Coal Log Pipeline Research at the University of Missouri

1st Quarterly Report for 1997
1/1/97 - 3/31/97

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PROJECT SPONSORS
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Executive Summary

During this 1st quarter of 1997 (1/1/97 to 3/31/97), significant progress was made in many fronts of coal log pipeline research, development and technology transfer including the following:

1. A set of revised (final) drawings on certain parts of the coal log compaction machine (250-ton press) was sent to the Gundlach Company in January. (Dr. Yuyi Lin and Kang Xue)

2. The coal log machine (250-ton press) is under construction at the Gundlach Machine Company. The machine is expected to be completed in May or June. (Gundlach Machine Company/Floproducts).

3. Design of the metal building to house the coal log machine (250-ton press), other compaction related equipment and the pipeline inlet/outlet has been completed, and bid specifications for this building are being prepared. (Burkett/Campus Facilities).

4. A preliminary set of equations for mathematical and computer modeling of the coal log compaction process has been derived. Plans to verify the equations through experiments have been made. Instrumentation for the tests have been prepared. (Dr. Yuyi Lin and Guoping Wen).

5. It was found that water temperature has a significant effect on coal log wear in pipe. More wear occurs when the water temperature is higher. This is good news because the water temperature in an underground pipe is expected to be relatively low. (Wei Li under Dr. Brett Gunnink).

6. The standard coal log compaction test has been conducted for a second time with improved results (supervised by Bill Burkett).

7. Tests were conducted to determine the effects of compaction pressure, binder concentration, binder-coal sample mixing time, compaction peak load time and coal log curing time. It was found that variation of pressure had the strongest effect on the tensile strength of the coal logs (Wilson/Zhao).

8. Practical experience has been gained in analyzing CLP effluent water, and dealing with regulatory officials on CLP effluent water discharge (Wilson/Pagano).

9. Costs of many items of the CLP Pilot Plant (6-inch-diameter pipeline 3,000 ft long recirculating loop) have been determined; pumps and pump seals have been selected; a clarifier for treating CLP effluent water has been selected; a sand bed has been designed to clean up the sludge discharged from the clarifier; detailed design of the diverters has been completed (Dr. Charles Lenau).

10. Much progress has been made in the preparation of the experimental set-up for testing Polyox drag reduction in CLP in the 8-inch-diameter test loop. The Polyox dissolution/injection tank has been built and tested. Test procedures for injecting and measuring Polyox concentration have been developed. Fluorescent dye (Rhodamine B) are being tested for possible use to determine Polyox concentration in water (Gangwei Wu under Dr. John Miles).

11. Hydrodynamic equations have been derived to determine the behavior of capsule trains entering and leaving a slope. A commercially available computational fluid dynamics (CFD) program (FLUENT) was used to determine the pressure field around a capsule in the turbulent regime (Xiang Gao under Dr. Henry Liu).

12. Five different biomass materials (sawdust, wood chips, alfalfa, soy bean hulls and cottonseeds) were compacted successfully into logs (1.94-inch-diameter solid cylinders) at room temperature without use of binder. Compaction ratios of these materials range from 2 to 8. The result looks promising (Chris Yates under Dr. Tom Marrero).

Future Research (Plan for Next Quarter):

1. Complete construction of the coal log machine by Gundlach Company, installation of the machine in Columbia, and preliminary testing--debugging (Gundlach Company).

2. Completion of the metal building to house the coal log machine (Campus Facilities).

3. Complete preliminary tests to check the equations for predicting coal log compaction, and revising of equations if needed (Dr. Liu/Gao).

4. Conduct a set of more detailed tests on the effect of water temperature on coal log wear and breakage in pipe (Dr. Liu/Tao).

5. Conduct rapid compaction test (3-second compaction time) by using the new 1.9-inch mold and the new alignment fixture (Dr. Gunnink/Li).

6. Compare small log wear (in Columbia) with large log wear (in Rolla) using logs made under similar conditions except for the size of the mold (Dr. Wilson/Zhao).

7. Complete design of the Pilot Plant pipeline system (Dr. Lenau).

8. Complete design and selection of the sensors and automatic control system for operating the pilot plant pipeline system automatically (Dr. Nair/Du).

9. Make resin logs for drag reduction study in 8-inch-diameter pipeline. Conduct drag reduction tests with Polyox, capsules but without fiber (Dr. Miles/Wu).

10. Complete CFD study of stationary capsule (comparing FLUENT results with Liu and Graze's 1980 measurements) (Dr. Liu/Dr. Miles/Gao).

