by using a piston with protruding edge or rim to make beveled logs. As the piston is retrieved, the clamping action pulls the log with the piston, again causing tensile in the log in a manner similar to the piston-adhesion failure. This is called "**piston-clamping failure**."

Both the piston-adhesion failure and the piston-clamping failure can be prevented or mitigated by using a smooth piston surface as by chromeplating, or by using a lubricant such as calcium stearate, or both. The piston-clamping failure can be further reduced by proper design of the bevel angle and the curvature of the piston rim.

From the above understanding of the capping mechanisms or causes, it is possible to develop a set of strategies to prevent capping from happening, including the following:

1. Use a smooth and hard surface for the mold. That will decrease the contact friction coefficient μ, which in turn decreases the maximum tensile stress in the log. Lubricating the mold will also help. However, not all lubricants are effective under all conditions. Read Li/Rockabrand's report on mold lubrication and surface conditioning before you attempt lubrication.

2. The fluidity index* of the coal log material, α, has the same effect as μ. In fact, it is the product $\alpha\ \mu$ which affects the maximum tensile stress in the coal log. How to reduce α is not clear at this point.

3. To reduce the adhesion between coal logs and pistons, all pistons should have a smooth surface. Chromeplating the piston will help; use of stainless steel piston will also help. For beveled-rim pistons, the bevel shape and angle are important. The optimum shape and angle can be determined experimentally through trial-and-error, or

* By definition, the fluidity index is the ratio of the radial-direction of compression or pressure to the axial-direction of compression or pressure.

from a finite-element analysis of the coal log stress using the same type of analysis used in (Thompson 1981).

4. A possible way to prevent the bulging type failure can also be done by operating the pistons in a more desirable manner. If compaction is followed immediately by ejection without first releasing the forces of the pistons on the log, bulging will not occur and capping will be prevented. For a vertical double-acting mold, this can be done by keeping the force on the top piston and gradually reducing but not eliminating the force on the bottom piston during the ejection process. In doing that, bulging will be reduced and failure prevented. This will also help to reduce circumferencial cracks elsewhere in the log. How to control pistons in such a matter should be left to innovative mechanical engineers.

Capsule Pipeline Research Center

Quarterly Report

for

Individual Projects

(Period Covered: 1/1/95-3/31/95)

Project Title: 1. Effectiveness of Adding Fiber to Enhance Coal Log Quality
2. Fast Compaction of Coal Logs

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

Research Assistants: Shiping Yang

Purpose of Study: 1. To determine whether using a small amount of low-cost, combustible fiber, such as wood pulp, can improve the wear resistance of coal logs.
2. Demonstrate that coal logs compacted in about 10 seconds are as wear resistant as those compacted in a much longer time -- say 5 minutes.

Work Accomplished During the Period:

We have continued studying the effects of fiber addition on coal log circulation performance. Specifically, we have begun 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.

The preparation process for making fiber reinforced coal logs is shown in Table 1 and Table 2 contains the common characteristics of the fiber reinforced coal logs and the compaction process that was used to make them. The fiber content is weight percent of the dry weight of the coal in the log.

Table 1 - Preparation process description 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; the operation of the blender is used to separate and disperse individual fibers; and finally, excess water is drained from the fibers.
3. Coal, water (25% of the dry weight of the coal), and saturated fiber are mixed for 5 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 place in the compaction mold and the log is made.

Table 2 - Common characteristics of the fiber reinforced coal logs and the compaction process that was used to make them.

Type of Coal	Mapco
Maximum Particle Size	No. 30 Sieve
Type of Binder	Orimulsion
Amount of Binder	3% (of dry weight of coal) Orimulsion is ≈ 70% Bitumen, 30% water
Compaction Pressure	20,000 psi
Compaction Temperature	Room, or 97 °C
Compaction Mold	Chrome Plated Split Mold
Compaction Times	Loading Time - 1 minute Peak Load Holding Time - 5 minutes Unloading Time - 1 minute

After the logs were made they were place in the water absorption apparatus. Logs were exposed to 500 psi water for 1 hour. They were then stored in atmospheric pressure water (for less than 4 days) until circulation testing was conducted. For the circulation test, the mean fluid velocity in the pipeline was equal to the theoretical lift off velocity for the coal log.

Initially, logs were made with wood fiber and at room temperature. Comparative weight loss results for the circulation tests are shown in Figure 1. 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, but very significant for 0.4% fiber addition. The average weight loss after 93 cycles was 18.7% for logs without fibers; the average weight loss after 95 cycles for logs with 0.2% fiber was 10.3%; 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%.

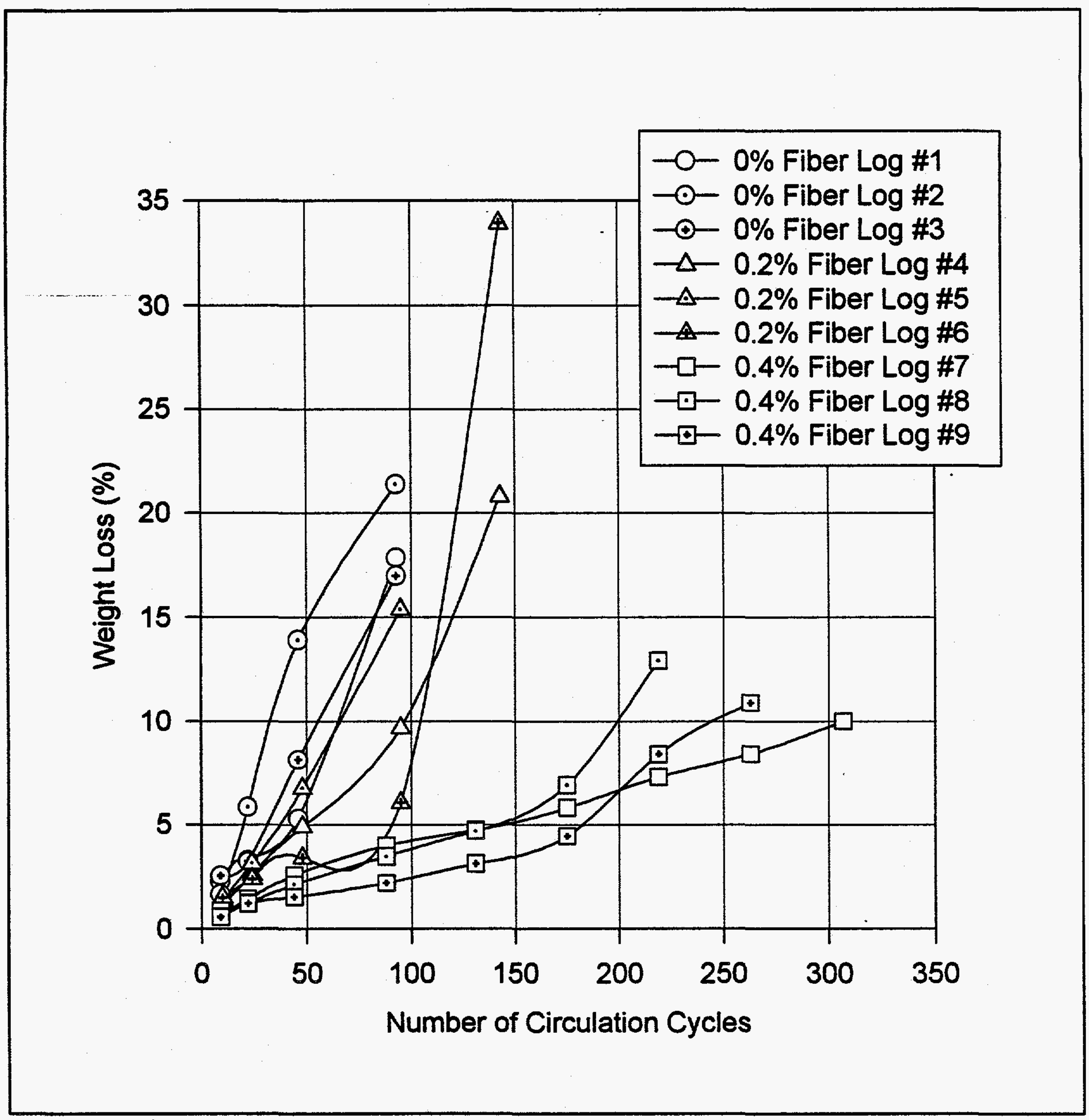

Figure 1 - Circulation performance data for fiber reinforced coal logs (3% Orimulsion binder, room compaction temperature, 20,000 psi compaction pressure, wood fiber)

Subsequent to this work, we made logs containing waste paper fiber (grocery store sacks) at a compaction temperature of 97 °C. The results of this study are incomplete but the results are shown in Figure 2 and some preliminary observations can be made. The waster paper fiber worked as well as the wood pulp fiber for improving circulation performance. All logs made at 97 °C contained 0.4% fiber. Binder concentrations varied from 0 to 3% Orimulsion. The addition of fiber improved the log circulation performance significantly. Logs made with fiber and binder performed better than logs with only fiber or only binder. For the same fiber concentration, increasing the binder concentration improved log performance. For example, logs made with 3% binder and 0.4% fiber had a weight loss of approximately 3.5% after 450 circulation cycles, whereas, the log with 0.4% fiber and no binder and the log with no fiber and 3% binder both had weight losses of 4% after 200 cycles. These observations are preliminary and we believe the completion of this study will more fully substantiate them.

We have also begun a study to evaluate the circulation performance or rapidly compacted coal logs are. For this study, coal logs were compacted with either a slow (1 minute load, 5 minute hold, 1 minute unload), fast (30 second total load and unload) and very fast (15 second total load and unload) final compaction step. All logs contained 0.4% waste paper fiber and 3% Orimulsion. The coal, fiber, binder mixtures were prepared as described in Table 1. The mixture was then oven dried to a moisture content of 10%. The mixture was heated in a solid cylinder tapered exit compaction mold and a rapid 2,000 psi pre-compaction load step was applied prior to final compaction. All logs were ejected from the mold while they were hot. Figure 3 shows the results of this testing.

For all three load steps (slow, fast, and very fast) there was one log out of three that performed significantly worse than the other two replicate logs and there was one slow log that performed exceptionally well. The slow compaction logs had less total weight loss, but at 100 cycles, most of the logs had a weight loss of about 5%, regardless of the speed of compaction.

Finally, we have prepared U.S. Patent Application Serial No. 08/405,599 entitled *Process for Forming Coal Compacts and Product Thereof*, UM disclosure No. 93UMC050. This application was filed March 17, 1995. Mr. Fen Cheng has completed the first draft of his thesis and will defend the thesis and graduate in May of 1995.

Work Proposed for Next Quarter:

We will continue studying the effects of fiber addition on coal log circulation performance. Specifically we will investigate other fiber concentrations, other compaction temperatures, and other binder concentrations. We will also continue the fast compaction study. Finally, we plan to experiment with making hyperbaric Hot Water Formed (HWF) coal logs.

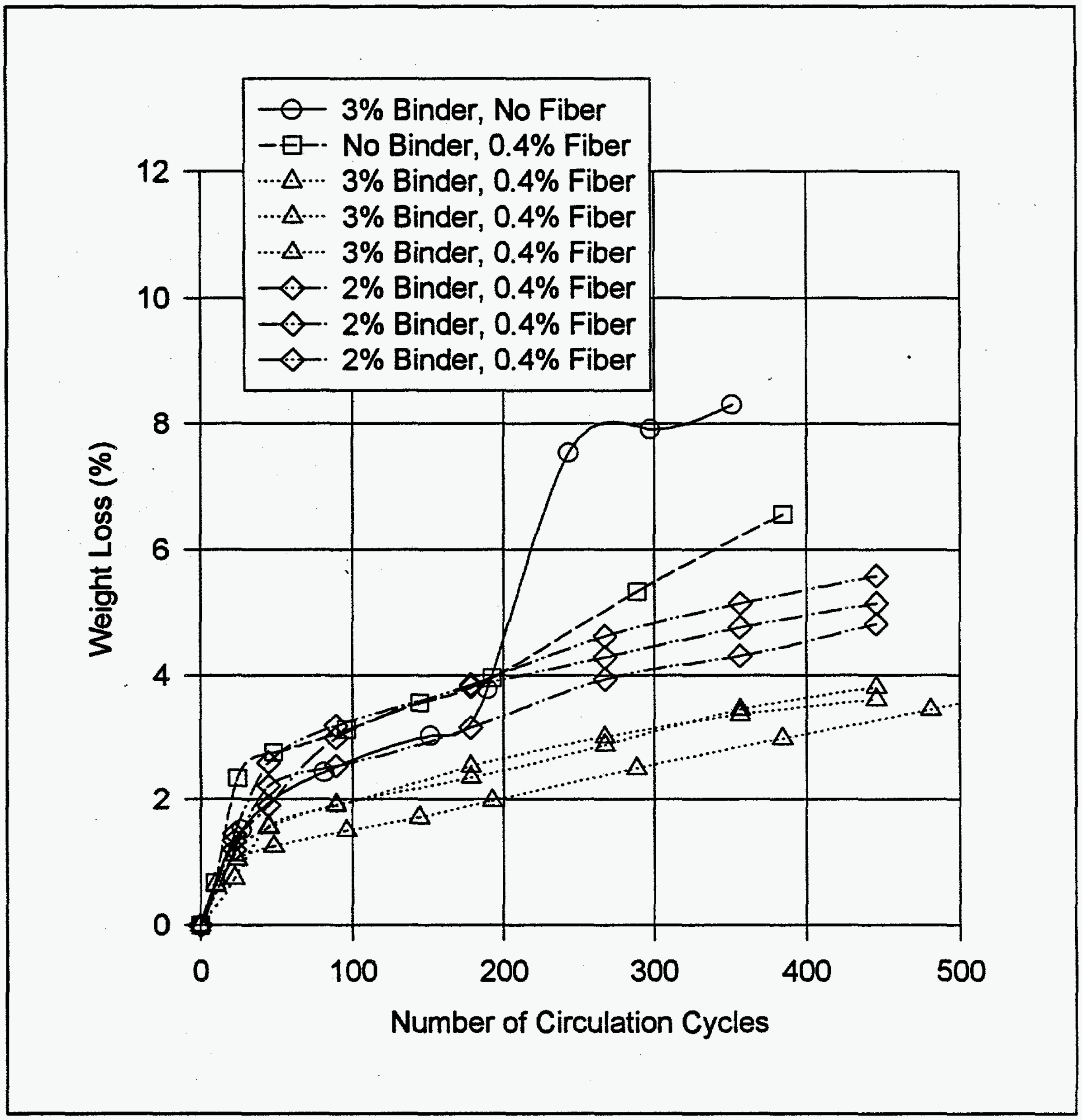

Figure 2 - Circulation performance data for fast compacted fiber reinforced coal logs (3% Orimulsion binder, 97 °C compaction temperature, 20,000 psi compaction pressure, waste paper fiber)

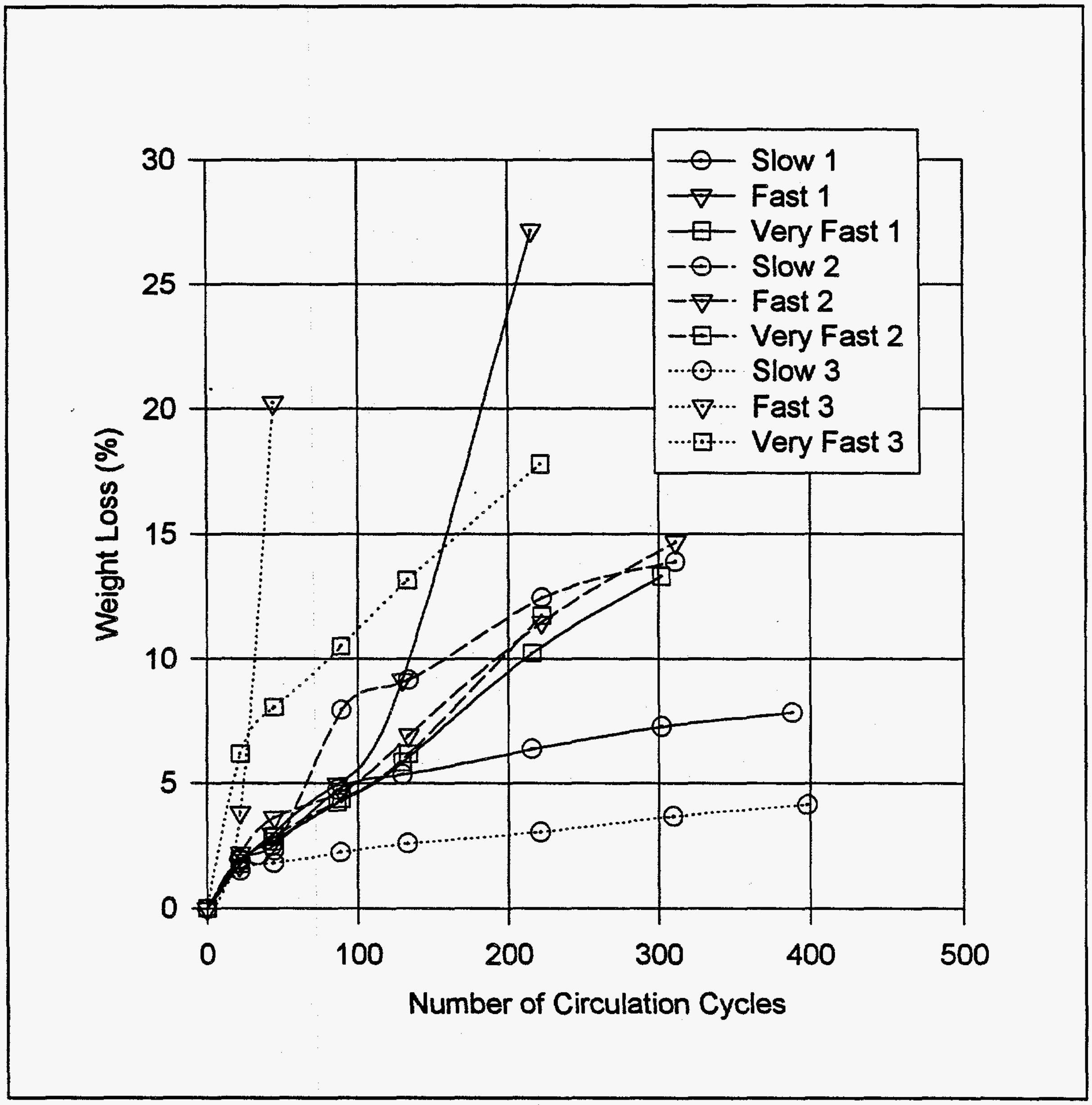

Figure 3 - Circulation performance data for fast compacted fiber reinforced coal logs (3% Orimulsion binder, 97 °C compaction temperature, 20,000 psi compaction pressure, waste paper fiber)

Quarterly Report Coal Log Pipeline Project

Jan. 1 - Mar. 31 1995

Project Title: Coal Log Fabrication Using Hydrophobic Binders

PI: Dr. John W. Wilson

Post-Doctoral Fellow: Dr. Yungchin Ding

Graduate Research Assistant: Bing Zhao and Brent Ward

OVERVIEW:

Due to the promising results obtained from the field tests of large (5.3" in diam.) coal logs at Conway, Kansas, Orimulsion was selected as the emulsion binder for use in manufacturing large coal logs using Mettiki (Mapco) coal.

In order to optimize the large (5.3" in diam.) coal log fabrication process, various compaction pressures and binder concentrations were tested to determine the most practical and economical parameters to manufacture large coal logs. A newly built single piece compaction mold was used to replace the damaged two pieces split mold for large log fabrication. Three different particle sizes of Mettiki coal were used in these tests. The optimum coal log fabrication parameters were evaluated from their respective tumbling degradation test results.

Powder River Basin coal was also tested to manufacture large coal logs at room temperature, using Orimulsion as binding agent. These coal logs were damaged when they were pushed out of the compaction mold. The cause of the unsuccessful fabrication of PRB coal log are currently being investigated by examining the surface charge and hydrophobicity of coal and Orimulsion as well as their chemical affinity.

PROGRESS TO DATE:

A. Large (5.3" in diam.) single piece compaction mold

Due to the deformation of the large two pieces split mold, large coal logs made with the split mold were damaged when they were pushed out or taken out from the mold. In order to continue the fabrication and testing of large coal logs, a new single piece large compaction mold was built to continue the task. Figure 1 shows the sketch of the single piece mold.

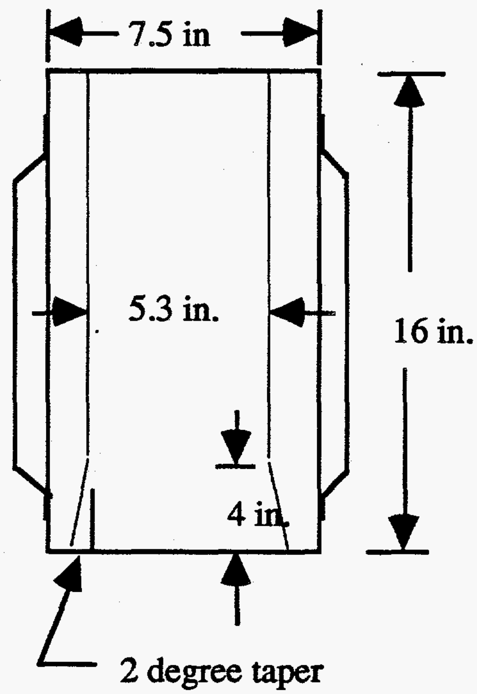

Figure 1. sketch of the Large Single Piece Mold.

The operation of the single piece compaction mold is described as follows:

1. Set short piston (4") into the tapered end of the compaction mold.

2. Feed coal-binder mixture into the mold from the top end (not tapered) of the mold.

3. Compact the coal-binder mixture using an uniaxial hydraulic press, with the long piston acting from the top of the mold.

4. The compaction pressure was gradually increased from zero to predetermined pressure at a rate of 2,000 to 2,500 lbf/sec.

5. A five minute peak loading time was maintained after the press reach the predetermined compaction pressure.

6. After compaction, the pressure was reduced to zero, at a rate of 4,000 to 5,000 lbf/sec.

7. The compaction mold was then flipped over (up-side-down) and log was pushed out of from the tapered end of the mold at a rate of 0.2 in/sec., using the same uniaxial hydraulic press.

B. Large (5.3" in diam.) coal log test results

Large (5" in diam.) coal logs were fabricated at various compaction pressures (4,000 to 10,000 psi) and Orimulsion concentrations (bitumen concentration of 1 to 3%). In these tests, three different particle sizes (-30 M x 0, -8 M x 0 and -6 M x 0) of Mettiki coal were used to fabricate coal logs. Since the large pipeline (Conway, Kansas) for coal log degradation test is not currently available, a tumbling test (24" in diam. tumbler) was used instead to evaluate the wear resistance of the large coal logs.

Table 1 shows the weight loss percentage of coal logs after subjecting to tumbling tests. These weight loss percentages can be used as index to evaluate the wear resistance of large coal logs. During the tumbling tests, coal logs were weighed at 5 min. intervals to record the weight loss percentage, for a total of 20 min. of tumbling period. On the basis of these preliminary tumbling tests, it appears that increasing the binder concentration causes the most improvement in log abrasion resistance, see item C below. The increase in compaction pressure seems to have less of an effect on log abrasion resistance. Further analyses are needed to evaluate the influence of the variations in particle size. The tumbling tests provide a fast and convenient method to evaluate coal log manufacturing parameters; a large 6 inches pipeline is needed for more meaningful flow tests.

Table 1. Large Coal Log Test Results (Mettiki Coal)

1% Binder:

Weight Loss, %; Tumbling Time, min

Compaction Pressure (psi	PSD-1				PSD-2				PSD-3			
	5	10	15	20	5	10	15	20	5	10	15	20
4000	13.5,	30.6,	NA,	NA	4.2,	18.5,	36.5,	NA	4.1,	34.0,	NA,	NA
6000	3.1,	6.3,	39.0,	NA	2.7,	4.0,	6.1,	21.7	1.6,	4.6,	7.9,	10.2
8000	1.8,	6.1,	21.5,	31.0	2.4,	4.9,	6.0,	36.7	5.1,	NA		
10000	3.7,	5.1,	6.7,	15.5	2.2,	3.8,	19.2,	31.1	12.4,	18.9,	21.7,	24.3

2% Binder:

Weight Loss, %; Tumbling Time, min

Compaction Pressure (psi	PSD-1				PSD-2				PSD-3			
	5	10	15	20	5	10	15	20	5	10	15	20
4000	1.4,	2.8,	5.2,	12.3	2.5,	22.7,	NA,	NA	1.4,	4.7,	7.2,	9.5
6000	0.8,	2.9,	4.2,	5.7	1.7,	4.5,	7.5,	10.4	1.4,	3.5,	7.1,	9.2
8000	0.8,	3.0,	3.5,	5.3	0.6,	2.3,	3.2,	8.0	0.6,	1.2,	2.5,	3.5
10000	1.1,	2.7,	3.9,	4.6	0.1,	2.3,	3.7,	4.6	0.9,	1.6,	2.5,	2.9

3% Binder:

Weight Loss, %; Tumbling Time, min

Compaction Pressure (psi	PSD-1				PSD-2				PSD-3			
	5	10	15	20	5	10	15	20	5	10	15	20
4000	0.0,	0.8,	2.3,	2.8	3.3,	19.7,	36.0,	63.6	0.7,	2.1,	4.0,	6.5
6000	0.0,	0.1,	1.2,	1.8	1.4,	3.3,	5.8,	21.8	0.4,	1.6,	2.8,	3.2
8000	0.0,	1.0,	1.9,	2.4	1.2,	4.2,	6.4,	9.3	0.7,	1.2,	3.3,	3.9
10000	0.1,	0.2,	1.2,	2.2	1.9,	3.0,	4.5,	6.0	0.7,	1.1,	1.5,	1.8

Notes:

1.) PSD-1 is 98% being -6 M x 0
2.) PSD-2 is 95% being -8 M x 0
3.) PSD-3 is 98% being -30 M x 0
4.) Weight loss taken at 5 minute interals
5.) NA: not available, coal log broke into pieces
6.) The log diameter to top-size particle diameter is as follows: PSD-1=40.2 PSD-2=121.3 and PSD-3=226.5

C. Effect of compaction pressure on the performance of coal logs

Figure 2 shows the effects of compaction pressure and particle size on the wear resistance of coal logs that were fabricated using 2% Orimulsion at ambient temperature. The coal log weight loss percentages shown in Figure 2 were measured after 20 minutes of tumbling. This figure indicates that the higher the compaction pressure, the better the wear resistance of the coal logs. At compaction pressures higher than 8,000 psi, coal logs made with finer particle size had better wear resistance than coarser particle coal logs. However, the difference of the wear resistance between coarse and fine particle coal logs are not significant. This indicates that the influence of particle size on the wear resistance of coal log is not critical, at compaction pressures higher than 8,000 psi.

D. Effect of tumbling time on the wear resistance of coal logs

Due to the lack of large coal log pipeline degradation test results, the tumbling time required to simulate the pipeline degradation test remains unknown. Therefore, the weight loss percentage of a coal log was measured at a 5 min. intervals for 20 min. of tumbling time. Figure 3 shows the wear resistance of coal logs made with 2% bitumen (Orimulsion) at 6,000 psi compaction pressure. As shown in Figure 3, the percentage weight loss of coal logs increased from less than 2% to 10% as the tumbling time increased from 5 to 20 min.

According to the previous small coal log (1.75" in diam.) tumbling test results, a 10% weight loss is equivalent to approximately 5% pipeline degradation weight loss. When comparing with the large coal log tumbling results shown in Figure 3, all logs made with different particle sizes at 6,000 psi also had less than 5% weight loss, after 10 min. of tumbling. These test results suggest that 6,000 psi compaction pressure will be adequate to produce strong and robust large coal log to meet pipeline transportation requirements, even for coarse (-6 M x 0) particle coal log.

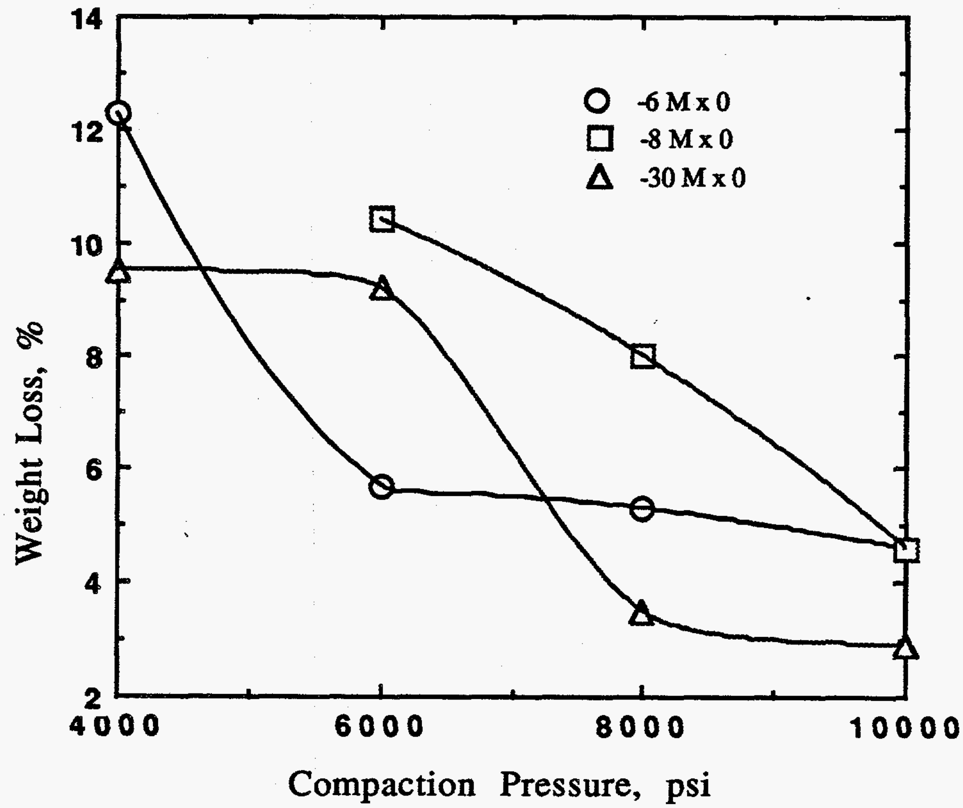

Figure 2. Influence of Compaction Pressures on the Wear Resistance of Coal Logs with 2% Bitumen (Orimulsion).

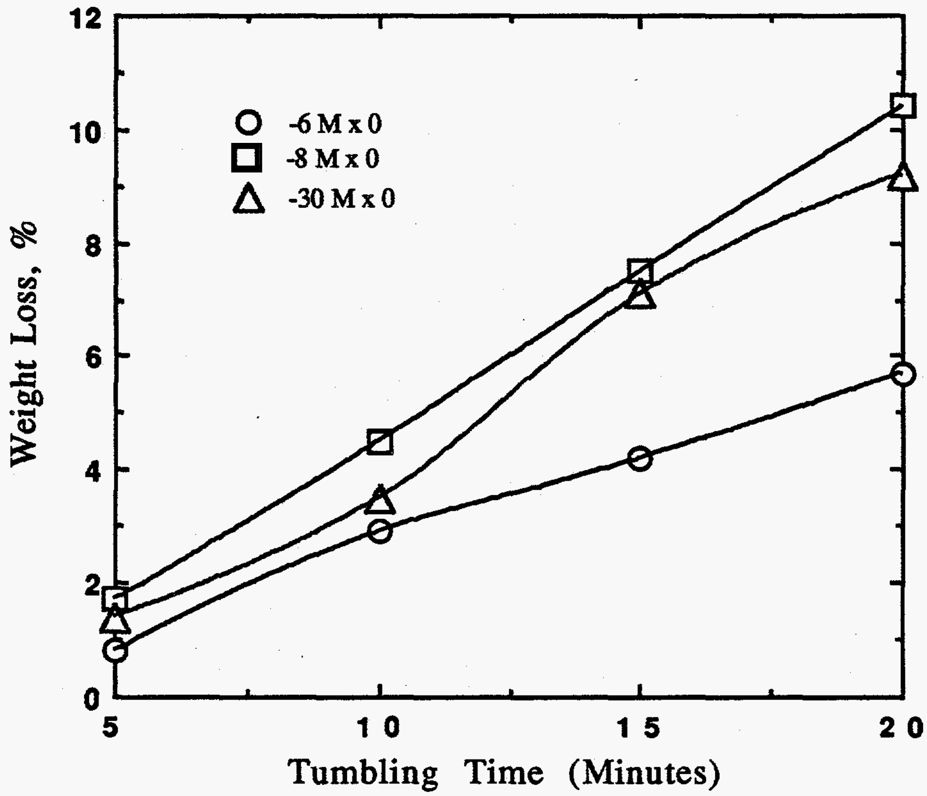

Figure 3. Influence of Tumbling Time on the Wear Resistance of Coal Logs Made With 2% Bitumen (Orimulsion) and 6,000 psi.

E. Influence of Orimulsion concentration on the wear resistance of coal logs

Figure 4 shows the influence of Orimulsion concentration on the wear resistance of large coal logs made at 10,000 psi compaction pressure. As shown in Figure 4, the higher the Orimulsion concentration the better the wear resistance of the coal logs. From the economical point of view, 2% Orimulsion concentration is believed to adequate to produce strong coal logs for pipeline transportation. Further tests are planned to see if the bitumen concentration can be reduced since this is a high cost item.

F. Water absorption characteristics of large coal logs

A few water absorption tests, using the large static immersion apparatus in Columbia, were carried out on large coal logs. These two logs were made with -30 M x 0 particles, 3% bitumen (Orimulsion) at 8,000 psi pressure and -6 M x 0 particles, 1% bitumen (Orimulsion) at 6,000 psi, respectively. The water absorption tests were conducted at 500 psi constant pressure for a period of 24 hours. According to the test results, the weight gained for the fine particle mix, high pressure and high binder concentration log was 6.9%, and 16.1% for the log made with the coarse particle mix, low pressure and low binder concentration. These test results suggest that the water absorption of large coal logs made at 6,000 to 8,000 psi pressures, and 1 to 3% bitumen (Orimulsion) concentrations will fall into the range of 6 to 16%, for various particle size of coal logs.

G. Coal log fabrication using PRB coal and Orimulsion

Because of inadequate binding strength between the Orimulsion and the coal surface, the large coal log fabrication using PRB coal and Orimulsion at room temperature was not successful. In order to compare the binding capability of Orimulsion and asphalt emulsion (PC-150) on PRB coal, two small (1.75") coal logs were made with 2% binder concentration at 10,000 psi pressure and 80°C compaction temperature. The 10 min. tumbling test results showed that PC-150 coal log had only 0.5% weight loss while the Orimulsion coal log had 7% weight loss. This poor binding capability of Orimulsion is probably due to incompatible surface charge of the Orimulsion and coal surface. More tests are currently being carried out to examine the surface charge and hy-

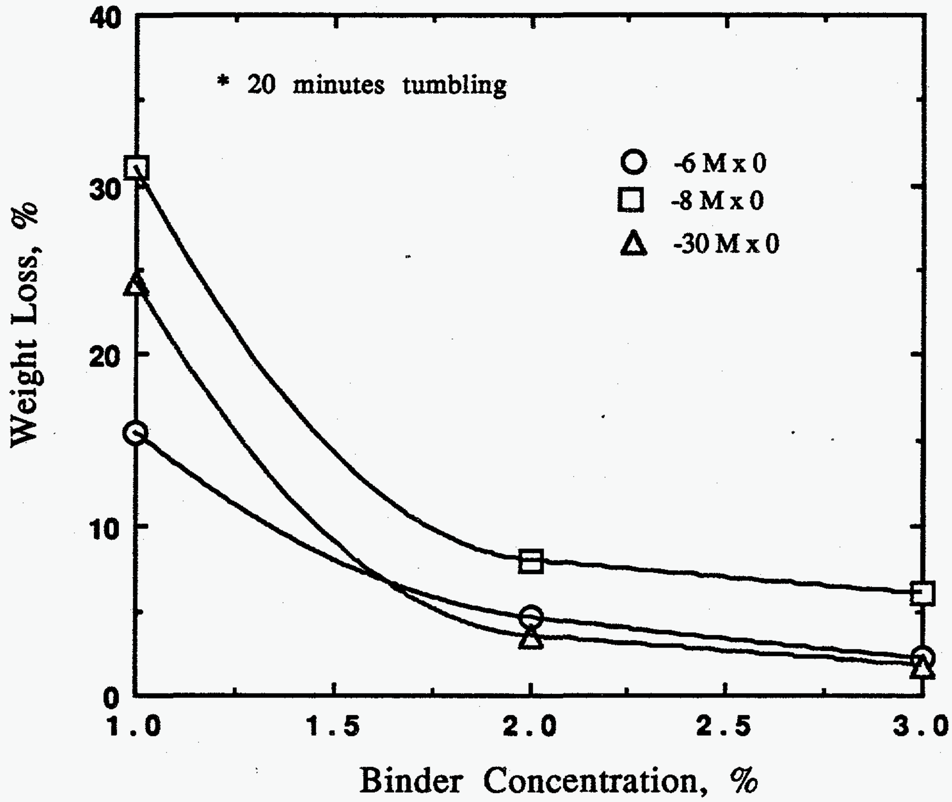

Figure 4. Effect of Orimulsion Concentration on the Wear Resistance of Coal Logs Made with 10,000 psi Compaction Pressure.

drophobicity of the PRB coal and the Orimulsion, as well as their chemical affinity. Through the understanding of their relationship, it is anticipated that strong PRB coal logs can be fabricated using Orimulsion at low compaction temperature.

Cost Estimation of Different Lubricants

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Supervisor: Dr. Henry Liu

March 27, 1995

INTRODUCTION:

The experimental results on lubrication effects showed that applying calcium stearate to the mold surface can result in the following:

1. Improving coal-log quality by increasing strength and wear resistance.

The force transmitted to the bottom piston increased significantly with lubrication, resulting in an increase in strength and wear resistance.

2. Improving coal-log quality by increasing uniformity of coal-log properties.

The variations of density, moisture content, porosity and wear resistance of coal logs are significantly reduced when the die wall is lubricated. As the result, the percentage of the "waste" logs made with die wall lubrication is 0-5% while it is at least 30% for logs made without lubrication.

If we assume coal-log fabrication cost is $2.99/Ton (Burkett, 1995), to rework 5% logs will cost an extra of

$0.15/Ton while to rework 30% logs will cost an extra of $0.90/Ton.

3. Extending the life of mold and pistons

Due to reduction of wall friction, the wear of mold and pistons will be reduced. Therefore, the life of the compaction tools will be extended and the tooling cost will be reduced.

COST ESTIMATION:

The major drawback of lubrication is an extra $0.1/ton to the cost of coal log fabrication (Burkett, 1995). In order to explore the possibilities of reducing the lubrication cost, we did the followings:

1. Selected several different solid lubricants based on the information from *Solid Lubricants and Self-Lubricating Solids* (Ed. by F. J. Clauss, Academic Press, 1972). See the attached tables in Appendix 1.
2. Contacted several companies and asked for the price of each lubricant selected.
3. Based on the prices provided by these companies, we did the cost estimation for each lubricant (see tables 1, 2, and 3).

Our calculation indicate that lubrication cost will be significantly reduced by fabricating larger logs. For example, if calcium stearate is used as the lubricant, fabricating one ton of

Table 1. Estimation of cost for lubrication (8 inch logs)

Lubricant	η	Price ($/lb)	Amount(g/ton)[2]	Cost ($/ton coal log)	Company	Telephone
Calcium stearate	0.107	0.54	78	0.09	RheoChem	
Hydrogenated tallow glyceride	0.082	0.35	78	0.06	CHEMOL Co.	1(800) 849-3050
HTG-molten bulk		0.30	78	0.05	"	
Tallow		0.18	78	0.03	"	
Molybdenum disulfide (MoS_2)[1]	0.091	5.00	0.78	0.009	CLIMAX MOLYBDENUM Co.	(412) 257-5181
			0.078	0.0009	"	

Table 2. Estimation of cost for lubrication (5 inch logs)

Lubricant	η	Price ($/lb)	Amount(g/ton)[2]	Cost ($/ton coal log)	Company	Telephone
Calcium stearate	0.107	0.54	125	0.150	RheoChem	
Hydrogenated tallow glyceride	0.082	0.35	125	0.096	CHEMOL Co.	1(800) 849-3050
HTG-molten bulk		0.30	125	0.083	"	
Tallow		0.18	125	0.050	"	
Molybdenum disulfide (MoS_2)[1]	0.091	5.00	1.25	0.014	CLIMAX MOLYBDENUM Co.	(412) 257-5181
			0.125	0.0014	"	"

Table 3. Estimation of cost for lubrication (2 inch logs)

Lubricant	η	Price ($/lb)	Amount(g/ton)[2]	Cost ($/ton coal log)	Company	Telephone
Calcium stearate	0.107	0.54	362	0.430	RheoChem	
Hydrogenated tallow glyceride	0.082	0.35	362	0.279	CHEMOL Co.	1(800) 849-3050
HTG-molten bulk		0.30	362	0.239	"	
Tallow		0.18	362	0.144	"	
Molybdenum disulfide (MoS_2)[1]	0.091	5.00	3.62	0.040	CLIMAX MOLYBDENUM Co.	(412) 257-5181
			0.362	0.004	"	"

1. MoS_2 bounded films will be used instead of powders. Thermosetting resins, such as phenolics will be used to form a strong bonded film of MoS_2 to the mold surface. The endurance life of resin-bonded MoS_2 was reported to be 9,860,000 cycles at 35,000 psi (P. M. Magie, Moly bonded films. Electromesh. Des. 4:50-54, 160). Our calculations were based on an endurance life of 100 and 1000 cycles.
2. Calculated based on our experimental results with calcium stearate. The amount of calcium stearate used for compacting each log (4.43 cm in diameter x 7.0 cm in length and 165g in initial weight) was about 0.05g. The lubricant was applied to the mold surface only.

8-inch logs cost $0.09 but producing one ton of 2-inch logs will cost $0.43.

The best way of reducing lubrication cost is to use solid bounded lubricating film, such as MoS_2. The endurance life of resin-bounded MoS_2 was reported to be 9,860,000 cycles at 35,000 psi. This will not only reduce the cost but also cut the time required for re-lubrication.

INVESTIGATION OF MoS_2 DRY FILM:

According to Clauss (1972) and Stupp (1958), MoS_2 can be bonded to metal surfaces to provide good lubrication and long endurance life.

1. Physical properties of MoS_2

Molybdenum disulfide (MoS_2) has ideal physical properties that are required by a solid lubricant. As Stupp (1958) reported, MoS_2 "has low shear strength and good affinity for metal surfaces. The hardness of MoS_2 is generally given as 1 to 1.5 on the Mohs scale and presumably the hardness can be altered some what by changing the distance of the shape lattice in the crystal structure."

2. Mechanism of lubrication

Unlike graphite, molybdenum disulfide does not depend on absorbed gases or liquids within its crystal structure for its lubricity. Johnson and Vaughn (1956) investigated the lubrication mechanism of molybdenum disulfide and reported that "the lubricant action of molybdenum disulfide is dependent upon an internally generated amorphous sulphur film which adheres to the crystal surfaces."

3. Commercial availability of MoS_2 dry film

Andy Rockabrand has obtained a product catalog of Dow Corning Corporation which manufactures MoS_2 dry film. Dry film lubricant (Dow corning 321) can be used in coal-log compaction. This product is a dispersion of MoS_2 in a solvent. Application of this product can be done by dipping, brushing or spraying. After application the lubricant will cure to a dry lubricating film. The complete curing time required is four hours. The temperature range that this type of lubricating film can be used is -325 ^{o}F to 842 ^{o}F. This product is available in 11 oz can of aerosol, 1 gallon pail and 5 gallon pail.

Another product that can be used is silicone dry film lubricant (Dow corning 557). Detailed catalog information for the above products is attached in Appendix 2.

RECOMMENDATION:

The effectiveness of MoS_2 dry-film lubrication on the quality of coal-log compaction and cost reduction should be investigated.

Appendix 1.

TABLE 3. Coefficients of Friction for Four Types of Solid Lubricants[a]

Classification	Solid lubricant	Coefficient of friction		Stick-slip action
		Kinetic	Static	
None	Steel on steel (dry)	0.40	0.40 to 0.80	
Layer-lattice inorganics	Molybdenum disulfide:			
	natural	0.050	0.053	no
	synthetic	0.091	0.106	no
	paste-concentrate	0.093	0.096	no
	Tungsten disulfide	0.090	0.098	no
	Titanium disulfide	0.25	—	yes
	Tellurium disulfide	0.25	—	yes
	Selenium disulfide	0.25	—	yes
	Graphite:			
	natural	0.25	—	no
	colloidal (22% in H_2O)	0.100	—	no
	Boron nitride	0.25	—	yes
	Barium hydroxide	0.151	0.163	no
	Lead chloride	0.191	0.214	no
	Mica	0.25	—	yes
	Silver iodide	0.231	0.245	yes
	Talc	0.25	—	yes
Other inorganics	Borax	0.210	0.226	no
	Kaolin	0.25	—	yes
	Rottenstone	0.189	0.195	no
	Lead oxide, zinc oxide	0.25	—	yes
	Vermiculite	0.160	0.167	no
Chemical conversion layers	Iron–manganese–phosphate layer	0.213	0.218	no
	Iron–manganese–phosphate layer with molybdenum disulfide rubbed on top	0.067	0.074	no
	Sulfide melt (570° C) "Sulfinuz"	0.242	—	no
Organics	Spermaceti wax (43–49° C)	0.048	0.062	no
	Beeswax (60–63° C)	0.050	0.055	no
	Bayberry wax (44–49° C)	0.054	0.070	no
	Synthetic wax (comm. average) (93–96° C)	0.061	0.062	no
Organics (continued)	Polyethylene glycol (high MW) (53–56° C)	0.077	0.078	no
	Hydrogenated tallow glyceride (59–63° C)	0.082	—	no
	Candelilla wax (67–70° C)	0.099	0.113	no
	Paraffin (49–77° C)	0.104	0.112	yes
	Montan wax (78–90° C)	0.108	0.120	yes
	Carnauba wax (83–86° C)	0.143	0.169	no
	Diethylene glycol stearate (54–59° C)	0.083	0.089	no
	Calcium stearate (157–163° C)	0.107	0.113	no
	Aluminium stearate (129–160° C)	0.114	0.119	no
	Sodium stearate (198–210° C)	0.164	0.192	yes
	Lithium-12-hydroxy stearate (210–215° C)	0.211	0.218	no

[a] A. Sonntag, Lubrication by solids as a design parameter. *Electro-Technol. (New York)* 66, 108–115 (1960).

Appendix 2.

DOW CORNING® 321 DRY FILM LUBRICANT

PHYSICAL FORM
Dispersion of MoS_2, graphite and resin in a solvent; cures to a dry lubricating film.

PRIMARY USE
This dry film coating is recommended where permanent lubrication is required or in dusty environments because the lubricant will not collect contaminants.

SPECIFIC APPLICATIONS
Lubricating gears, cutting tools, gear cutters, milling cutters, taps, drills, punches, splines, threaded connections, disconnects; cold extrusion; lubricating moving parts in domestic appliances.

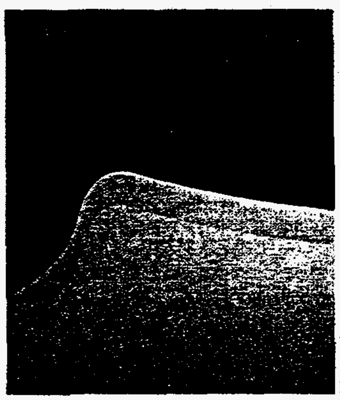
SPECIAL CHARACTERISTICS
Easy to apply; dries to touch in seconds; cures by reaction with moisture in air; complete cure in four hours at normal conditions; extreme loads at low speeds; resistant to oils and greases.

RESTRICTIONS
Contains solvent which may affect certain rubbers and plastics; test thoroughly before use.

TEMPERATURE RANGE
-325 to 842 F.

APPLICATION METHOD
Dipping, brushing, spraying.

CONTAINER SIZES
11 oz. aerosol, 1 gallon pail, 5 gallon pail.



BL29067-28

DOW CORNING® 7400 WATER DILUTABLE DRY FILM LUBRICANT

PHYSICAL FORM
Dispersion of MoS_2 and solid lubricants in a water-dilutable resin binder; cures to a dry film lubricant.