11. Continue biomass study with an estimate of the compaction cost (Dr. Marrero/Yates).

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report
(Period Covered: 1/1/97-3/31/97)

Project Title: Machine Design for Coal Log Fabrication

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

Graduate Research Assistants: Guoping Wen (50% GRA support), Kang Xue (25% staff)

Purpose of Study:

The purpose of this project is to research and design fast and efficient machines for manufacturing high quality coal logs at low cost.

Work Accomplished During the Period:

We continue to work with the 250-ton press manufacturing contractor (Gundlach Machine Company) and the subcontractor (Floproducts), for construction of the hydraulic press. Based on the hydraulic system information we received, a revised and complete set of machine design drawings was sent to Gundlach in late January. The machine in the revised design is about two feet taller than in the original design due to increased length of the hydraulic cylinders. We have also provided to the manufacturer, for their reference and information, our design of the PLC control program. This program is part of Li's MS thesis [1996] work. Mr. Li graduated last December and is now working for the Caterpillar Company.

Experimental work, including fixture design and strain gage arrangement design, has been completed. Experiments to determine the compaction parameters will be carried out intensively during next 3 to 6 months. The purpose of the experimental work is to obtain constitutive parameters for the mathematical modeling of the coal log compaction process. The model will greatly enhance our understanding of the mechanics of the coal log compaction process, and help to improve compaction tools design. The tools include the mold and the compaction piston. A preliminary set of equations for modeling coal log compaction has been derived.

Future Plans:

In the next three months, the following research and development tasks will be carried out. Some of these tasks will take more than three months to complete.

Task 1--Mechanical and computer model of compaction process

Most work on mathematical modeling of the compaction of coal logs will be done in the next 3-month period. It includes conducting experiments to obtain modeling parameters, checking the correctness of the mathematical model (equations), and experimental verification of the model. The model includes three parts: mold, piston and coal log. Stress distribution and deformation of the mold and piston, although both are made of ideal elastic and metallic material, are related to the compacted log, and cannot be accurately described without the coal log model.

The current model is different from previous models [Cheng, 1994; Deng, 1995] in the following perspectives:
(A) Deng's model is one dimensional. The new model is three dimensional.
(B) Cheng's parameters for compaction were based on post compaction experiments. The new model emphasizes the variable parameter at different compaction pressure settings, especially at pressure close to 20,000psi.

It is important to include the optimal shape design for compaction tools (piston, mold, etc.) in this task. However, tool design cannot start until the model is well developed and verified. Currently, the focus is on the model development.

Task 2--Design of accessories and tools for the 250-ton hydraulic press

After the new compaction machine is installed, there will be needs for developing small to medium size tools and accessories for this new machine. For example, a work platform was designed in the past which now must be modified to suit the layout of the manufacturing shop.

Even if it is just for semiautomatic operations, some special material handling device must be designed and manufactured. For example, one of the commercial volume or weight measurement feeders may work better than the other with the coal mixture. They need to be tested, chosen, or modified for our purpose. There are many small devices, with various importance and priority for manufacture. This work is a continuation of the log conveyor design, log removal and material feeding subsystem design.

Task 3--Collecting performance data for future machine design

Each subsystem of the 250-ton hydraulic press, which itself is still under construction, has not been tested in an integrated machine. Some of these subsystems can be and will be used in future compaction machine design. As examples, the following performance evaluation and test data are very important:

(A) Measured by the quality of the compacted coal logs, is pressure control good enough? Do we want to test displacement control as well (which can be done by re-programming the PLC and PC)? The rate of compaction at high pressure may be important. Do we want to control compaction rate, in addition to pressure or displacement control?

(B) The response rate of the hydraulic power system is very important design information for future design, even if a rotary press type of machine is design. This is because rotary press may have hydraulic cylinders with large bores, large flow rate, and large valves.

(C) Most control functions are executed by the PLC (Programmable Logic Controller), which is likely to be used for future machines regardless of the types of the machine. We will need to re-program the PLC for some experiments, and test its interaction with the monitoring PC and various sensors and control valves in the system.

References:

Cheng, C. C., 1994, *Wear and Damage of Coal Logs in Pipeline*, Ph.D Dissertation, University of Missouri-Columbia.

Deng, Q., 1995, *Analysis of Coal Log Extrusion*, MS Thesis, University of Missouri-Columbia.

Li, H. C., 1996, *Research on Mechanical Design Methodology and Automation Tools with Application to a Hydraulic Press,* MS thesis, University of Missouri-Columbia.

Publications During this Period:

Lin, Y. Y. and **Xue, K.**, February 1997, "Revision and Engineering Changes made to the 250-ton Hydraulic Press," CPRC Report.