PRIMARY USE
Dry film coating for permanent lubrication or in dusty environments where solvents are unacceptable.

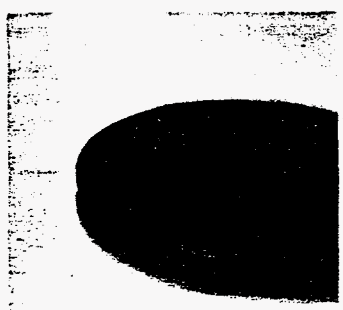
SPECIFIC APPLICATIONS
Running-in of gears; cold forging of metals; lubricating ball joints, gears, splines, sliding parts, screw actuators, hinges, brake parts, ball bearing cages.

SPECIAL CHARACTERISTICS
Water dilutable; environmentally acceptable formulation; rapid drying at room temperature; strong adhesion; high load-carrying capacity; resistance to oils and greases.

TEMPERATURE RANGE
-94 to 482 F.

APPLICATION METHOD
Spraying, dipping or brushing.

CONTAINER SIZES
11 lb. pail, 397 lb. drum.



BL29067-53

Dry Film Lubricants

DOW CORNING® 557
SILICONE DRY FILM LUBRICANT

PHYSICAL FORM
Waxlike silicone dispersed in a noncombustible solvent.

PRIMARY USE
This nonstaining, colorless product is used to lubricate aluminum and stainless steel in sliding and rolling contact and to extend the life of tools and dies. It also can be used for sizing and coining powdered metal parts.

SPECIFIC APPLICATIONS
Reducing wear and slip-stick motion or metal seizure on metal bearings, slides and cams; lubricating slitter blades, tools and dies, taps and drills, slides, conveyors, adjusting screws, guides, ways, handling equipment, metal stamping machines; protective coating for metal parts; improving surface finish of aluminum during extrusion; used in the textile and woodworking industries to reduce staining from spinning frames, scissors, punches and material handling and packaging equipment.

SPECIAL CHARACTERISTICS
Colorless; nonstaining; high loads at low speeds.

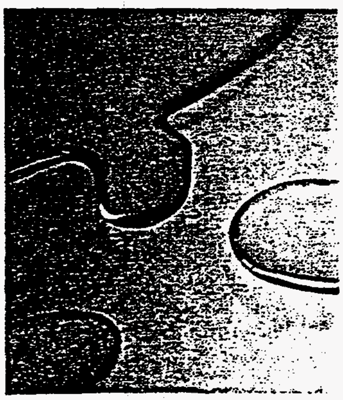
RESTRICTIONS
Contains a chlorinated solvent; should not be used with pressurized aluminum handling equipment for dispensing or storage.

TEMPERATURE RANGE
-20 to 115 F.

AUTHORIZATION
Product complies with USDA H2.

APPLICATION METHOD
Spraying, dipping or brushing.

CONTAINER SIZES
13.5 oz. aerosol, 5 gallon pail, 55 gallon drum.



Dispersions

DOW CORNING® C-40
HIGH TEMPERATURE CHAIN LUBRICANT

PHYSICAL FORM
Low-viscosity fluid dispersion of graphite in a synthetic oil.

PRIMARY USE
This fluid is designed to lubricate light and moderately loaded chains, conveyors and bearings that operate at elevated temperatures.

SPECIFIC APPLICATIONS
Lubricating chains in high temperature ovens used for heat treating, paint dryers, oven conveyors, ventilators, blower fans and oven carts.

SPECIAL CHARACTERISTICS
Suitable for automatic dispensing systems; material penetrates inaccessible areas, leaving a solid film behind that lubricates to 1000 F; base fluid evaporates leaving no carbon deposits; moderate loads at low speeds.

RESTRICTIONS
Surface temperature at the time of application should be below 250 F; continuous operation between 250 and 350 F may cause gumming; best operating conditions are over 350 F.

TEMPERATURE RANGE
350 to 1000 F.

AUTHORIZATION
Product complies with USDA H2.

APPLICATION METHOD
Brushing, hand oiling or automated equipment.

CONTAINER SIZES
1 quart bottle, 5 gallon pail, 55 gallon drum.

SEALS		PAGE
Chemical and solvent resistant; medium consistency	DOW CORNING 3451 Chemical Resistant Bearing Grease	13
Chemical and solvent resistant; heavy consistency	DOW CORNING 3452 Chemical Resistant Valve Lubricant	13
FDA compliant; silicone compound	DOW CORNING 111 Valve Lubricant/Sealant	26
Shear stability; silicone compound	DOW CORNING 112 High Performance Lubricant/Sealant	26
Resists washout by water	DOW CORNING 1122 Chain and Open Gear Lube	15
SPINDLES		**PAGE**
High speed, to 600,000 Dn	DOW CORNING BG 20 High Performance Synthetic Grease	16
General-purpose petroleum grease (contains MoS_2)	DOW CORNING BR2-Plus Multi-Purpose E.P. Grease	14
Long life at high temperatures (silicone)	DOW CORNING 44 High Temperature Bearing Grease	11
THREADED CONNECTIONS		**PAGE**
Reduce friction	DOW CORNING Gn Metal Assembly Paste and Spray	18
Controlled bolt tension; corrosion protection	DOW CORNING 1000 High Temperature Anti-Seize Paste	17
Permanent lubricant film	DOW CORNING 321 Dry Film Lubricant	22
Loosen rusted bolts	DOW CORNING Pene-Lube	20
Easier disassembly	DOW CORNING Moly Pene-Lube	20
White paste	DOW CORNING D General Purpose White Paste	17
VALVES		**PAGE**
Fluorosilicone; chemical, solvent resistance	DOW CORNING 3452 Chemical Resistant Valve Lubricant	13
Silicone compound; FDA compliant	DOW CORNING 111 Valve Lubricant/Sealant	26
Silicone compound; shear stability	DOW CORNING 112 High Performance Lubricant/Sealant	26

Lubricating – Processes

ASSEMBLY, GENERAL		PAGE
Metal-to-rubber; O-rings (swells rubber)	DOW CORNING 55 O-Ring Lubricant	12
Metal assembly; general purpose; reduce friction	DOW CORNING Gn Metal Assembly Paste and Spray	18
Metal assembly; broad operating temperature range	DOW CORNING 77 Part Assembly Paste	18
Metal-to-plastic; metal-to-rubber	DOW CORNING 112 High Performance Lubricant/Sealant	26
Sheet metal fasteners	DOW CORNING 557 Silicone Dry Film Lubricant	19
ASSEMBLY, PRESS-FITTING		**PAGE**
General-purpose paste; reduce friction	DOW CORNING Gn Metal Assembly Paste and Spray	18
Broad operating temperature range; MoS_2 in silicone	DOW CORNING 77 Part Assembly Paste	18
Clear, nonstaining, extreme-pressure lubricant	DOW CORNING 557 Silicone Dry Film Lubricant	19
MoS_2 powder; control fretting; cold welding	DOW CORNING Z Moly-Powder	16
White extreme-pressure paste	DOW CORNING D General Purpose White Paste	17
ASSEMBLY, THREADED CONNECTIONS		**PAGE**
General-purpose anti-seize paste; reduce friction, torque	DOW CORNING 1000 High Temperature Anti-Seize Paste	17
Lowest coefficient of friction	DOW CORNING Gn Metal Assembly Paste and Spray	18
Protects threaded connections and fasteners in storage	DOW CORNING Metal Protective Coating	21
Protect threaded connections and fasteners at high temperatures, corrosive environments	DOW CORNING 1000 High Temperature Anti-Seize Paste	17
Reduces torque; protects, even after periods of nonuse	DOW CORNING 321 Dry Film Lubricant	22
Loosen rusted connections	DOW CORNING Pene-Lube	20
Loosen severely rusted and corroded connections	DOW CORNING Moly Pene-Lube	20
Reduces torque requirements; MoS_2 powder	DOW CORNING Z Moly-Powder	16
COLD EXTRUSION		**PAGE**
Brass and aluminum drawing	DOW CORNING 557 Silicone Dry Film Lubricant	19
Lowest coefficient of friction	DOW CORNING Gn Metal Assembly Paste and Spray	18

Aluminum extrusion dies	DOW CORNING 321 Dry Film Lubricant	22
Draw box lubricant	DOW CORNING Z Moly-Powder	16
Gearbox oil additive	DOW CORNING M Gear Oil Additive	20
CUTTING AND SHEARING		**PAGE**
High-temperature metal shearing	DOW CORNING 321 Dry Film Lubricant	22
Clear, nonstaining, extreme-pressure lubricant; improve blade life	DOW CORNING 557 Silicone Dry Film Lubricant	19
Gear box oil additive to reduce friction, temperature	DOW CORNING M Gear Oil Additive	20
Punch press lube	DOW CORNING Gn Metal Assembly Paste and Spray	18
METAL FABRICATION AND FORMING		**PAGE**
Metal tapping lubricant	DOW CORNING Gn Metal Assembly Paste and Spray	18
Thread rolling lubricant	DOW CORNING Gn Metal Assembly Paste and Spray	18
Prevent metal buildup, seizing, galling (bonded)	DOW CORNING 321 Dry Film Lubricant	22
Cold forging steel	DOW CORNING 321 Dry Film Lubricant	22
Sheet metal fabrication	DOW CORNING 557 Silicone Dry Film Lubricant	19
Extreme-pressure additive for cutting oils; improve tool life	DOW CORNING M Gear Oil Additive	20
Small-part lubrication by tumbling	DOW CORNING Z Moly-Powder	16
Corrosion protection for in-process and finished parts	DOW CORNING Metal Protective Coating	21
Gears and bearings of sheet metal presses	DOW CORNING M Gear Oil Additive	20
POWDERED METAL FORMING		**PAGE**
Coining, sizing	DOW CORNING 557 Silicone Dry Film Lubricant	19
RELEASE COATINGS		**PAGE**
Foundry mold release; plastic extruders; process equipment	DOW CORNING 7 Release Compound	25
Anti-stick sealant for pre-cut gaskets	DOW CORNING 111 Valve Lubricant/Sealant	26
General-purpose silicone spray; FDA/USDA compliant	DOW CORNING 316 Silicone Release Spray	21
Silicone RTV release	DOW CORNING Metal Protective Coating	21
RUNNING-IN		**PAGE**
Plain, sleeve, journal bearings	DOW CORNING Gn Metal Assembly Paste and Spray	18
Gears, dry	DOW CORNING Gn Metal Assembly Paste and Spray	18
Chains and sprockets	DOW CORNING 321 Dry Film Lubricant	22
Gearboxes	DOW CORNING M Gear Oil Additive	20

Grease Formulating Fluids and Fine Machine Oils

BASE OIL FOR GREASES		**PAGE**
Phenylmethyl silicone; low-temperature greases	DOW CORNING 510 Fluid	28
Phenylmethyl silicone; high-temperature greases	DOW CORNING 550 Fluid	28
Phenylmethyl silicone; long life at high temperatures	DOW CORNING 710 Fluid	28
Fluorosilicone; solvent, chemical resistance	DOW CORNING FS-1265 Fluid	28
MISCELLANEOUS APPLICATIONS		**PAGE**
Cable-pulling lubricant	DOW CORNING 7 Release Compound	25
Moisture barrier for electrical assemblies, connections	DOW CORNING 4 Electrical Insulating Compound	25
Moisture, chemical barrier	DOW CORNING 3452 Chemical Resistant Valve Lubricant	13
Dry lubricant; use in vacuum, oxygen, radiation environments	DOW CORNING 321 Dry Film Lubricant	22
Additive to greases, plastics, rubbers	DOW CORNING Z Moly-Powder	16
Protect metals from corrosion	DOW CORNING Metal Protective Coating	21
Disassembly	DOW CORNING Pene-Lube or DOW CORNING Moly Pene-Lube	22
Threaded connections	DOW CORNING 1000 High Temperature Anti-Seize Paste	17
General purpose	DOW CORNING BR2-Plus Multi-Purpose E.P. Grease	14
Electric motors	DOW CORNING BG 20 High Performance Synthetic Grease	16

College of Engineering

Capsule Pipeline Research Center

E2421 Engineering Building East
Columbia, Missouri 65211
Telephone (314) 882-1810
FAX [314] 884=4888

UNIVERSITY OF MISSOURI-COLUMBIA

TO: Bill Burkett
Dr. Li
R. Zuniga

FROM: T. R. Marrero TRM

DATE: March 3, 1995

RE: Calcium Stearate Cost

According to Fred Durenberger, RheoChem sells calcium stearate at 54¢/pound; maximum 60¢, and coal could be less than 54¢/lb. The ca stearate is manufactured in Arkansas.

Bearings, Inc. – Dixie Bearings, Inc. – Bruening Bearings, Inc

Bearings and Power Transmission Components

INTEGRITY IN DISTRIBUTION

QUOTATION

TO:

Capsul Pipeline Research Center
2421 Engineering Bldg. East
University of Missouri
Columbia, MO 65211

ATTENTION OF: Mr. Andrew Rockabrand

DATE: February 23, 1995

INQUIRY NUMBER:

QUOTATION NUMBER:

TERMS: Net 30 Days

ITEM	QUANTITY	DESCRIPTION		UNIT COST	EXTENDED COST	FOB	ESTIMAT DELIVE
1	1-11 pcs	557 11oz	DOW	10.91			
	12-47 pcs.			10.03			
	48 & over			9.58			
	1-3	557 5gallon	DOW	227.31			
	4-9			223.48			
	10 & over			219.64			
2	1-11 pcs	1122 14oz	DOW	19.94			
	12 & over			17.72			
	1-3	1122 110#DRUM	DOW	1158.89			
	4-9			1138.24			
	10 & over			1117.58			

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Attention: Robyn L. Abrahamson

Submitted By: Robyn L. Abrahamson

Date: February 23, 1995

Capsule Pipeline Research Center
Quarterly Report

(Period Covered : 1/1/95 - 3/31/95)

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 :
<u>Preparation of Material for the "CLP Manual of Practice"</u>
The Control Group wrote a chapter for the Manual of Practice, Chapter 5, "Automation and Control of a CLP". This required considerable time on the part of the PI and the Research Associate Sanjay Mistry. Since the contents of the chapters indicate the implementation and real-world issues which are also being actively pursued by the group, the section and subsection headings of the chapter are listed below :

5.1 Introduction
  5.1.1 Overall Control Problem and Issues
5.2 Subsystem Control Needs
  5.2.1 Manufacturing and Distribution Subsystem
  5.2.2 Injection Subsystem
  5.2.3 Train Separator Subsystem
  5.2.4 Booster Subsystem
  5.2.5 Ejection Subsystem
5.3 Design Issues for Automation

5.3.1 Design of Y-joints
5.3.2 Connections Between Multiple Y-joints
5.3.3 Design of the Train Separator
5.3.4 Design of the Diverter
5.4 Component Control
5.4.1 Selection of Ball Valves
5.4.2 Selection of Pumps
5.4.3 Selection of Diverter and Stopper Actuators
5.4.4 Selection of Sensors
5.5 Design of the SCADA System
5.5.1 General Issues
5.5.2 Operator Interface
5.5.3 Master Terminal Unit (MTU)
5.5.4 Communication
5.5.5 Remote Terminal Unit (RTU)
5.5.6 Safety and Expandability
5.6 Small-Scale Prototype Coal Log Pipeline System
5.6.1 Mechanical Design Details
5.6.2 Control and Communication Hardware
References

The chapter length was 49 pages and each of these issues is discussed in detail. The reader is referred to the chapter draft for further details.

Train-Separator Design

The group also provided material for Section 4.7, "Coal Log Train Separator Design and Operation," of Chapter 4. The details of the section, again to provide the reader with the issues involved, are :

4.7 Coal Log Train Separator Design and Operation
4.7.1 Overall Function
4.7.2 Flow-Bypass Train Separator Design
4.7.3 Analysis of the Proposed Train Separator Design
4.7.4 Small-Scale System Prototype Studies

Figure 1 and 2 show the pump bypass station (booster station) and the train separator subsystem that is located at its upstream. The train separator is a novel system designed with much care and thought, to simplify the control issues. It represents a significant breakthrough in the operational aspect of the pipeline. The control group has consistently followed such a 'design for control' philosophy where the considerable effort is devoted to considering the control issue at the mechanical design stage itself, and considerable effort is also devoted to simplifying the mechanical design so that control can be affected easily. The train separator design represents such a design that the group has developed.

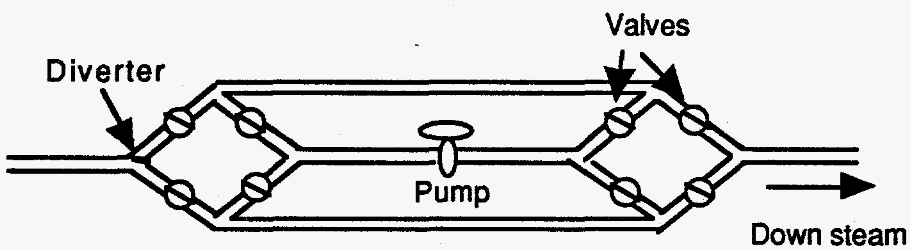


Figure 1 Pump Bypass Station

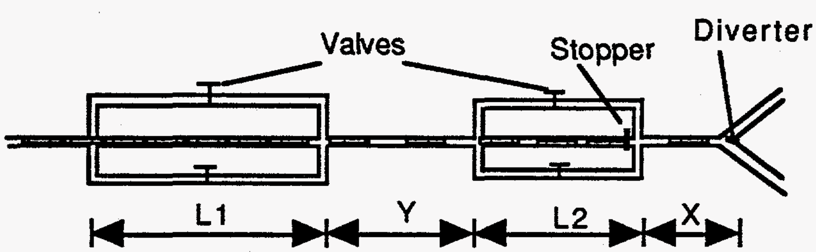


Figure 2 Flow Bypass Coal Log Train Separator

The design currently uses two laser beams to detect the presence of coal logs before the stopper is engaged using a simple control strategy. The stopper is engaged only if neither of the lasers, which are positioned carefully, detect coal logs. A reliable design for the stopper has been developed using solenoid type actuation. The design is almost ready for testing.

Work Proposed for the Next Quarter :

(i) The train separator design, as cited, is almost ready to be tested. Extensive observation experiments on the small-scale system will be conducted including investigating train spacing changes , effectiveness of flow bypass in reducing capsule speeds, energy loss analysis, etc.

(ii) Initiate the design of a recirculating loop to be added to the small-scale system so that long duration train travel can be simulated resulting in capsules arriving at the booster station with random intra-capsule spacing. This will be very essential in checking the reliability of the laser sensors and the stopper design.

(iii) 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.

(iv) Develop a control strategy for the distributed control architecture, taking into account reliability and safety.

(v) Initiate development of a SCADA type display package for the small scale system using Visual-C.

Capsule Pipeline Research Center

Bi-weekly Report

Individual Project

(Period Covered: Mar. 15, 1995 to Mar. 31, 1995)

Project Title: CLP System Design

P.I.: Dr. Henry Liu

Post Doctoral Fellow: Jianping Wu

Project Progress

(1) Completed the first draft of Chapter 4 for CLP Manual of Practice.

In this chapter, the design of systems for injection, ejection and pumping of coal logs were discussed. Several designs of a multi-lock injector were analyzed and compared, and their relative merits were assessed. The design aspects for an injector include: (a) coal log feeding method; (b) design of injection lock unit; (c) arrangement of injection lock unit. The operation of the injection system was also discussed. The design procedures of a multi-lock injector were listed in the chapter. The design of a pump bypass and ejection systems and their operations were also addressed. Practical examples involving the design of an 8-in CLP injection, pumping and ejection systems were given in this chapter.

(2) Hydraulic design of an 8-in CLP injection, pump bypass and ejection systems.

Hydraulic design of an 8-in CLP injection, pump bypass and ejection systems was completed. The system layouts were drawn and the components included in the each system were listed. Pumps and valves used in the injection and pump bypass systems were selected. The land consumption for the systems were also calculated. The steady state operations of injection and pump bypass systems were discussed.

Work accomplished during the period

(1) Unsteady state operation of injection system

I was working on the unsteady state operation of injection system: valve stroking and pump operations. The modification of computer program for the unsteady state operation of injection system with water only were completed. This computer program can handle the pipe network with different diameter pipes. Since the program requires large computer memory to run, the RISC1 computer in ECN will be used. I have requested the ECN staff to install the ethernet card and Pathwork software on the PC in my office to connect the PC with ECN computer network. The ECN staff was here on April 6, trying to install the software but unsuccessfully. He will try it again. After the completion of the connection, I should finish the debugging of program and have some results in a week.

(2) Design of EPRI testing pipeline

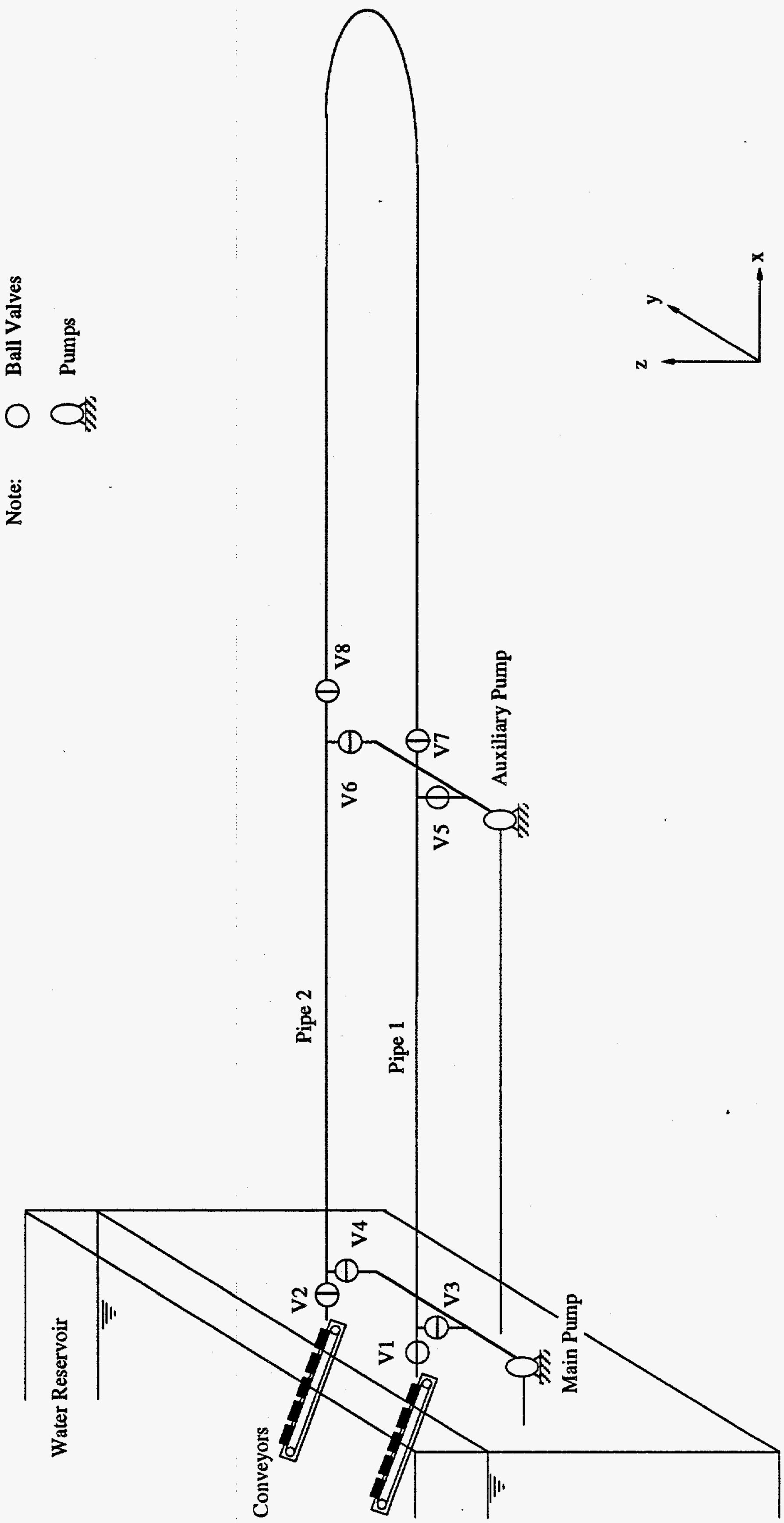
I started working on the EPRI testing pipeline design while waiting the ECN staff to install the ethernet card and software in the PC.

In the original design (Fig. 1 in EPRI proposal), one pump and seven valves are associated with the testing pipeline loop. This design has a difficulty to draw coal logs in the pipeline initially. To make it work, a suction pump and one more valve are needed as shown in Figure 1. To draw coal logs in the pipeline 1, valves 1 and 5 are open and valves 2, 3, 4, 5, 6, 7 and 8 are closed. Coal logs are drawn into pipe 1 through valve 1. After pipe 1 are filled with coal logs, close valves 1 and 5, open valves 2, 3, 7 and 8, turn the main pump on, and coal logs in pipe 1 will be pumped into downstream pipe. When the coal logs enter pipe 2 close valve 2 and open valve 6 to let coal logs accumulate in pipe 2. Once all the coal logs are in pipe

2, close valves 3 and 6, and open valve 4 to run the coal log train backward.

The alternate of using only one pump in the system is also studied. One pump with nine valves may make the system work.

The two water reservoir must be big enough to hold all the water when the pipeline is empty. The lowest point in elevation of pipeline must be at the water reservoir to empty the pipe when needed. The topographical map of pipeline site is needed for the layout design. The water reservoir also serves as a sedimentation tank to remove the coal particles after pipeline shutdown.


Note:
Ball Valves
Pumps
z
y
x
V8
V7
V6
V5
Auxiliary Pump
Pipe 2
Pipe 1
V4
V3
V2
V1
Main Pump
Water Reservoir
Conveyors

Capsule Pipeline Research Center
Quarterly Report
(period covered: 1/1/95 to 3/31/95)

Project Title: Coal Log Train Transport

Principal Investigator: Dr. James Seaba, MAE Dept.

Research Assistant: Wenwei Xu

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.

Work Accomplished During this Period:

The new data acquisition system and program has analyzed water flow through the 2-inch continuous loop system in the hydraulics lab. The results were compared with the Moody diagram to determine the roughness factor in the pipe test section. These results compared well with previous works of similar pipe material.

Future Work:

The measurement of capsule and static pressure drops in the 2-inch pipeline is expected in the near future. Initial tests will compare the short capsule train (approx. 5 capsules) in the new system with previous works. Afterwards, long capsule train variables will be assessed, in particular; capsule geometry (aspect ratio, and diameter ratio), capsule density, train length, and gap between capsules in train. The flow conditions will cover all capsule flow regimes. This data base will provide important information to improve the current capsule transport model.

Capsule Pipeline Research Center

Quarterly Report

(Period Covered: 1/1/95 - 3/31/95)

Project Title	Economics of Coal Log Pipeline
Principal Investigator	Dr. James S. Noble Assistant Professor of Industrial Engineering
Research Assistant	Robert Zuñiga, Industrial Engineering
Purpose of Research	To study the economics of the coal log pipeline as compared to other modes of transportation.

Work Accomplished During This Period

1. Completed Manual of Practice chapter on Coal Log Pipeline Economics.
   - included in Manual of Practice three different approaches to economic evaluation: OTA, EPRI, and Standard

2. Updating 1993 Economic Report
   - determined ranges of different system parameters
   - obtained new cost estimates for a various components of system
   - revised economic model
   - updated cost estimation software
   - conducted economic analysis of current pipeline configuration

Future Plan

- concluded revision of 1993 Economic Report
- conduct site specific economic evaluations as needed
- Zuñiga work on writing MS thesis
- revise submitted paper

4-7-95

Capsule Pipeline Research Center

Quarterly Report

(Period Covered: 1-1-95 to 3-31-95)

Project Title: **Legal Aspects of CLP**

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

Research Ass'ts: Eileen Petito

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) *Public service requirement for eminent domain.* State utility & railroad eminent domain law is being examined to determine whether the condemnor must provide public service to local residents in order to qualify for exercise of statutory eminent domain power. In progress. [Eileen Petito]

(2) *Model remedial legislation.* Begin drafting remedial legislation to enhance viability of coal pipeline projects. It will cover right-of-way and water rights acquisition, crossing highways & railroads, and conversion of petroleum & gas pipelines to coal transport. In progress. [Peter Davis & Eileen Petito]

(3) *Effect of public trust on eastern and western water rights.* Examine public trust cases which reduce the amount of water available for diversion. These usually are portions of streamflow designated for instream aquatic habitat and recreation uses. Completed. [Peter Davis]

(4) *Interstate water allocation.* Summarize generally law of interstate allocation of river flows and groundwater. [This research is not be specific to any particular river basin, since the relevant factors vary greatly from basin to basin.] Completed. [Peter Davis]

(5) *Clean Water Act permitting*. Summarize permitting requirements under federal Clean Water Act. Completed. [Peter Davis]

(6) *Wetlands disturbance permitting*. Summarize permitting requirements under Clean Water Act § 404. Completed. [Peter Davis]

(7) *Environmental Impact Statements*. Summarize requirements of National Environmental Policy for Environmental Impact Statements accompanying applications for federal licenses and permits. Completed. [Peter Davis]

Publication work:

(1) *Manual of Practice: Legal Aspects*. Prepared first draft of the legal chapter for the Manual of Practice. [Peter Davis]

Work Proposed for Next Quarter:

Research work:

(1) *Pipeline rupture issues*. Examine brine pipeline rupture and petroleum well brine discharge cases to determine potential liability for brine discharges from pipeline desalination plants. [Peter Davis]

(2) *Public service requirement for eminent domain*. Complete research on state utility & railroad eminent domain law to determine whether the condemnor must provide public service to local residents in order to qualify for exercise of statutory eminent domain power. [Eileen Petito]

(3) *Model remedial legislation*. Finish drafting remedial legislation to enhance viability of coal pipeline projects. It will cover right-of-way and water rights acquisition, crossing highways & railroads, and conversion of petroleum & gas pipelines to coal transport. [Peter Davis & Eileen Petito]

(4) *Miscellaneous legal issues for completing Manual of Practice*.
- (a) is pipeline water diversion a "beneficial use" under prior appropriation law? [Peter Davis]
- (b) water rights of Indian tribes; relation to prior appropriation law. [Peter Davis]
- (c) permitting of waste discharges under state statutes (summary). [Peter Davis]
- (d) permitting of wetlands disburbances under state statutes (summary). [Peter Davis]
- (e) proposed federal property rights (compensable taking definition) statute (summary). [Peter Davis]

(f) requirements of Endangered Species Act (summary). [Peter Davis]
(g) state environmental impact reports (summary). [Peter Davis]

(5) *Platte Pipeline easements in northern Missouri.* Determine easement language used in sample recorded easements for Platte Pipeline in some northern Missouri county. This work could not be done before summer 1995 because law research assistants would not be available until after exams in May. [not yet assigned]

Publication work:

(1) *Manual of Practice: Legal Aspects.* Prepare second draft of the legal chapter for the Manual of Practice. [Peter Davis & Eileen Petito]

(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 Davis, Cress & Sullivan, *Legal Aspect of Coal Pipelines in the United States -- Preliminary Findings* (Apr. 1993), and on the Manual of Practice (final draft).

Key Results of Recent Work:

The work completed this quarter were summaries of various federal statutes which could have an incidental effect on pipeline design and location, and a potential major effect on water supply availability. *See* Research conducted this period, items 3-7, above. In particular, the public trust doctrine and the equitable apportionment doctrine could significantly limit the amount of fresh water available for transwatershed and interstate diversion in a pipeline. *See* Manual of Practice (1st draft) for details.

Publications:

None.

Unpublished Research Reports:

Manual of Practice (1st draft, March 3, 1995).

file: rpt495

Capsule Pipeline Research Center

Quarterly Report

(Period covered: 1/1/95 - 3/31/95)

Project Title Heating, Cooling, and Drying of Coal Logs

Principal Investigator Dr. Thomas R. Marrero
Associate Professor of Chemical Engineering

Research Assistant Ssu-Hsueh Sun

Purpose of the Research The purpose of this study is to predict the heating, cooling, and drying rates of coal logs under various practical conditions encountered in CLP processes.

Work Accomplished During this Period

During this period, the modeling studies focused on transient heat and moisture transfer analysis by the Finite Element Method. A **robust** (subject to various boundary conditions) computer program was coded. Most components in the program are finished and the program is at the stage of systems integration and performance testing.

In order to easily adapt to various boundary conditions, the program is implemented by Object-Oriented Programming (OOP). This is a relatively new programming concept. In OOP, the term "Object" means a collection of both data and functions. The program is coded by an OOP language, Borland C++; FORTRAN 77 is not considered because it does not provide OOP supports until the latest version (FORTRAN-90). Three important concepts in OOP are briefly introduced as follows:

1. **encapsulation** : include user interfaces in a object such that allow other objects to easily handle this subject without understanding the detail inside the objects.
2. **abstraction** : developing a module subject to **Abstract Data Type (ADT)**, the data type can be easily changed to any data type in the future, such that the module is more robust,

which can handle objects of any type of object if user interfaces are provided.

3. **polymorphism** : generate new objects, so called **derived objects**, by inheriting from the existed objects, **base objects**, such that a complex object can be implemented easier.

The whole program is divided into several individual objects, see Figure 1. Each component is designed as independent as possible such that the interference between two objects is prevented and each object can be tested separately. This makes it a lot easier to adapt to various boundary conditions. In addition, the readability of the program is also increased.

The **sparse matrix solver**, one of the most important components in this program, is already finished and successfully tested separately. Due to the large amount of random access memory (RAM) required in solving transient 2-dimensional partial differential equations, sparse matrix skill is such that the amount of required memory can be reduced to reasonable range. The memory required by array storage and sparse matrix skill used in the program are compared in Table 1. The solver is construct by a algorithm based on Gaussian elimination with partial pivoting. This allows the solver to handle more general linear algebraic systems; usual sparse solvers are only good for symmetric and positive define system. Some of the test results show that the execution time needed of this algorithm is proportional to the square of matrix rank. It means that this solver will be much effective than the full matrix Gaussian elimination algorithm, which has the execution time proportional to the cube of matrix rank.

Table 1. The comparison of Required Memory (Megabyte) Between Two Storage Skills

No. of Element	Full Array	Sparse Matrix
4	0.01	0.02
16	0.13	0.06
64	1.50	0.21
256	21.18	0.78
Note		Required memory depends on the number of nonzero elements in the matrix

Work Proposed for the Next Quarter

Complete the finite element analysis of the transient heat and moisture transfer in coal logs

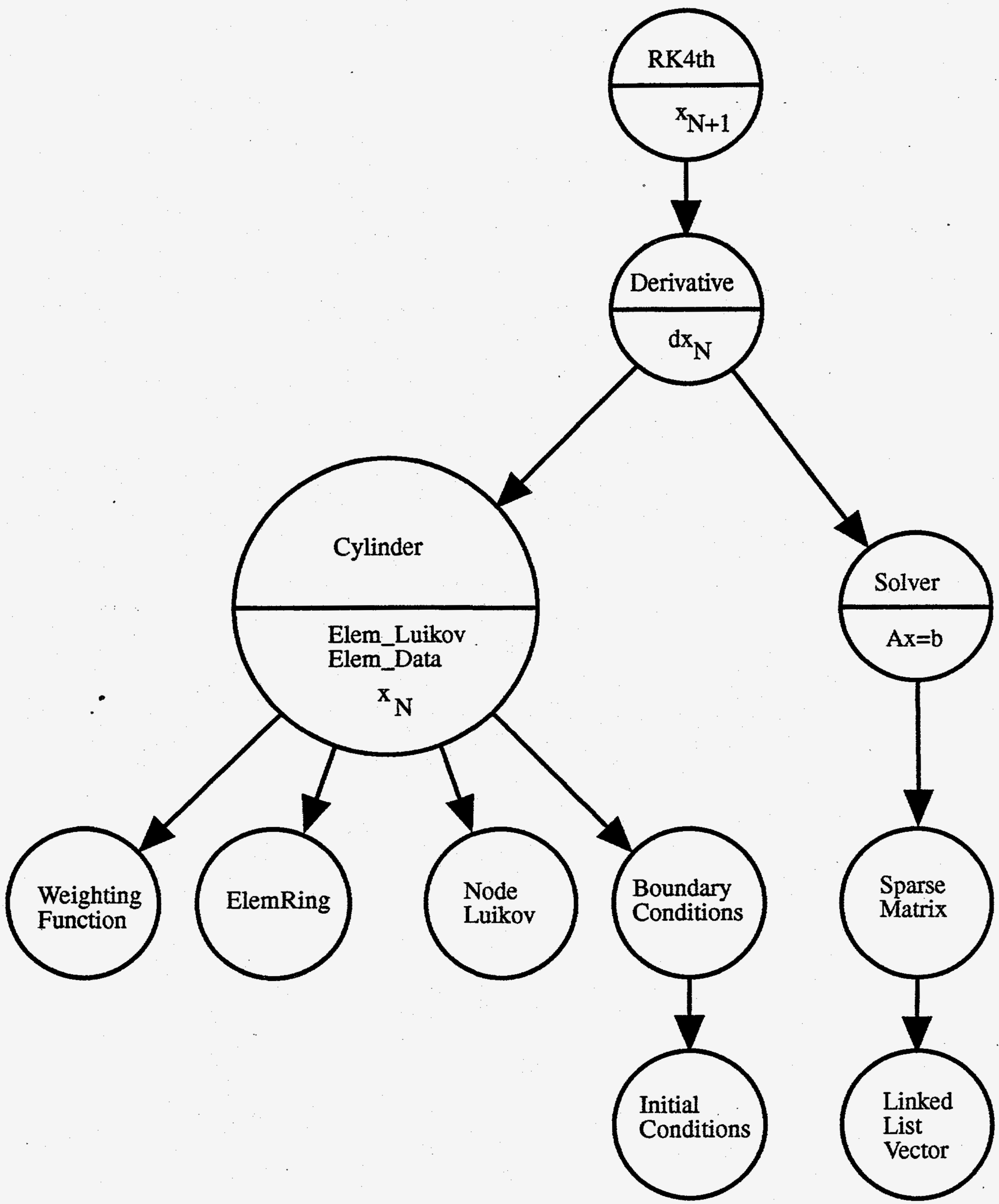


Figure 1. The Implementation of Finite Element Analysis on Coal Log Heating Cooling and Drying by Object-Oriented Programming

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 1/1/95 - 3/31/94)

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
David Woerner

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, only. Work accomplished includes: 1) improvements to the Phase I split mold based on experimental results, 2) addition of tanks and another vacuum pump to the Phase I system, 3) installation and checkout of complete automatic control system, 4) conduct of additional experiments with steam heating and vacuum, 5) development of cost estimates to support hydropulping, and 6) commencment of work on Phase II equipment.

As a result of experiments conducted in December, the 1.75 inch mold and associated pistons were modified in a number of ways. Due to problems from coal log capping with steam heating, a flat piston was fabricated for use as the upper piston in the mold. Also, the bevels on the existing pistons were modified to a 30 degree angle to reduce the possibility of capping in the coal log. And, the pistons and mold were chrome plated. Additionally, steam admission to the mold was modified so that steam was admitted at the top of the mold through the flat piston, with a beveled piston located at the bottom of the mold. These measures seem to have solved problems with capping for logs fabricated with direct contact steam heat.

Other improvements to the 1.75 inch split mold and associated systems have been undertaken to improve that ability of experimental apparatus to maintain stable vacuum at levels up to one tenth of an atmosphere. As one step to this goal, an additional tank and vacuum pump system was added to double vacuum pump capacity. Secondly, a complete micro-computer based control system was installed and tested. This system uses the National Instrument software package Labview to control system operation, and vacuum levels are now stable within the system. Thirdly, a number of leaks have been systematically eliminated. Unfortunately, air leaks into the mold during compression, and vacuum grease has been successfully used as an initial solution. However, more aggressive steps are being taken by adding O-ring seals to significantly reduce air leakage.

Work Accomplished During the Period (Continued):

In addition to improvements to the Phase I system, experiments were conducted with steam pre-heating to 97 degrees Centigrade. Sets of three coal logs were fabricated using electric and direct contact steam heat. Two different levels of asphalt emulsion as Orimulsion were tried. One experiment used 2.0% asphalt per dry coal weight and another used 0.5% asphalt per dry coal weight. Figures 1 and 2 show the results of these experiments. The logs made with 2.0% asphalt were not appreciably better under steam preheating. However, differences in weight loss for logs with 0.5% asphalt improved significantly under steam preheat when compared with logs made with electric heating alone. (There was an average of 5 percent wear versus 8.5 percent wear for 350 cycles in the test loop).

Cost estimates for hydropulping were provided. This activity supported tasks which involve the addition of wood fiber from waste paper to improve coal log strength. This work was undertaken because of Dr. Butler's eight years of experience in the pulp and paper industry, and his familarity with hydropulping of waste paper.

During this quarter, the last components for Phase II experiments were delivered. Design and fabrication has begun for the assembly of Phase II equipment and will continue during the coming months.

Future Plans:

Research with the Phase I apparatus will continue. Future experiments will focus on using vacuum and steam heat to improve the speed of compaction, and further characterization of the benefits available by using vacuum and steam preheating.

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 3. 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. It is anticipated that fabrication and check out of the manufacturing prototype system will be complete by early summer of 1995.

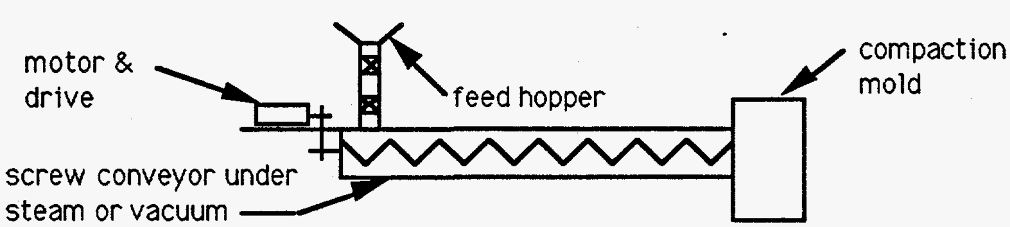


Figure 3 - Manufacturing Prototype System

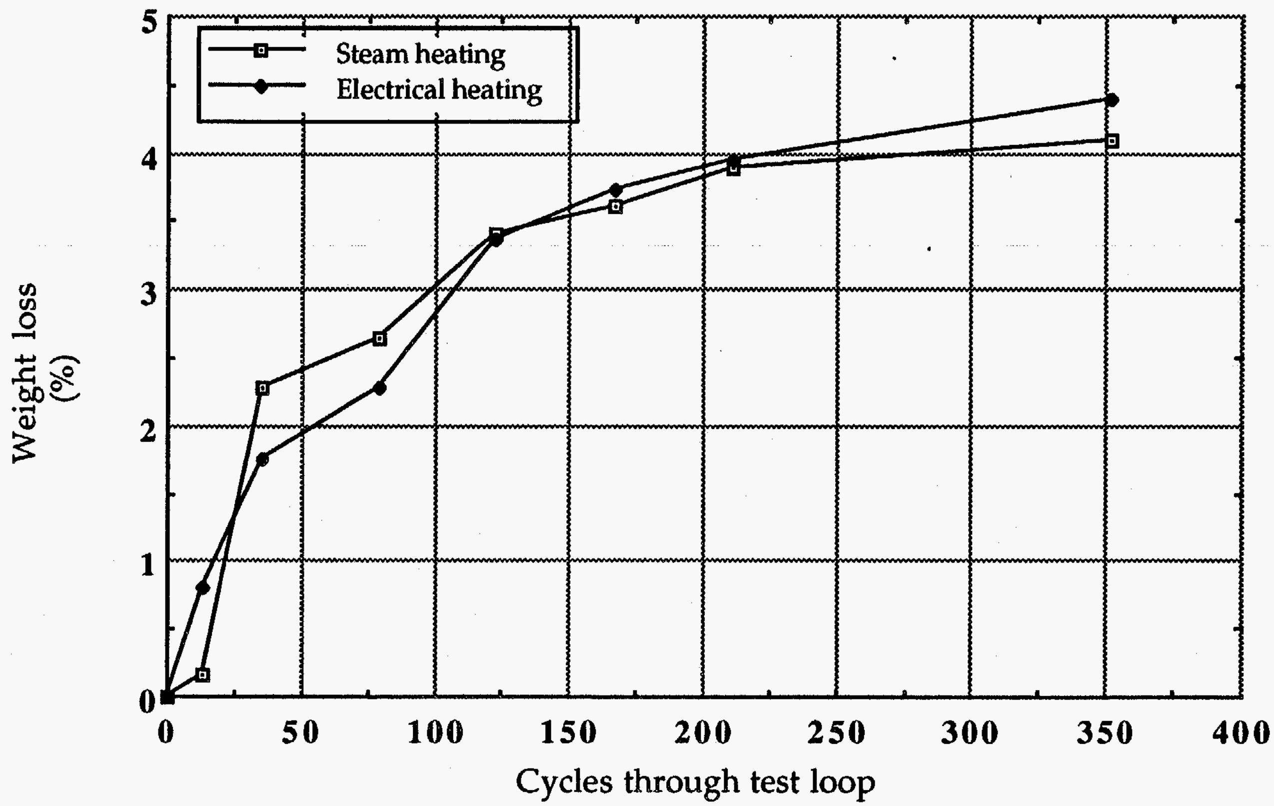


**Fig.1 Weight loss as a function of cycles through the test loop (average of 3 logs)
One flat end and one beveled end, with 2% asphalt**

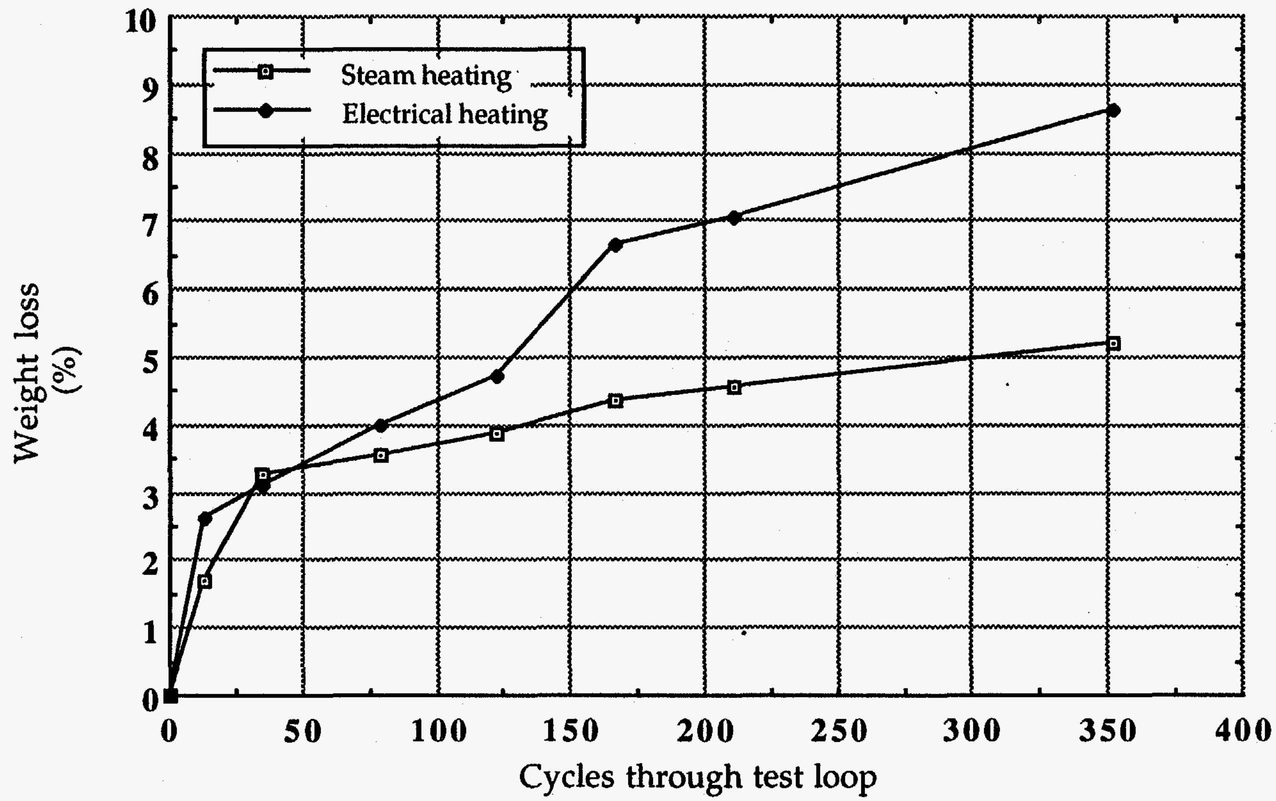


Fig. 2 Weight loss as a function of cycles through the test loop (average of 3 logs) One flat end, one beveled end, with 0.5% asphalt

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 1/1/95-3/31/95)

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 Ji (1/1-95-3/15/95), Guopin Wen

Work Accomplished During the Period:

We have completed the final report on the conceptual design of a coal log compaction plant based on hydraulic press concept, 8 inch pipeline (7 inch log diameter), and 3 million ton annual production rate. The report compared cost estimates for 10-second and 30-second compaction processes, and found out that it was more cost effective to compact coal logs at higher speed. These results are presented in Tables 4.2a and 4.2b attached, which indicates that the ratio of capital costs between fast and slow process is 1:1.8. The design is based on 20 000 psi compaction pressure which is twice as high as last year's design. This increase in pressure by a factor of two is based on the process research and change of coal type from sub-bituminous to bituminous, which requires higher pressure to compact. Another major difference between the present design and last year's design is the compaction time. Previously two second compaction time had been assumed. The current design is based on 30-second compaction time. The use of 30-second compaction time results in more compaction machines and higher capital cost, however, the process is proven in the lab to produce durable logs. The increase in capital cost is less than a factor of two for the longer time compaction process. Most important data and drawings from the current design is attached to this report (9 tables, 13 drawings).

Another machine design for a fast compaction machine uses hydraulic cylinders to make 1.9" coal logs. This design is being refined to production quality specifications. The machine has three major subsystems: the hydraulic power system which contains two-pump system with control valves and two cylinders, the structure, and the mold and feeder. The purpose of improving 1.9" coal log compaction machine design to production quality specifications:

1. The basic design of the 7" coal log compaction plant (Mr.Ji's thesis work) can be verified on a reduced scale machine (1.9" log instead of 7"). This machine can be easily configured to simulate the three-stage (loading material with preliminary compaction, higher pressure compaction, and ejection) manufacturing process. This machine can also perform combined three-stage operations into one machine continuous process, which may be slower but use less hydraulic cylinders and pump stations.

2. Current laboratory compaction machines have difficulty compacting faster than 30 seconds per stroke. The current available machines are adopted for coal log compaction, but not made for rapid compaction. It is showed in Mr. Ji's design report, a shorter manufacturing time per log can reduce the total manufacturing cost, therefore it is necessary to continue to shorten the manufacturing time for each log.

We have started literature search and collecting information for the design of a compaction machine based on the principle of tableting rotary press. Companies manufacturing tableting presses have been contacted, however, they seem unwilling to scale up their machines for manufacturing our laboratory size coal logs (1.9" diameter, 3.05" to 3.8" length). Rotary press works on a different principle than the hydraulic compaction cylinders. Longer compaction times and faster production rate are conflicting requirements for a hydraulic press, but can be achieved simultaneously on a rotary press.

Future Plans:

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

1. Finish production specification for the 1.9" inch coal log, 50T fast compaction machine in a month, and then assist the successful bidder to manufacture the machine.

2. Finish the conceptual design of a rotary press, which can produce 1.9" coal logs in about one second. The design will include engineering analysis and cost estimate for major parts.

Attachment:

Main results from the 7" coal log compaction plant (which is for an 8" nominal diameter pipeline) design report.

Table 4-2(a) Cost estimate for purchased equipment
(machine speed: 10 seconds per log per machine)

Equipment Name	Item No.	Specification (size)	Number Required	Unit Price ($)	Total Price ($)
Hydraulic cylinder I	5	14"*5"	90	6,700	603,000
Hydraulic cylinder II	7	10"*17"	180	4,211	757,980
Injection system: injection conveyor, with support, drive, injection rail	23,26 22	12" wide 50' long 150 fpm	6	10,000	60,000
Lift-clamping cylinder	12	3"*5"	540	560	302,400
Screw feeder and support	13	331,88 TPH	9	15,000	135,000
Ejection cylinder	19	8"*25"	90	3,650	328,500
Mounting bolt	17,20	all sizes	5000	0.50	2,500
Ejection system: automatic gate, proximity sensor, ejection rail	24 25 27-29		90	2,000	180,000
Mold transportation conveyor	8,11	12"wide 6'long,30fpm	90	3,500	315,000
Hydraulic pump I	unlabeled	M09*2500	450	420	189,000
Hydraulic pump II	unlabeled	PV092*5000	90	4,500	405,000
Total					3,278,380

Table 4-2(b) Cost estimate for purchased equipment (machine speed: 30 seconds per log per machine)

Equipment Name	Item No.	Specification (size)	Number Required	Unit Price ($)	Total Price ($)
Hydraulic cylinder I	5	14"*5"	264	6,700	1,768,000
Hydraulic cylinder II	7	10"*15"	176	4,211	741,136
Injection system: injection conveyor with support, drive injection rail	23,26 22	12"wide 50'long 150fpm	6	10,000	60,000
Lift-clamping cylinder	12	3"*5"	880	560	492,800
Screw feeder and support	13	331.88TPH	9	15,000	135,000
Ejection cylinder	19	8"*25"	88	3,650	321,200
Mounting bolt	17,20	all sizes	5000	0.50	2,500
Ejection system: automatic gate, proximity sensor, ejection rail	24 25 27-29		88	2,000	176,000
Mold transportation conveyor	8,11	12"wide 6'long,30fpm	264	3,500	924,000
Hydraulic pump I	unlabeled	M09*2500	352	420	147,840
Hydraulic pump II	unlabeled	PV080*5000	264	4270	1,127,280
Total					5,895,756

Table 4-3 Sketch routing for a compaction mold
(Part 4 and part 8 in hydraulic and mechanical processes respectively)

Operation	Description	Setup Time (Minute)	Handling Time (Minute)	Run Time (Minute)
1	Obtain material	15		
2	Hold at face 2	10		
3	Turn (c) face 4		2	10
4	Turn (f) face 4		1	3
5	Turn (c) face 5		2	10
6	Turn (f) face 5		1	3
7	Hold at face 6 (other side of face 2)	10		
8	Turn (c) face 3		2	10
9	Turn (f) face 3		1	3
10	Hold at face 9	10		
11	Turn (c) face 11		2	12
12	Turn (f) face 11		1	5
13	Drill holes 10	10	5	30
14	Hold at face 16	10		
15	Turn (c) face 17		2	12
16	Turn (f) face 17		1	5
17	Assemble 2 handles	10	15	
18	Assemble 2 rings	10	20	
Total time (Minute)		85	55	103

Material cost: $250.00
Machining cost: $120.15 (=4.005hr * $30/hr)

Total cost for a mold: $370.15

Table 4-4(a) Estimated cost for manufactured parts
(machine speed: 10 seconds per log per machine)

Item Number	Description	Quantity	Unit Cost ($)	Cost ($)
1	Static base	90	500.00	45,000
2	Retractable piston	90	125.00	11,250
3	Sliding clamp	270	95.00	25,650
4	Mold	540	370.00	199,800
6	Cylinder base I	90	1000.00	90,000
8,9	Loading piston with piston rotate screw	180	200.00	36,000
10	Piston guide	180	150.00	27,000
14	Cylinder base II	180	1000.00	180,000
15	Loading house support	180	300.00	54,000
16	Ejection piston	90	200.00	18,000
18	Mold clamp	270	150.00	40,500
21	Ejection cylinder base	90	1000.00	90,000
31	Supporting V-block	270	125.00	33,750
Total Cost ($)				850,950

Table 4-4(b) Estimated cost for manufactured parts
(machine speed: 30 seconds per log per machine)

Item Number	Description	Quantity	Unit Cost ($)	Cost ($)
1	Static base	264	500.00	132,000
2	Retractable piston	264	125.00	33,000
3	Sliding clamp	440	95.00	41,800
4	Mold	1584	370.00	568,080
6	Cylinder base I	264	1000.00	264,000
8,9	Loading piston with piston rotate screw	176	200.00	35,200
10	Piston guide	176	150.00	26,400
14	Cylinder base II	176	1000.00	176,000
15	Loading house support	176	300.00	52,800
16	Ejection piston	88	200.00	17,600
18	Mold clamp	440	150.00	66,000
21	Ejection cylinder base	88	1000.00	88,000
31	Supporting V-block	440	125.00	55,000
Total Cost ($)				1,573,880

Table 4-5 Required land area and cost comparison

	10 seconds compaction process	30 seconds compaction process
Required land area for each machine (square feet)	10*12	40*12
Total land needed (square feet)	250*150	700*150
Unit cost for building house (dollar/foot^2)	100.00	100.00
Unit land cost (dollar/acre)	2,000.00	2,000.00
House cost (dollars)	3,750,000	10,500,000
Land cost (dollars)	1,728	4,838
Road accessing cost (dollars)	50,000	50,000
Total land, house, and road cost (dollars)	3,801,728	10,554,838

Table 4-6 Costs for power line supply

	10 seconds compaction process	30 seconds compaction process
Required power (kw)	24,506	34,378
Power line supply cost (dollars)	215,047	263,474

Table 4-7 Capital cost summary for 10 seconds and 30 seconds compaction processes

	10 seconds compaction process	30 seconds compaction process
Purchased equipment (dollars)	3,278,380	5,895,756
Manufactured parts (dollars)	850,950	1,573,880
Building cost (dollars)	3,750,000	10,500,000
Land cost (dollars)	1,728	4,838
Road accessing cost (dollars)	50,000	50,000
Power line supply cost (dollars)	215,047	263,474
Total (dollars)	8,146,105	18,287,948

Table 4-8 Energy consumption

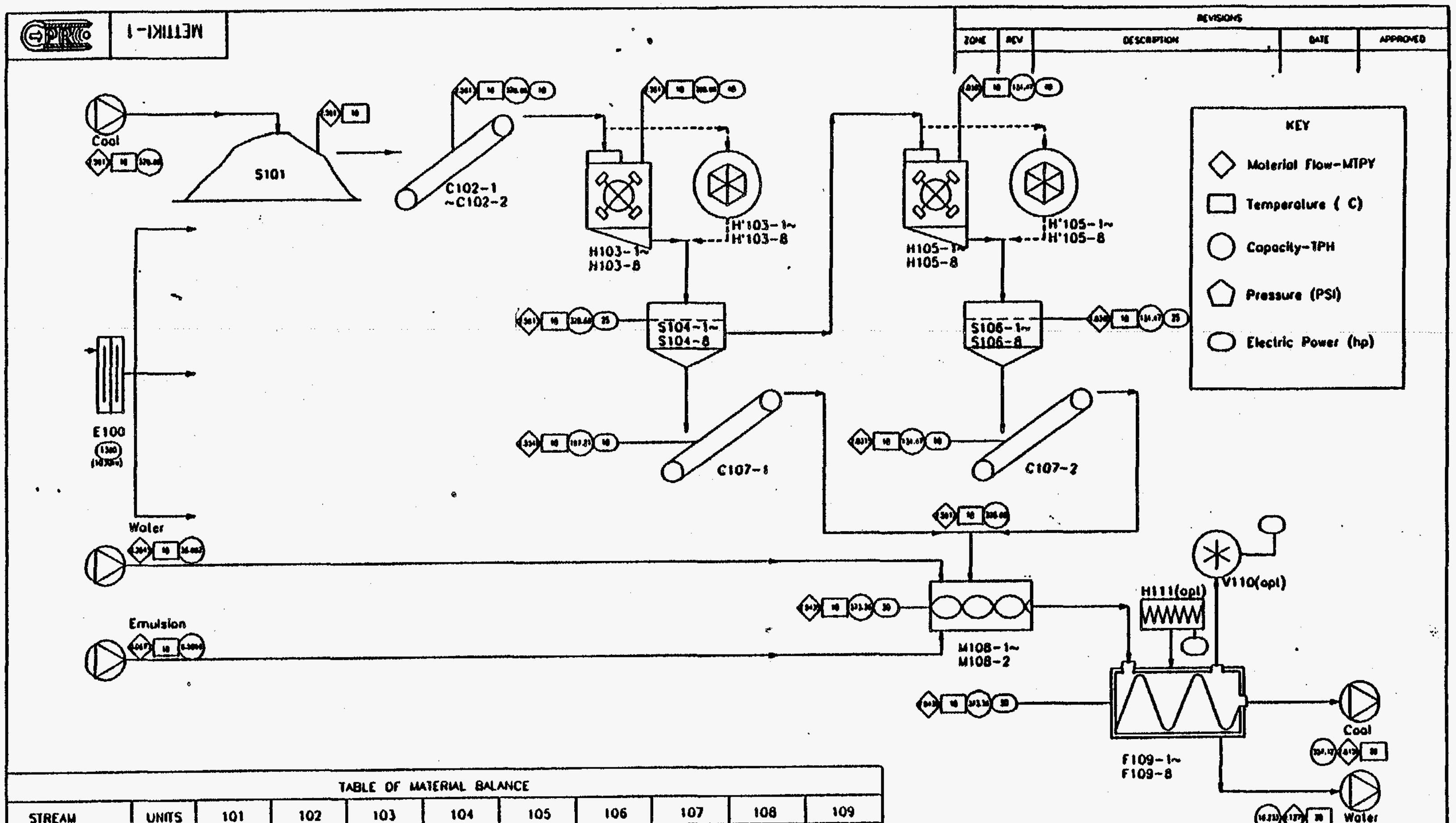
	10 seconds compaction process	30 seconds compaction process
Material preparation (kw)	1030	1030
Compaction (kw)	23,476	33,348
Total (kw)	24,506	34,378
Operation ratio	2/3	2/3
Unit energy cost (dollar/kwh)	0.06	0.06
Total cost (dollars)	7,728,212	10,841,446

Table 4-9 O/M cost summary

	10 seconds compaction process	30 seconds compaction process
Energy consumption (dollars)	7,728,212	10,841,446
Water consumption (dollars)	55,987	55,987
Labor cost (dollars)	800,000	1,200,000
Maintenance and insurance cost (dollars)	651,688	1,463,035
Total O/M cost (dollars)	9,235,887	13,560,468

LIST OF MAJOR PARTS IN HYDRAULIC COMPACTION SYSTEM
—for 10 second compaction process

Item No.	Part Name	Make/Purchase	Quantity	Remark
1	Static Base	M	90	09-004
2	Retractable Piston	M	90	09-004
3	Sliding Clamp	M	270	09-004
4	Mold	M	540	09-004
5	Hydraulic Cylinder I (high pressure)	P	90	09-004
6	Cylinder Base I	M	90	09-004
7	Hydraulic Cylinder II	P	180	09-003
8	Piston Rotate Screw	M	180	09-003
9	Loading Piston	M	180	09-003
10	Piston Guide	M	180	09-003
11	Conveyor Support	P	90	09-004
12	Lift-Clamping Cylinder	P	540	09-004
13	Screw Feeder	P	9	09-003
14	Cylinder Base II	M	180	09-003
15	Loading House Support	M	180	09-003
16	Ejection Piston	M	90	09-005
17	Clamp Stop Screw	P	1080	09-005
18	Mold Clamp	M	270	09-005
19	Ejection Cylinder	P	90	09-005
20	Mounting Bolt	P	numerous	09-005
21	Base of Ejection Cylinder	M	90	09-005
22	Injection Rail	P	6	09-005
23	Conveyor Drive	P	fitted	09-005
24	Automatic Gate	P	90	09-005
25	Proximity Sensor	P	fitted	09-005
26	Injection Conveyor	P	6	09-005
27	Ejection Rail Frame	P	90	09-005
28	Ejection Rail	P	90	09-005
29	Adjustable Rail Support	P	90	09-005
30	Coal Log	M	numerous	09-005
31	Supporting V-block	M	270	09-005
32	Mold Conveyor	P	90	09-005



STREAM		UNITS	101	102	103	104	105	106	107	108	109
			TABLE OF MATERIAL BALANCE								
METTIKI	RAW COAL-2"	LBS/HR	657,360	328,680•2							
	RAW COAL 1/2"-20M	LBS/HR			82,170•8		32,867.5•8				
	RAW COAL-20M	LBS/HR				49,302.5•8		32,867.5•8	1-394,420 2-262,940	657,360	657,360
	WATER	LBS/HR								72,163	39,701
	EMILSION	LBS/HR								17179	17179
	TOTAL	LBS/HR	657,360	657,360	657,360	394,420	262,940	262,940	657,360	746,702	714,240
	VOLUME	CFH	13,173	13,173	13,173	7,904	5,269	5,269	13,173		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS ANGULAR
.XX ±.05 ±0.5
.XXX ±.010
DO NOT SCALE DRAWING

DRAWN Guoping Ji DATE Dec.1
CHECKED
DESIGN Guoping Ji Oct.7

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Fig.1-Flowsheet for grinding,mixing and heating

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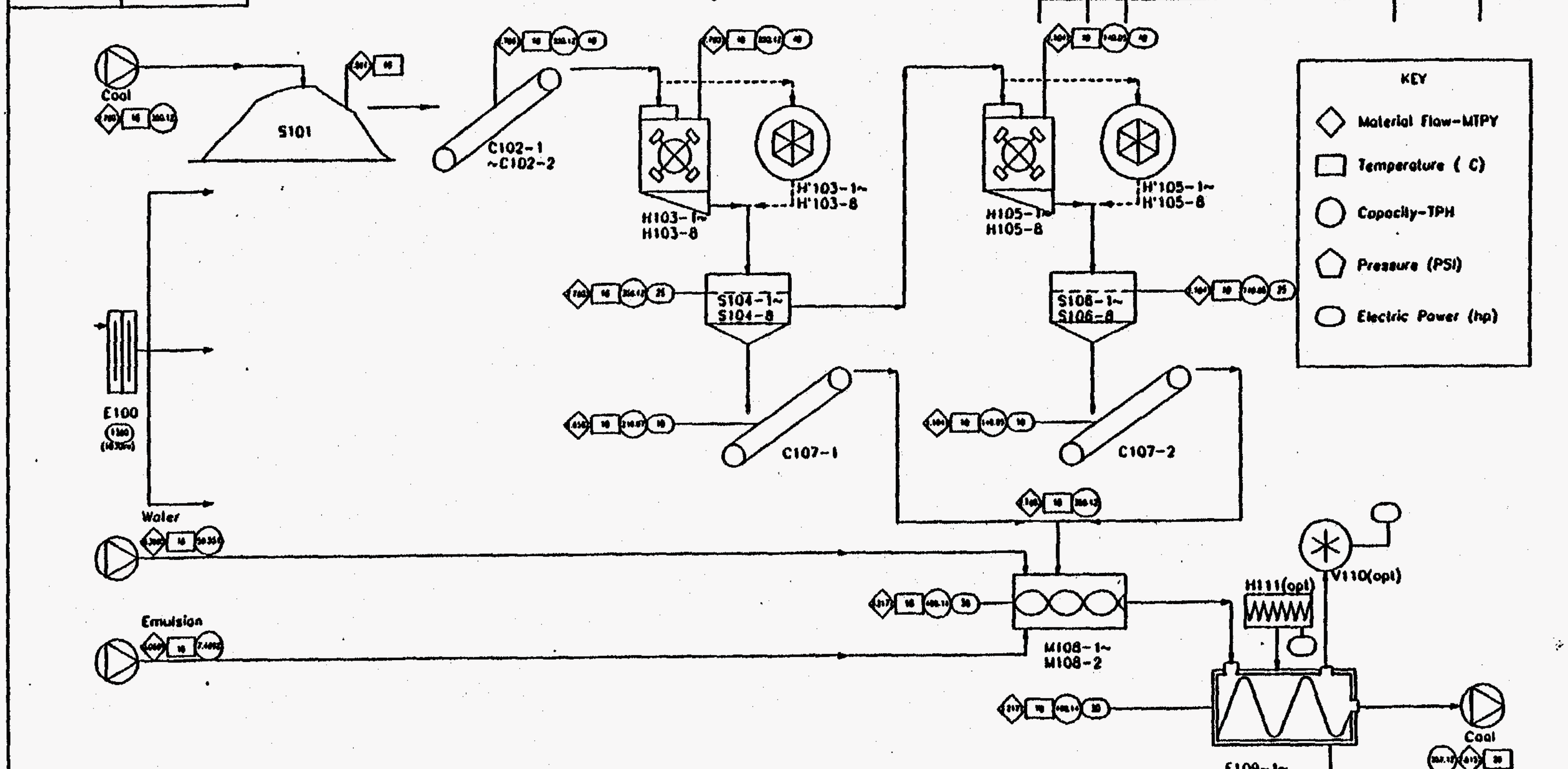
SCALE | SHEET 1 OF 4

P.R.B.-1



REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED

TABLE OF MATERIAL BALANCE

	STREAM	UNITS	101	102	103	104	105	106	107	108	109
P.R.B. COAL	RAW COAL-2"	LBS/HR	700,239	350,119*2							
	RAW COAL 1/2"-20M	LBS/HR			87,530*8		35,011*8				
	RAW COAL-20M	LBS/HR				52,518*8		32,867.5*8	1-420,148 2-280,091	700,239	700,239
	WATER	LBS/HR								101,101	-934
	EMILSION	LBS/HR								14,938	14,938
	TOTAL	LBS/HR	700,239	700,239	700,239	420,148	280,091	280,091	700,239	816,278	714,243
	VOLUME	CFH	14,033	14,033	14,033	8,420	5,613	5,613	14,033		

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TOLERANCES
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DO NOT SCALE DRAWING

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DRAWN	Guoping Ji	Dec.1
CHECKED		
DESIGN	Guoping Ji	Oct.7

CPRC Capsule Pipeline Research Center

Fig.1-Flowsheet for grinding,mixing and heating

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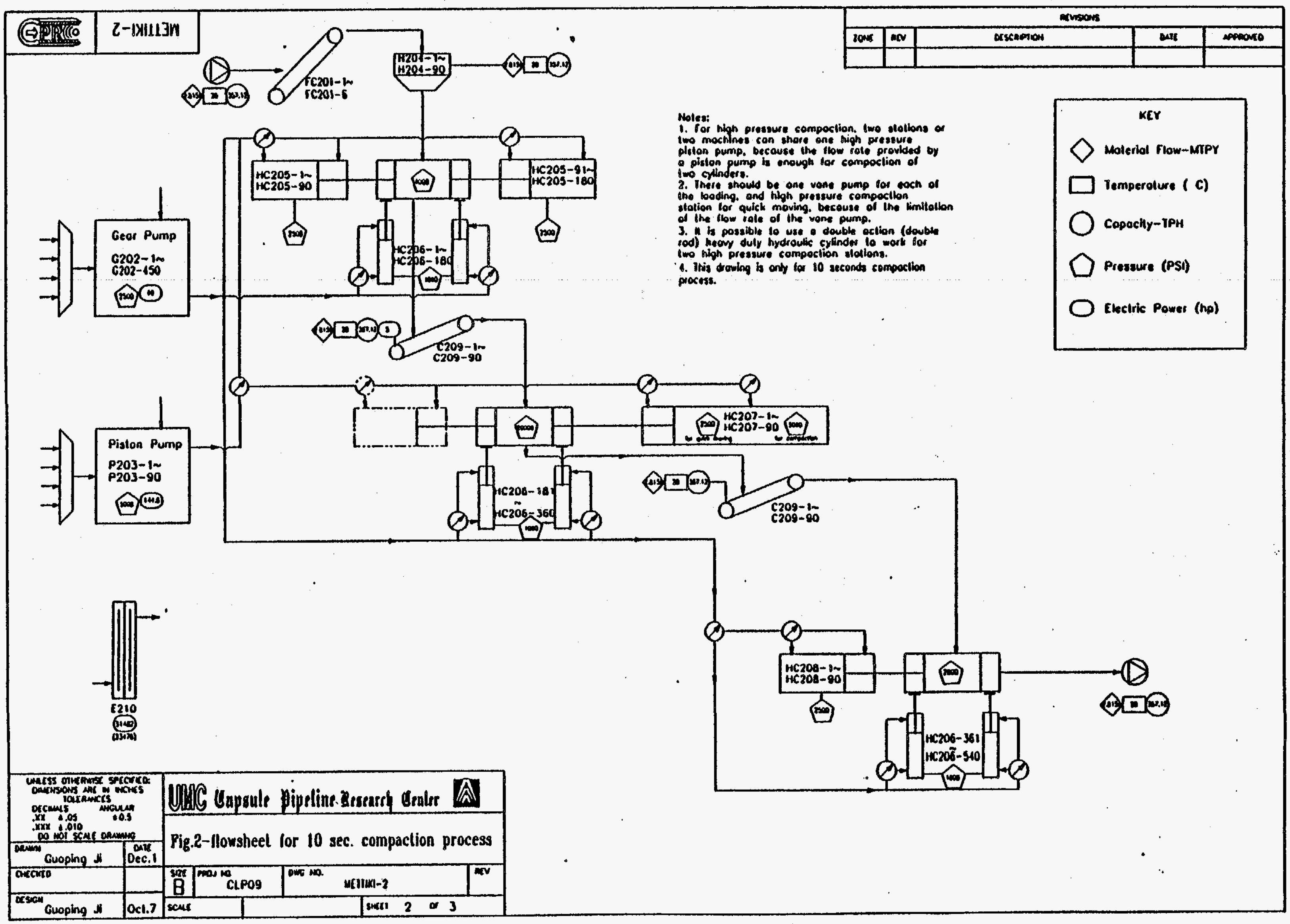
SCALE		SHEET 1 OF 4	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DATE
APPROVED
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FC201-6
H204-1~
H204-90
HC205-1~
HC205-90
HC205-91~
HC205-180
HC206-1~
HC206-180
Gear Pump
G202-1~
G202-450
Piston Pump
P203-1~
P203-90
C209-1~
C209-90
HC207-1~
HC207-90
HC206-181
~
HC206-360
E210
HC208-1~
HC208-90
HC206-361
~
HC206-540
Notes:
1. For high pressure compaction, two stations or two machines can share one high pressure piston pump, because the flow rate provided by a piston pump is enough for compaction of two cylinders.
2. There should be one vane pump for each of the loading, and high pressure compaction station for quick moving, because of the limitation of the flow rate of the vane pump.
3. It is possible to use a double action (double rod) heavy duty hydraulic cylinder to work for two high pressure compaction stations.
4. This drawing is only for 10 seconds compaction process.
KEY
Material Flow-MTPY
Temperature (C)
Capacity-TPH
Pressure (PSI)
Electric Power (hp)
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS ANGULAR
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DO NOT SCALE DRAWING
DRAWN Guoping Ji
DATE Dec.1
CHECKED
DESIGN Guoping Ji
Oct.7
UMC Capsule Pipeline Research Center
Fig.2-flowsheet for 10 sec. compaction process
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DWG NO. METIIKI-2
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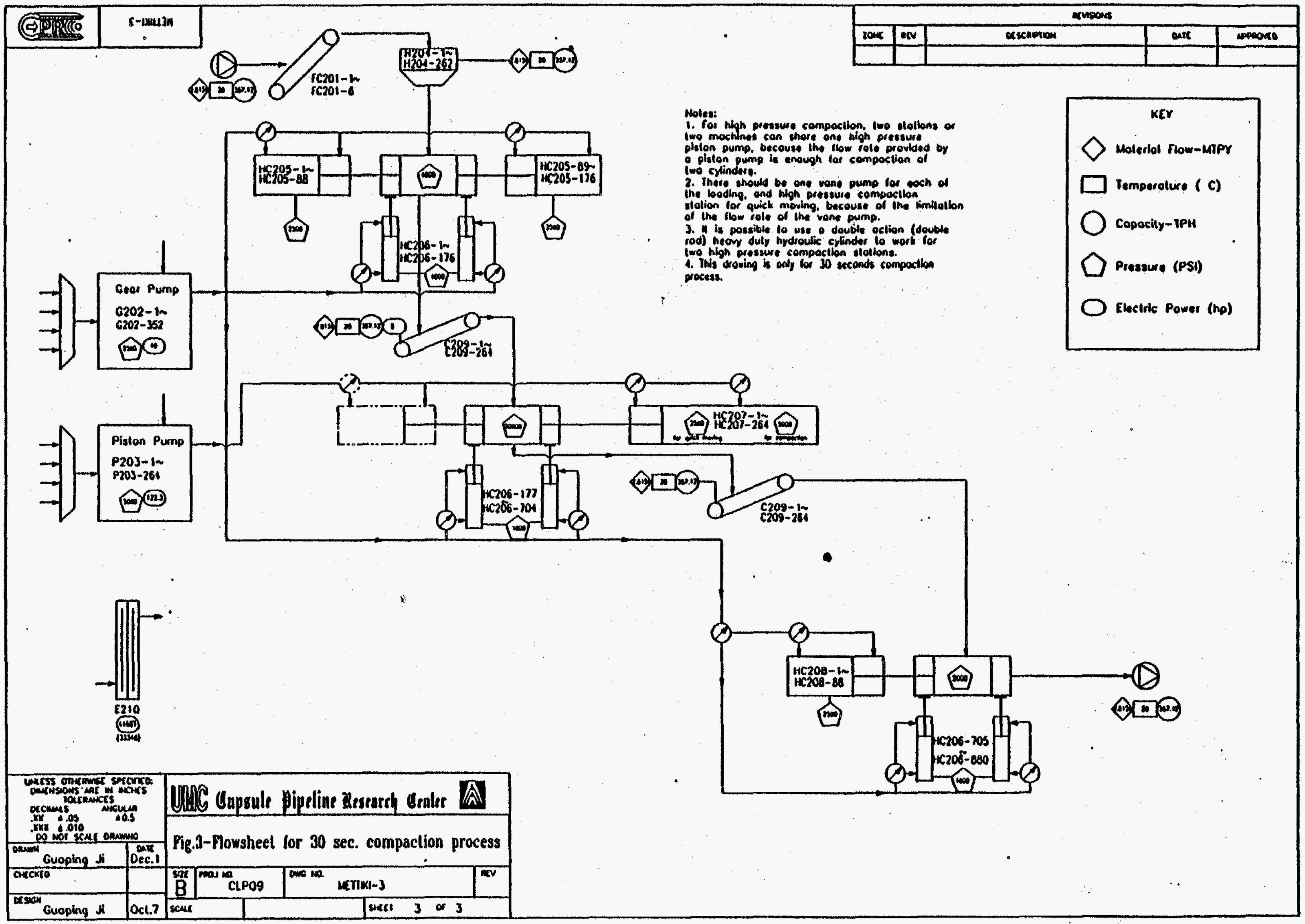
SHEET 2 OF 3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FC201-6
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H204-262
HC205-1~
HC205-88
HC205-89~
HC205-176
HC206-1~
HC206-176
Gear Pump
G202-1~
G202-352
C209-1~
C209-264
Piston Pump
P203-1~
P203-264
HC207-1~
HC207-264
for quick moving
for compaction
HC206-177
HC206-704
C209-1~
C209-264
E210
HC208-1~
HC208-88
HC206-705
HC206-880
REVISIONS
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DESCRIPTION
DATE
APPROVED
Notes:
1. For high pressure compaction, two stations or two machines can share one high pressure piston pump, because the flow rate provided by a piston pump is enough for compaction of two cylinders.
2. There should be one vane pump for each of the loading, and high pressure compaction station for quick moving, because of the limitation of the flow rate of the vane pump.
3. It is possible to use a double action (double rod) heavy duty hydraulic cylinder to work for two high pressure compaction stations.
4. This drawing is only for 30 seconds compaction process.
KEY
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Temperature (C)
Capacity-TPH
Pressure (PSI)
Electric Power (hp)
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Oct.7
UMC Capsule Pipeline Research Center
Fig.3-Flowsheet for 30 sec. compaction process
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METIKI-3
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SHEET 3 OF 3

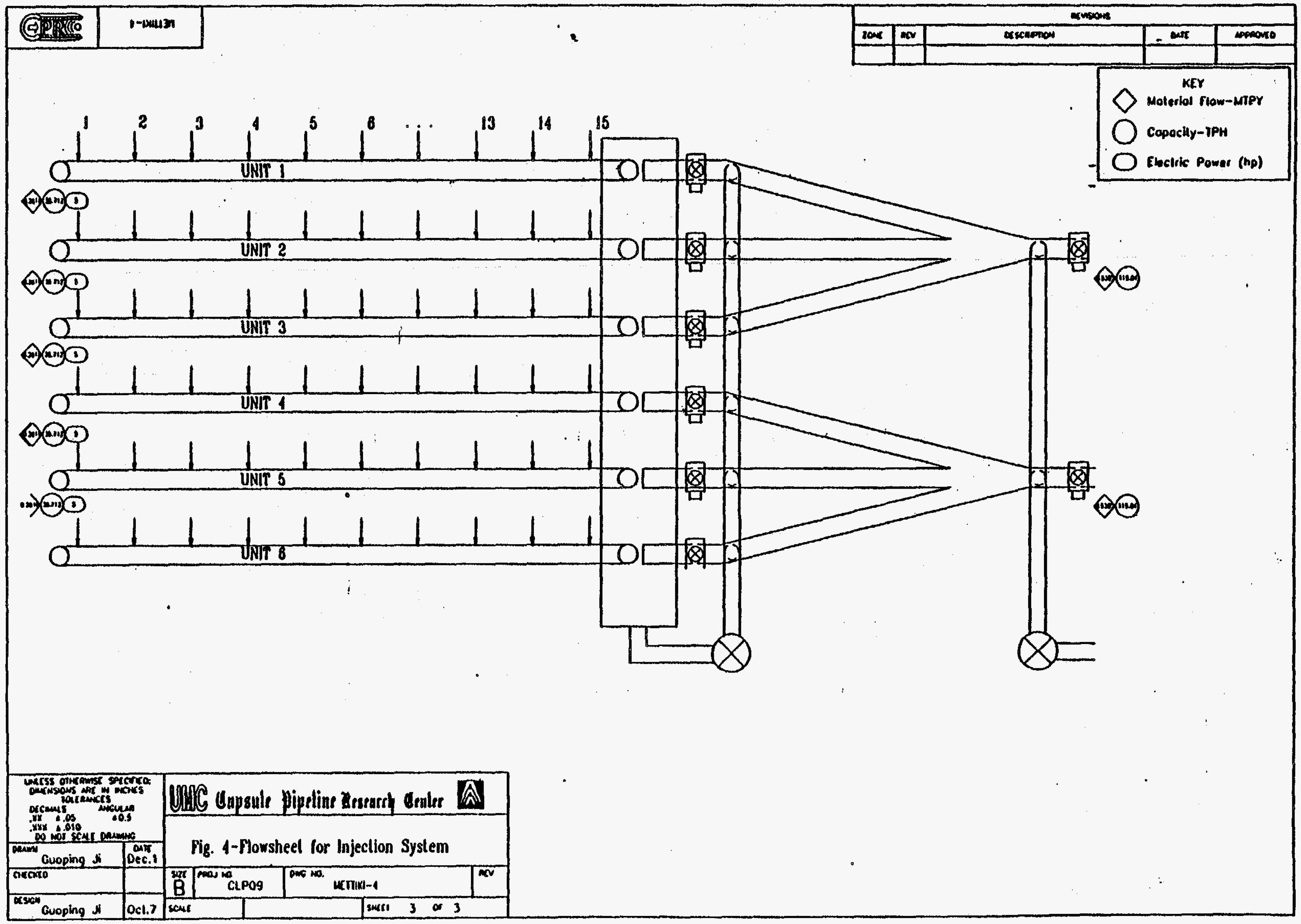
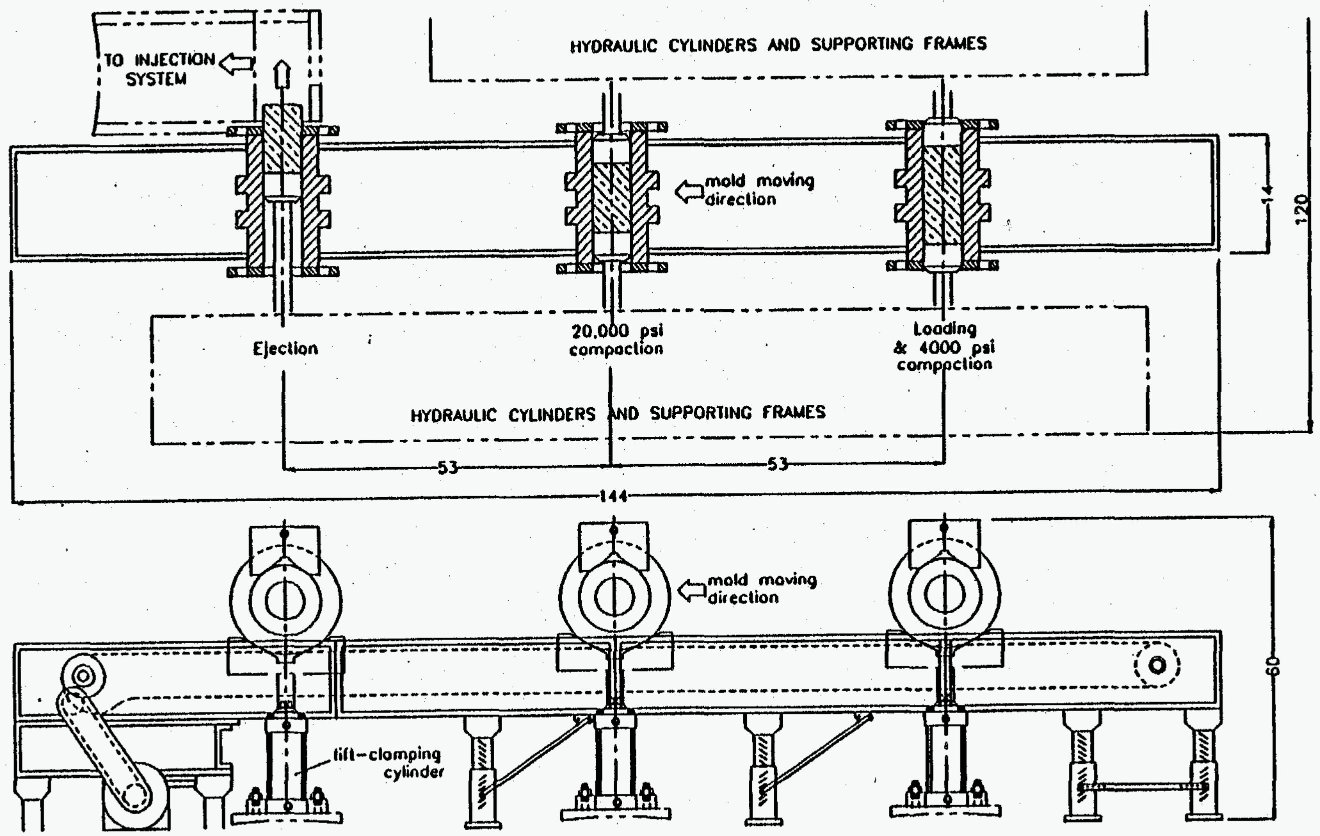


Fig. 4-Flowsheet for Injection System

CPRC 100-60



NOTES:
1 CONVEYOR: 30 FPM, 1.5 HP, 14 INCHES WIDTH
2 HYDRAULIC CYLINDERS: 5000 PSI NOMINAL PRESSURE, 14" BORE DIAMTER
3 HYDRAULIC PUMPS: 1. 40 HP, EACH FOR LOADING AND EJECTION
2. 144.8 HP EACH FOR COMPACTION
4 DETAIL ARRANGEMENT AND PARAMETERS FOR PUMPS AND CYLINDERS ARE ON THE FLOWSHEETS

REVISIONS				
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TOLERANCES
DECIMALS .XX ±.05 .XXX ±.010 ANGULAR ±0.5
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DESIGN	Guoping Ji

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Layout of loading, compaction, and ejection stations

SIZE	PROJ NO.	DWG NO.	REV
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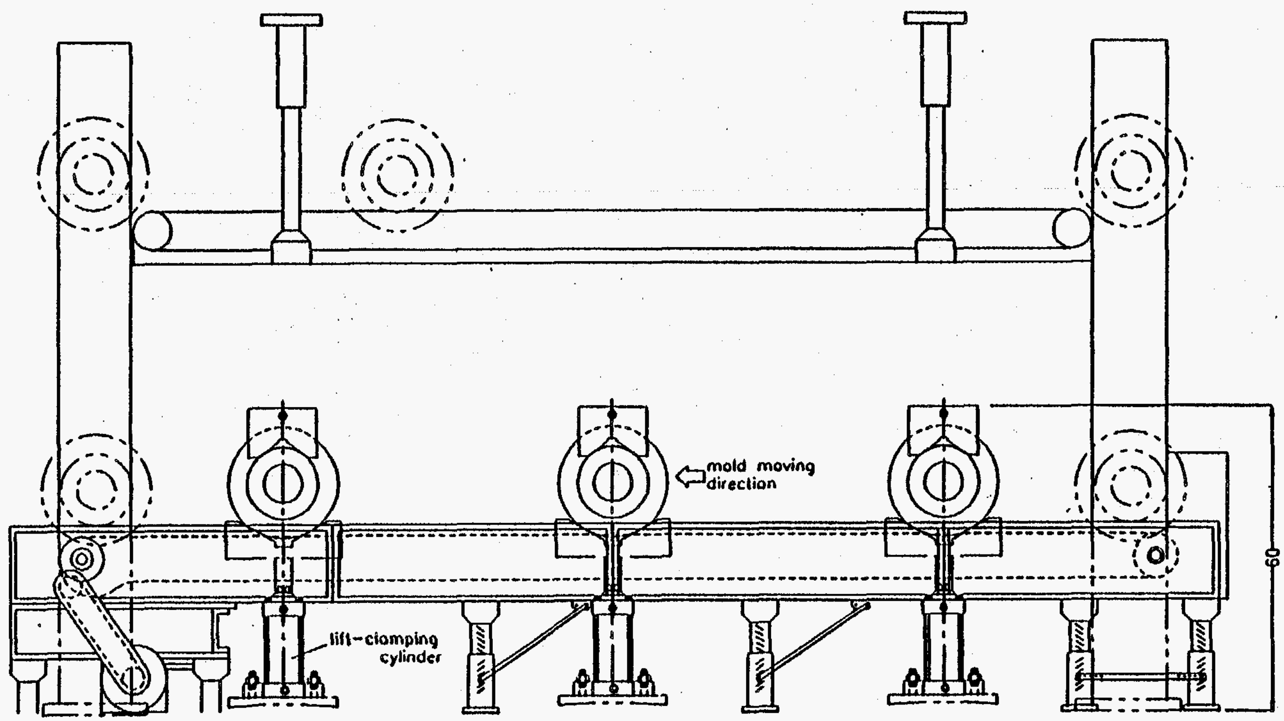

NOTES:
1 CONVEYOR: 30 FPM, 1.5 HP, 14 INCHES WIDTH
2 HYDRAULIC CYLINDERS: 5000 PSI NOMINAL PRESSURE, 14" BORE DIAMTER
3 HYDRAULIC PUMPS: 1. 40 HP, EACH FOR LOADING AND EJECTION
2. 144.8 HP EACH FOR COMPACTION
4 DETAIL ARRANGEMENT AND PARAMETERS FOR PUMPS AND CYLINDERS ARE ON THE FLOWSHEETS

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS .XX ±.05 .XXX ±.010
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MOLD RECYCLE

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09-002

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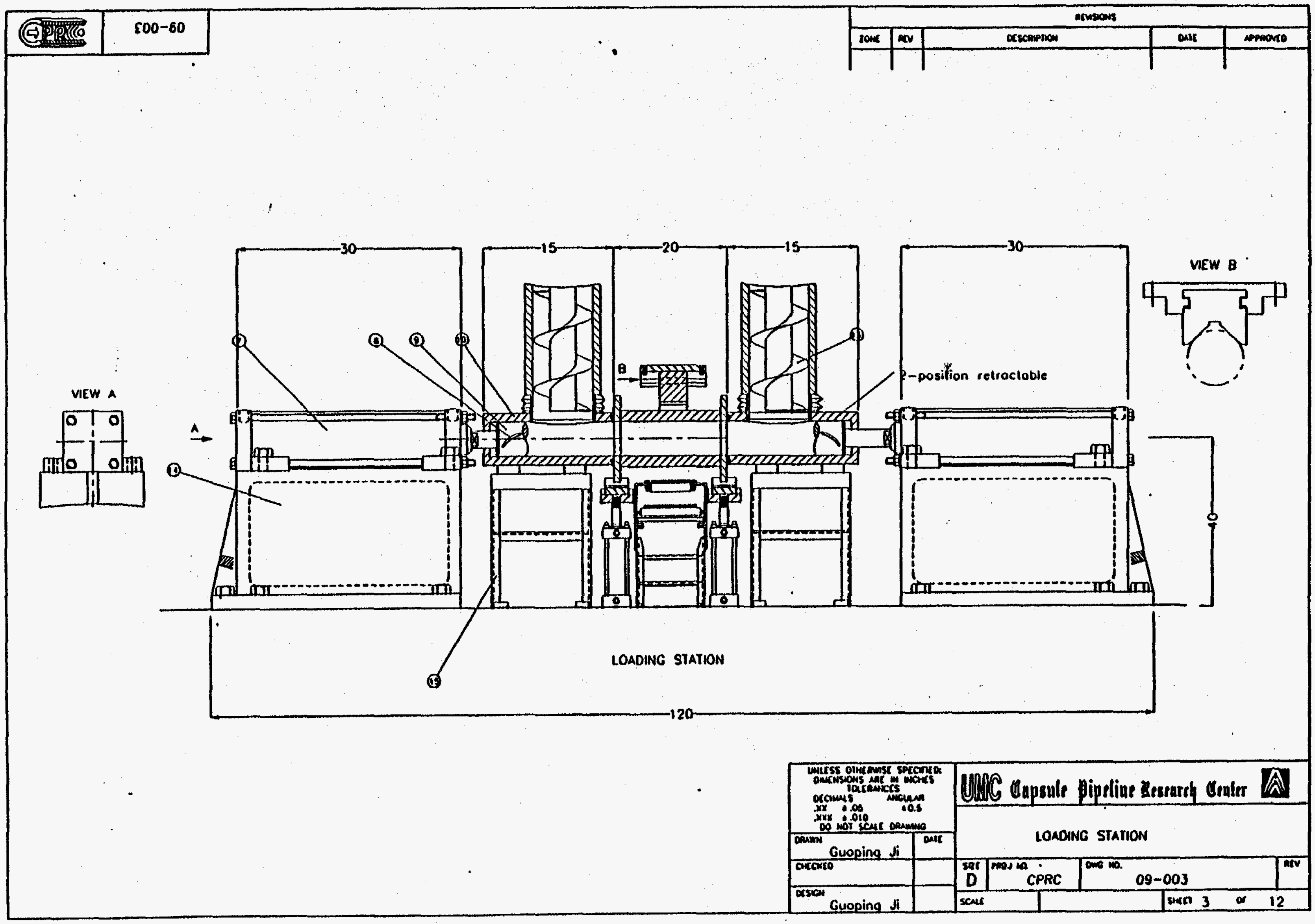
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30
40
120
2-position retractable
LOADING STATION
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS ANGULAR
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DO NOT SCALE DRAWING
DRAWN
Guoping Ji
DATE
CHECKED
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Guoping Ji
UMC Capsule Pipeline Research Center
LOADING STATION
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PROJ NO.
CPRC
DWG NO.
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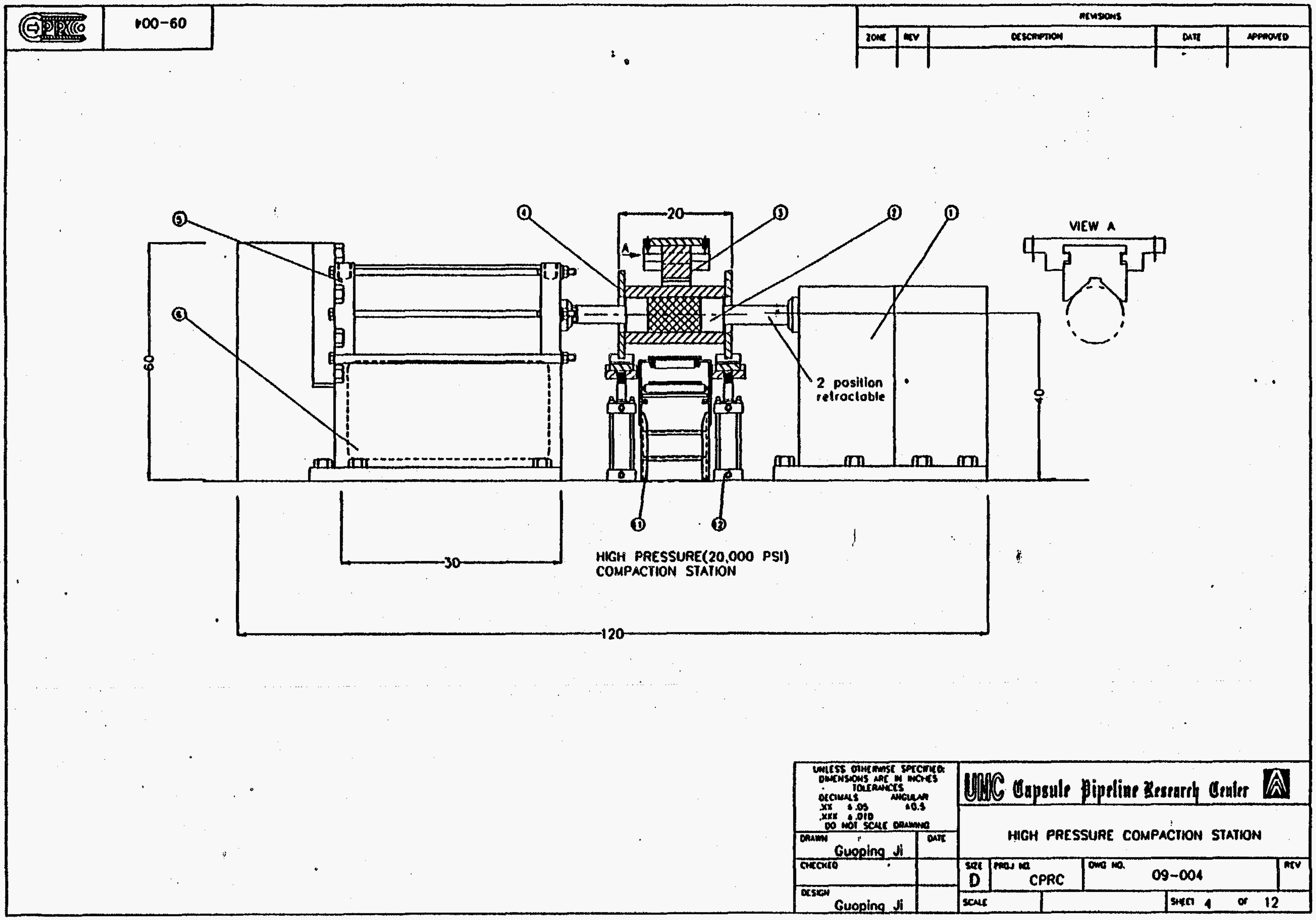
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120
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VIEW A
A
2 position retractable
HIGH PRESSURE(20,000 PSI) COMPACTION STATION
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS .XX ±.05 .XXX ±.010
ANGULAR ±0.5
DO NOT SCALE DRAWING
DRAWN Guoping Ji
DATE
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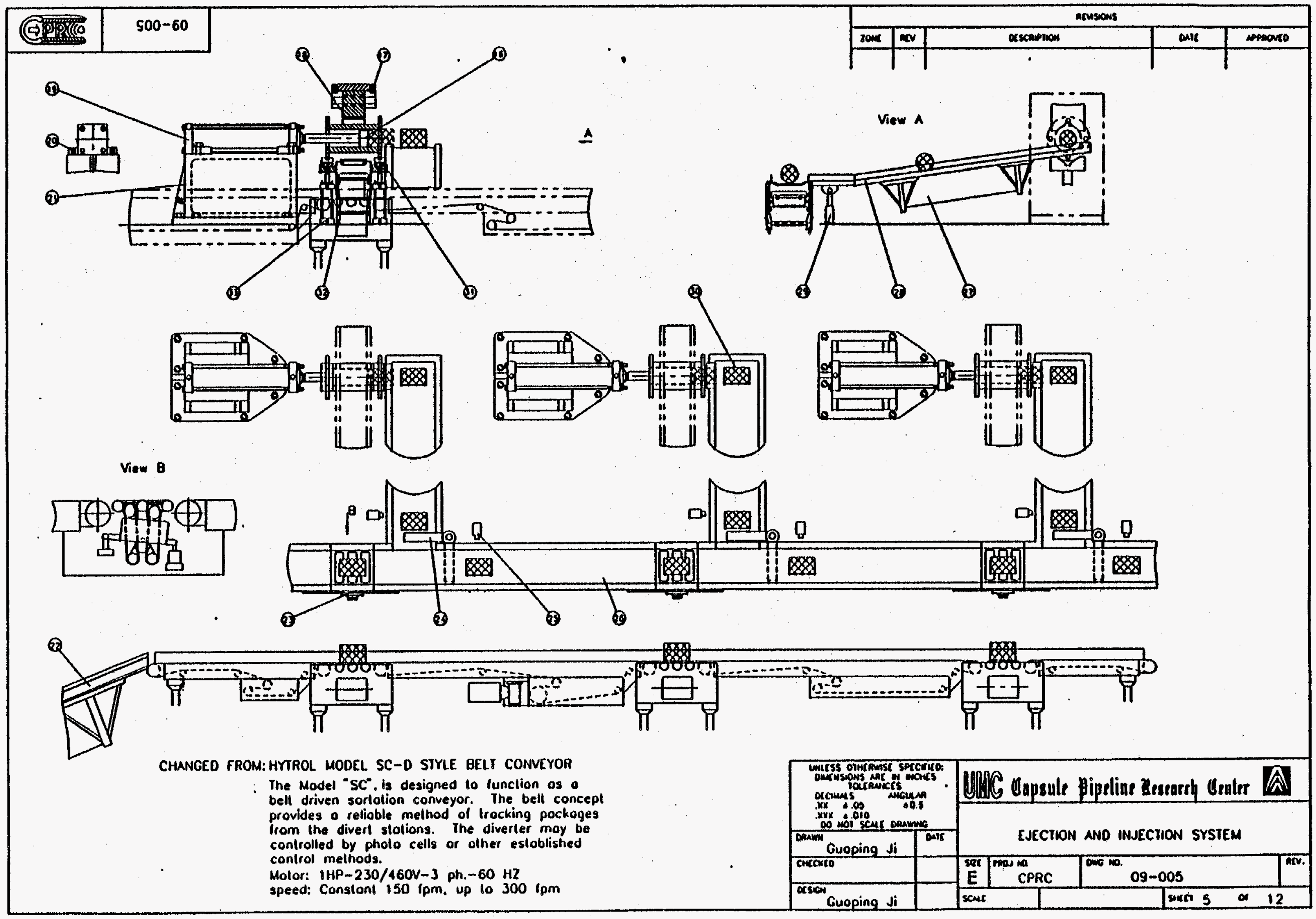
DESIGN Guoping Ji
UMC Capsule Pipeline Research Center
HIGH PRESSURE COMPACTION STATION
SIZE D
PROJ NO. CPRC
DWG NO. 09-004
REV
SCALE
SHEET 4 OF 12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View A
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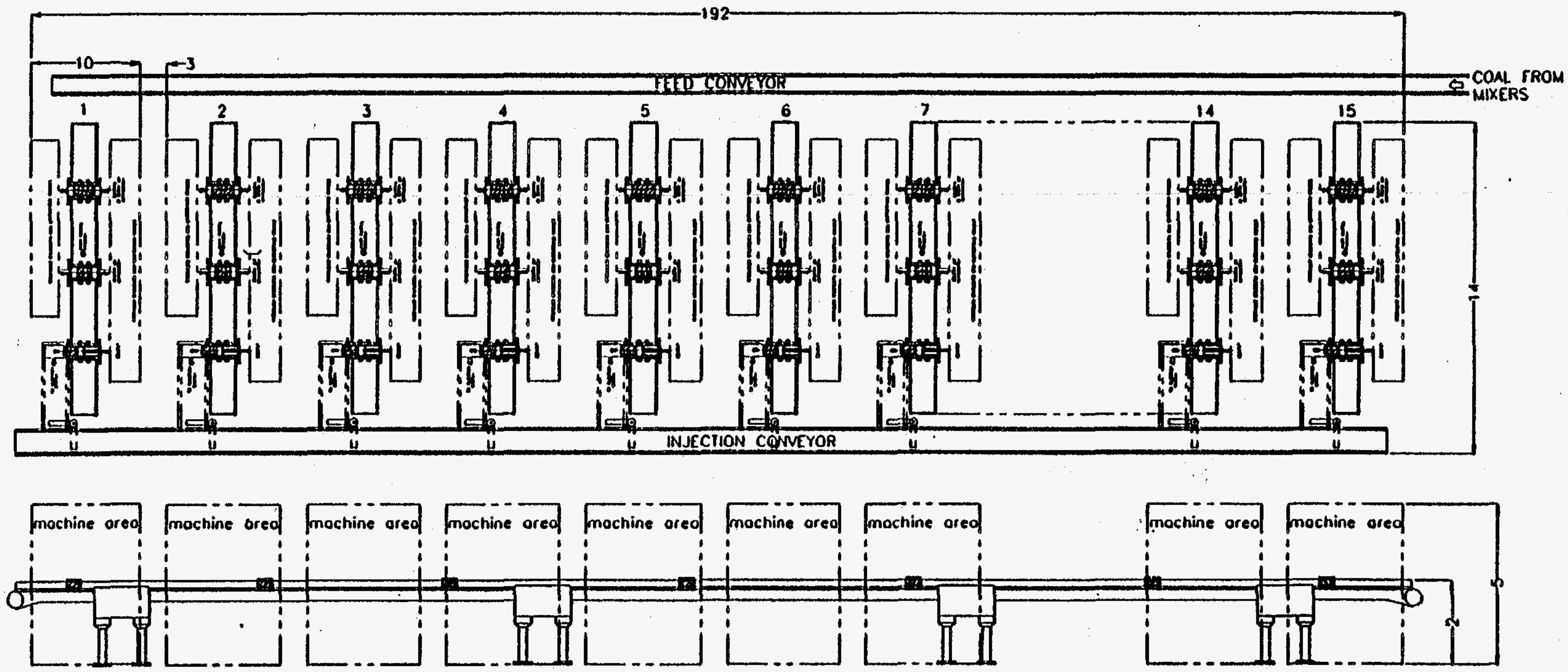
A
CHANGED FROM: HYTROL MODEL SC-D STYLE BELT CONVEYOR
The Model "SC", is designed to function as a belt driven sortation conveyor. The belt concept provides a reliable method of tracking packages from the divert stations. The diverter may be controlled by photo cells or other established control methods.
Motor: 1HP-230/460V-3 ph.-60 HZ
speed: Constant 150 fpm, up to 300 fpm
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMALS ANGULAR
.XX ±.05 ±0.5
.XXX ±.010
DO NOT SCALE DRAWING
DRAWN Guoping Ji
DATE
CHECKED
DESIGN Guoping Ji
UMC Capsule Pipeline Research Center
EJECTION AND INJECTION SYSTEM
SIZE E
PROJ NO. CPRC
DWG NO. 09-005
REV.
SCALE
SHEET 5 OF 12

900-60

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED



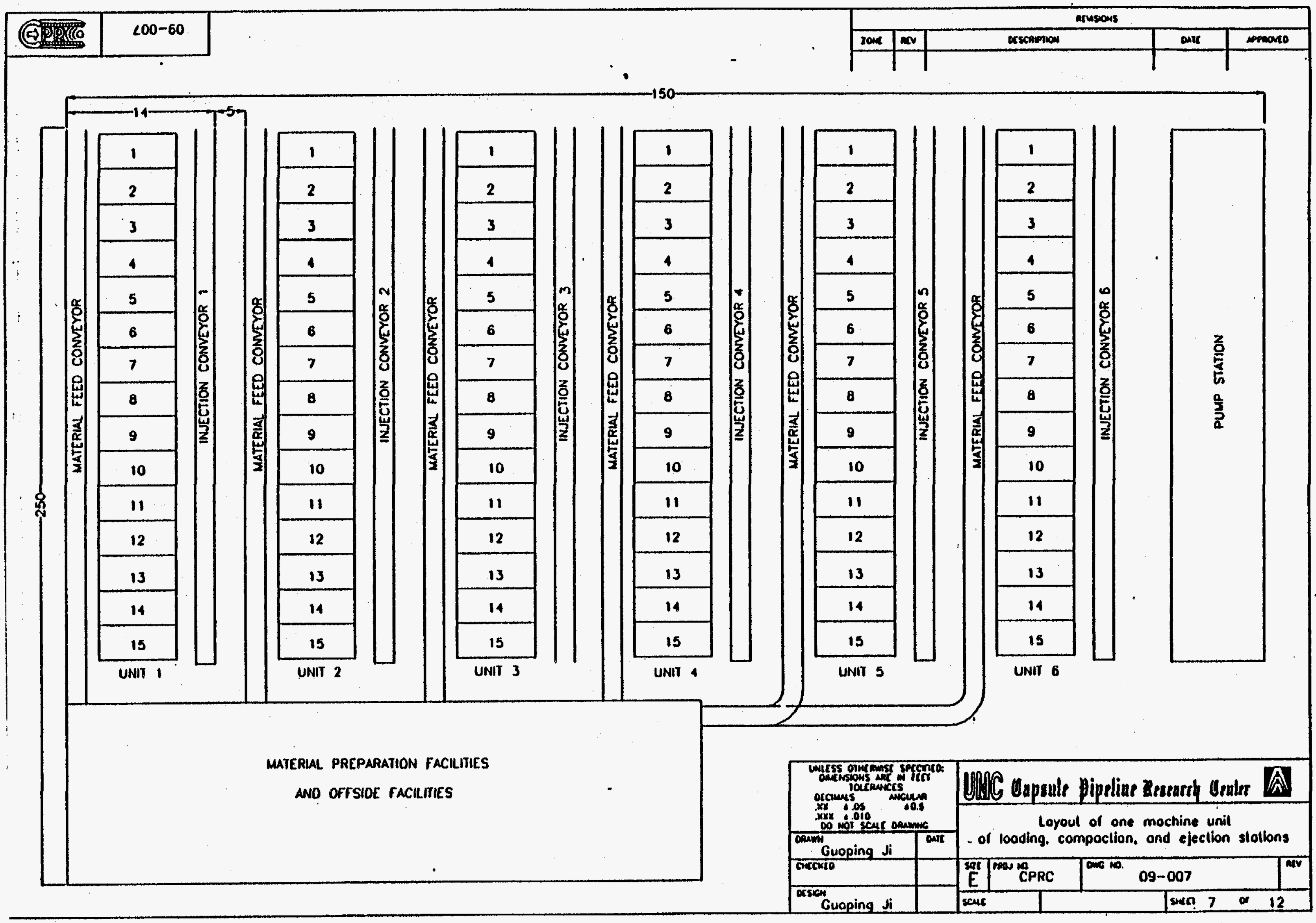
NOTE:
1. CONVEYOR: 300 FPM, 500 LB/FT, 3 HP, 14 INCH WIDTH, AND 200 FEET OVERALL LENGTH.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN FEET
TOLERANCES
DECIMALS .XX ±.05 .XXX ±.010 ANGULAR ±0.5
DO NOT SCALE DRAWING

UMC Capsule Pipeline Research Center

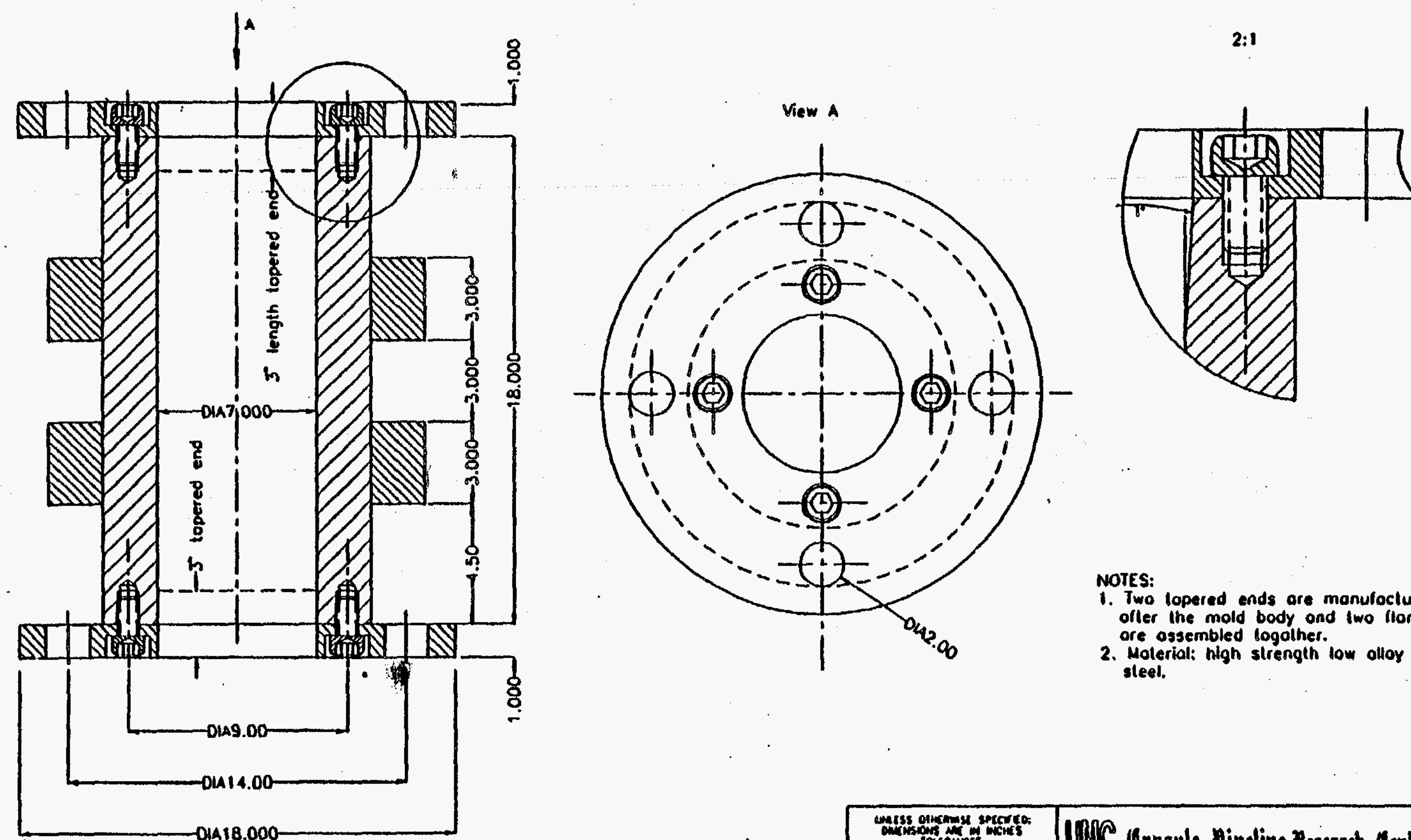
Layout of one machine unit of loading, compaction, and ejection stations

DRAWN: Guoping Ji	DATE	SIZE: E	PROJ NO. CPRC
CHECKED		DWG NO. 09-006	REV
DESIGN: Guoping Ji		SCALE	SHEET 6 OF 12


09-007
REVISIONS
ZONE
REV
DESCRIPTION
DATE
APPROVED
150
14
5
250
MATERIAL FEED CONVEYOR
INJECTION CONVEYOR 1
INJECTION CONVEYOR 2
INJECTION CONVEYOR 3
INJECTION CONVEYOR 4
INJECTION CONVEYOR 5
INJECTION CONVEYOR 6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
UNIT 1
UNIT 2
UNIT 3
UNIT 4
UNIT 5
UNIT 6
PUMP STATION
MATERIAL PREPARATION FACILITIES
AND OFFSIDE FACILITIES
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN FEET
TOLERANCES
DECIMALS ANGULAR
.XX ±.05 ±0.5
.XXX ±.010
DO NOT SCALE DRAWING
DRAWN Guoping Ji
DATE
CHECKED
DESIGN Guoping Ji
UMC Capsule Pipeline Research Center
Layout of one machine unit
of loading, compaction, and ejection stations
SIZE E
PROJ NO. CPRC
DWG NO. 09-007
REV
SCALE
SHEET 7 OF 12

CPRC	09-008

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED



NOTES:
1. Two tapered ends are manufactured after the mold body and two flanges are assembled together.
2. Material: high strength low alloy steel.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES DECIMALS .XX ± .05 .XXX ± .010 ANGULAR ± 0.5 DO NOT SCALE DRAWING	UMC Capsule Pipeline Research Center
DRAWN Guoping Ji DATE	MOLD ASSEMBLY DRAWING
CHECKED	SIZE B PROJ NO. CPRC DWG NO. 09-008. REV
DESIGN Guoping Ji	SCALE SHEET 8 OF 12

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Coverd: 1/1/95 to 3/31/95)

Project Title: Effect of Piston Modification on Capping

Principal Investigators: Dr. Henry Liu and Dr. Yuyi Lin

Research Associate: Rebecca Smith

Purpose of the Research:

Capping is a compaction phenomenon indicated by a thin end surface layer breaking away from the compact. In the literature, capping is generally attributed to entrapped air or to stresses produced by compaction. The purpose of this study is to investigate the effect of piston shape on coal log capping. Four piston shapes as shown in Figure 1 were used to compact coal logs.

Work Accomplished During the Period:

Twelve coal logs, three of each piston shape were compacted from MAPCO coal. The coal particle size distribution is given in Table 1. Compaction feed mixture contained 21% moisture (by total weight) and 2% asphalt (by dry coal weight). The asphalt binder was added in the form of Orimulsion, an emulsion containing 70% water and 30% asphalt.

Three batches of compaction feed for four logs each were prepared. One log for each piston shape was compacted from each batch. This procedure was adopted to minimize batch and tempering effects.

Coal logs were compacted at 20,000 psi and 97°C by the process shown in Figure 2. These compaction conditions were previously known to cause capping in flat-ended coal logs. The piston shapes shown in Figure 1 were used on the bottom of the compacted log. The top end of all coal logs was flat. The bottom end was the back end of the coal log during circulation. Coal logs were ejected hot immediately after compaction.

Each coal log was subjected to the 500 psi water absorption test for one hour and then to the circulation wear test. Results for the circulation wear test are shown in Figures 3 through 6. Figure 7 compares average weight loss during circulation for each piston shape. Table 2 summarizes the capping tendency observed in all samples. Only piston shape C, the shape producing a dimpled log, succeeded in reducing capping.

It should be noted that capping does not occur in fast compacted logs (30 sec compaction). A separate phenomenon called lamination occurs in fast compacted logs, producing cracks around the sides. Expansion of the coal log upon pressure release causes lamination. Typically, two cracks caused by lamination are observed on fast compacted coal logs, one approximately 1/2" from the bottom of the log and a second approximately 1" from the top. Occasionally, a fast compacted log will break at the bottom crack. Lamination also occurs for slower compacted logs, but the higher strength of slow compacted logs prevents breakage.

Future Plans:

Future tests for the dimpled piston are planned. Compaction using this piston shape at both ends of the coal log will be done. A series of experiments will be conducted to determine if the dimpled piston can also help reduce lamination under fast compaction conditions.

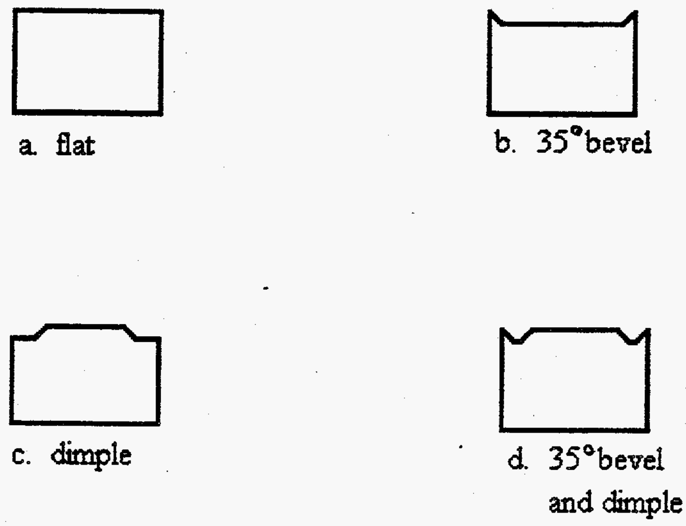


Figure 1: Piston Shapes

Table 1: Coal Particle Size Distribution

Passing Through Sieve	Retained On Sieve	Weight Percent
30	50	30
50	100	28
100	200	21
200	pan	21

Table 2: Summary of Capping Tendency

Piston Shape	Log	Comments
Flat	A1	Bottom capped after log ejection from mold Top capped during circulation
	A2	Bottom capped during circulation Top capped during circulation
	A3	Bottom capped during circulation Top capped during circulation
35° Bevel	B1	Bottom capped after log ejection from mold Top capped during circulation
	B2	Bottom capped after log ejection from mold Top capped after log ejection from mold
	B3	Bottom capped after log ejection from mold Top capped after log ejection from mold
Dimple	C1	Bottom did NOT cap Top capped during circulation
	C2	NO CAPPING
	C3	NO CAPPING
35° Bevel and Dimple	D1	Bottom capped after log ejection from mold Top capped after log ejection from mold
	D2	Bottom capped after log ejection from mold Top capped after log ejection from mold
	D3	Bottom capped after log ejection from mold Top did NOT cap

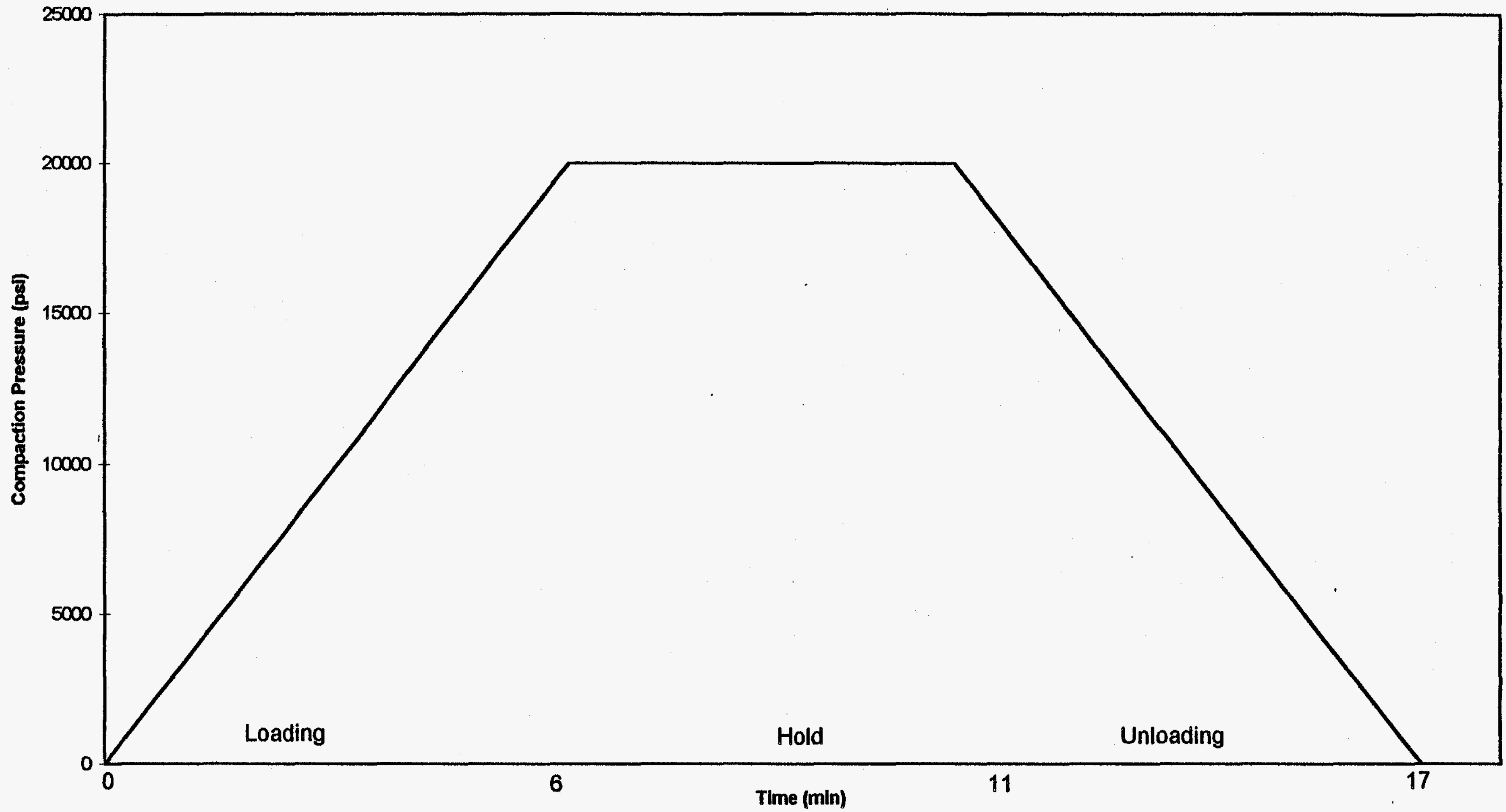


Figure 2: Compaction Process

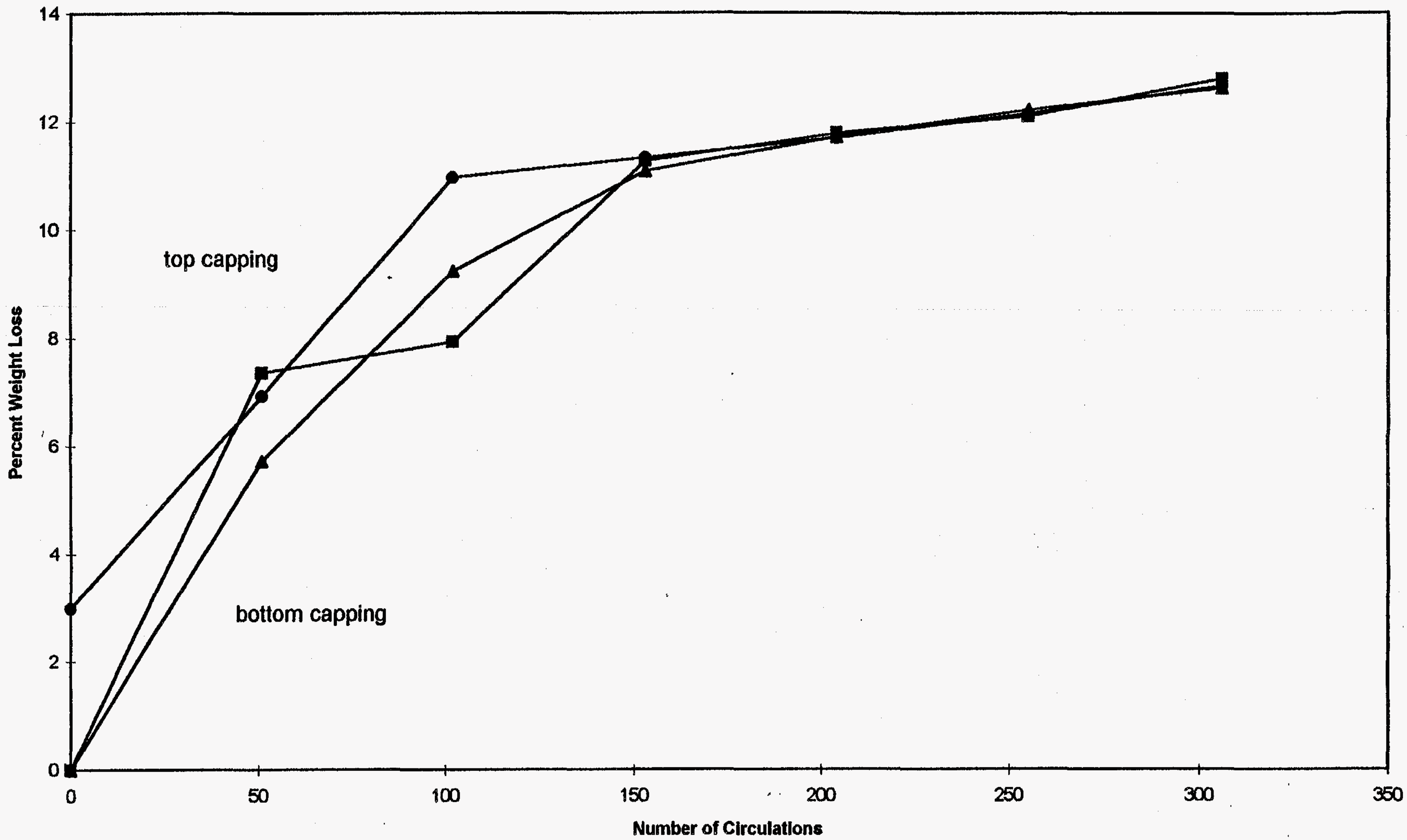


Figure 3: Circulation of Flat-Ended Coal Logs

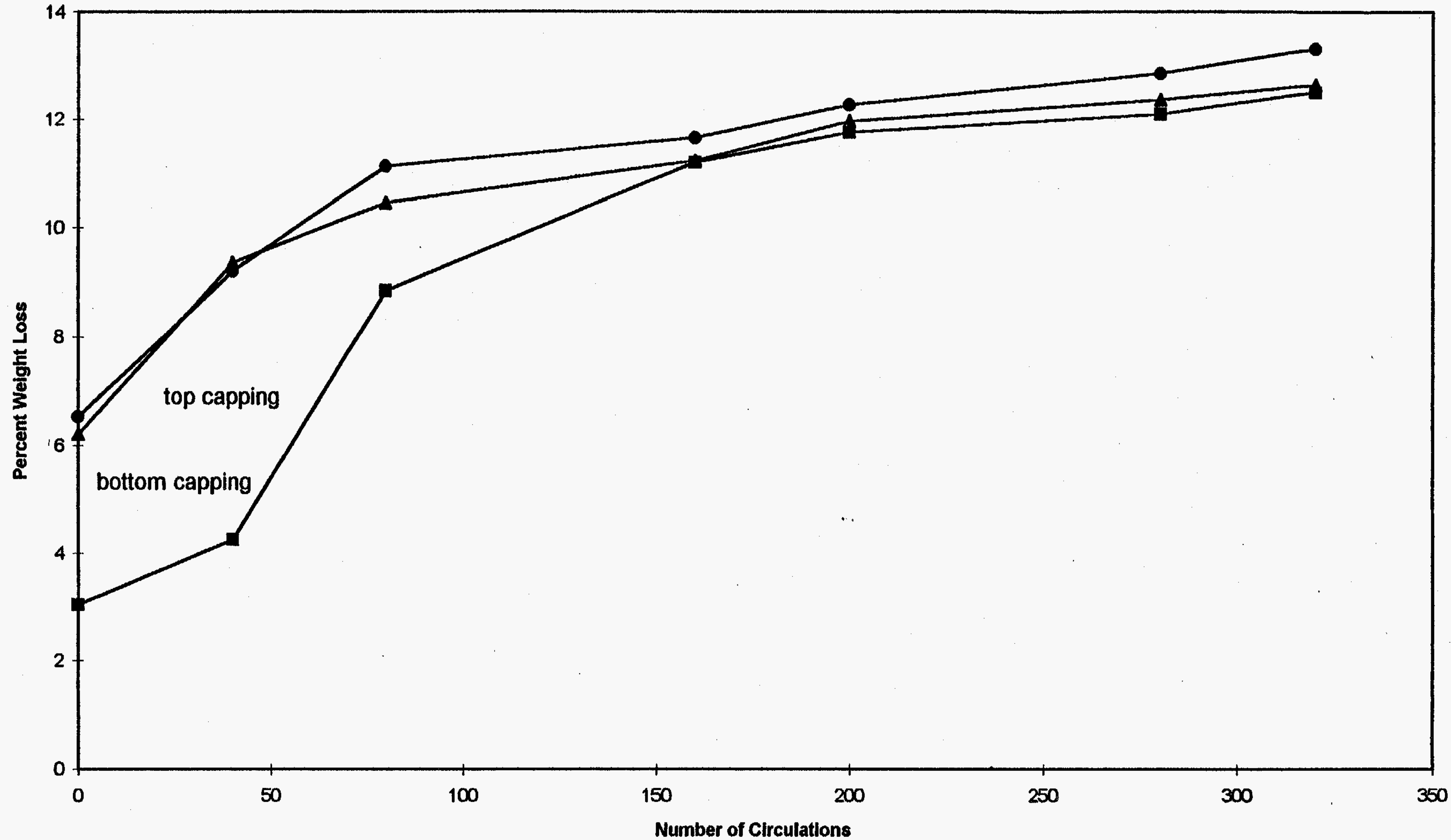


Figure 4: Circulation of 35° Bevel-Ended Coal Logs

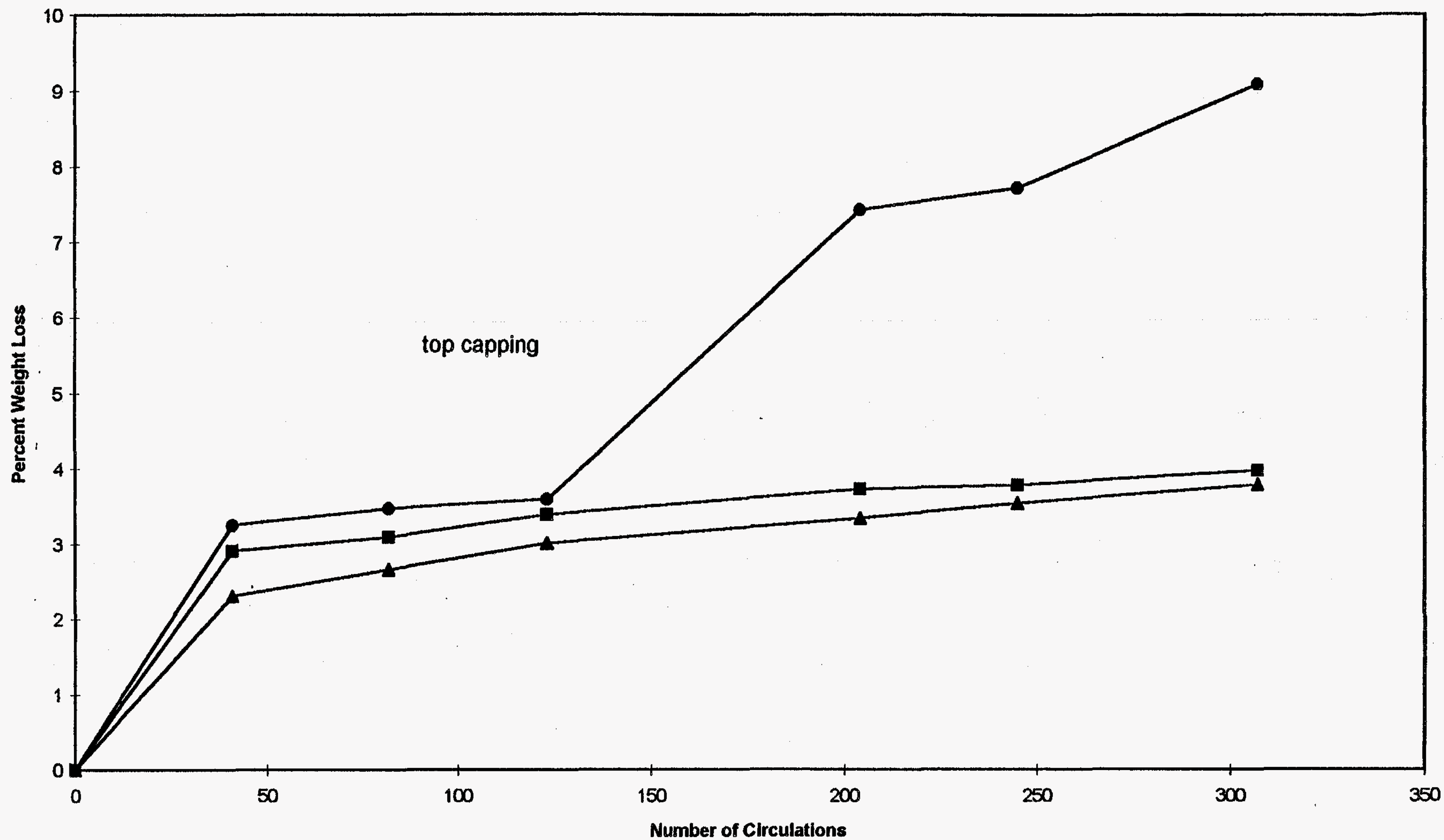


Figure 5: Circulation of Dimple-Ended Coal Logs

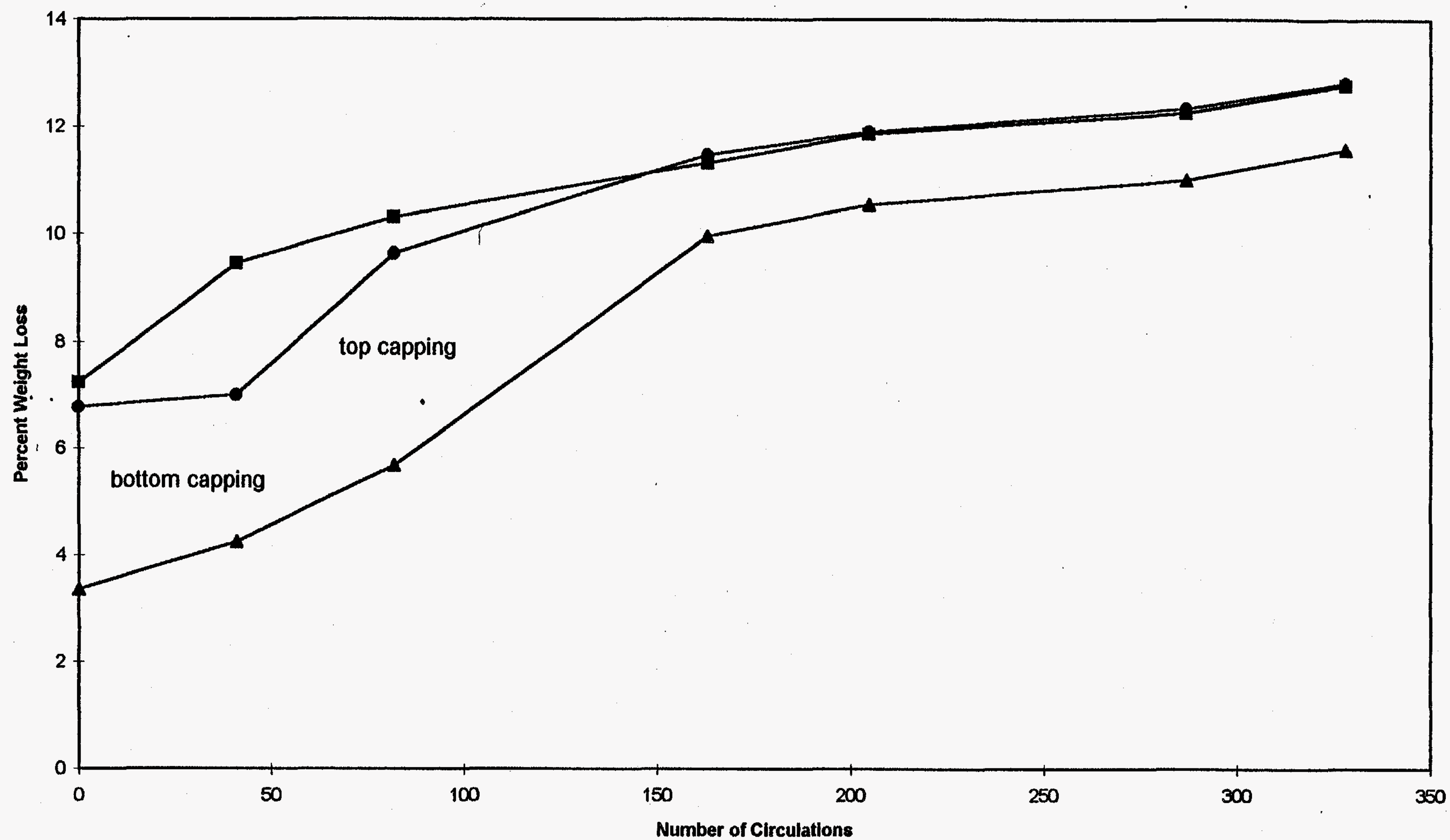


Figure 6: Circulation of Bevel and Dimple-Ended Coal Logs

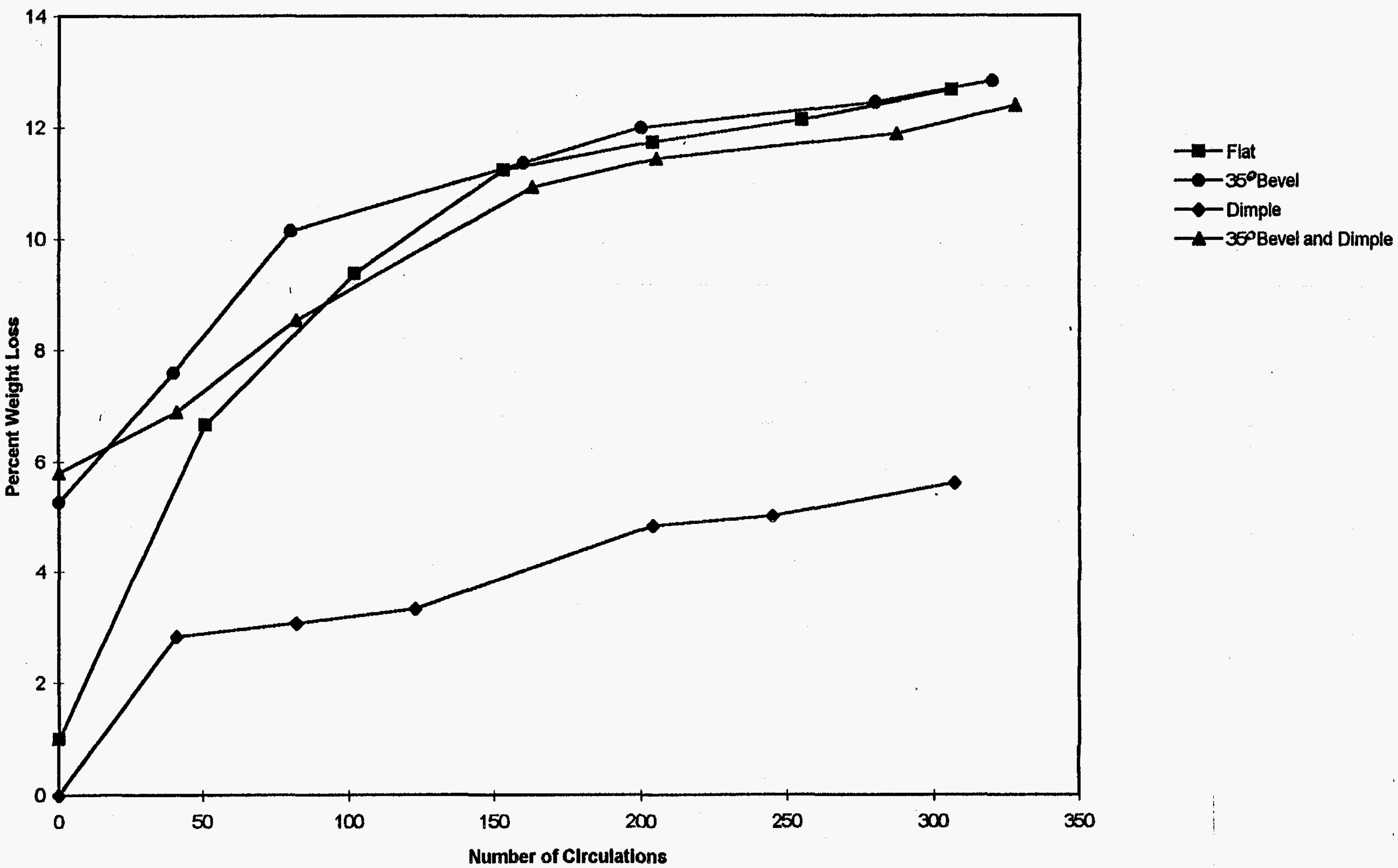


Figure 7: Comparison of Circulation Performance