Lin, Y. Y. and **Xue, K.**, February 1997, "Revision of Coal Material Feeder for 250-Ton Hydraulic Press," CPRC Report. (12 drawings)

Wen, G. P. and **Lin, Y. Y.**, February 1997, "Determination of Constitutive Parameters for Coal Logs under High Pressure Compaction,"CPRC Report. (8 pages, 3 figures.)

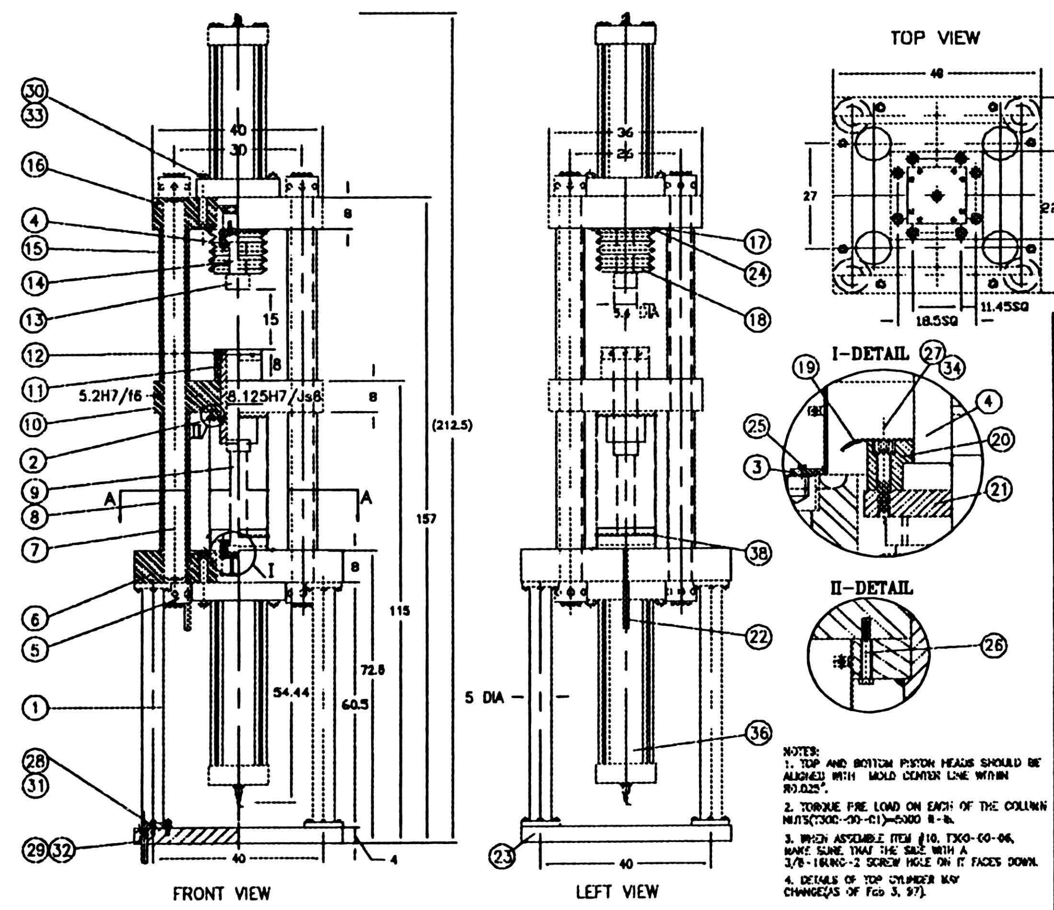
Wen, G. P. and **Lin, Y. Y.**, February 1997, "Determination of Friction Coefficient for Coal Logs under High Pressure Compaction,"CPRC Report. (16 pages, 11 figures.)

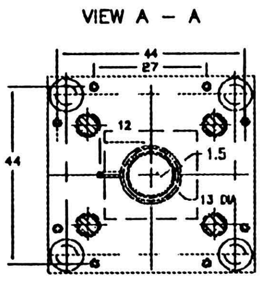
Wen, G. P. and **Lin, Y. Y.**, February. 1997, "Strain Measurement and Mold Wall Pressure Calculation using Finite Element Method," CPRC Report. (22 pages, 14 figures.)

Wen, G. P. and **Lin, Y. Y.**, March 1997, "Criteria for Determining the Effect of Tooling Profiles on Coal Log Quality,"CPRC Report. (8 pages, 4 figures.)

Lin, Y. Y., T. Marrero, Xue, K. and **Zhang, M. J.**, March 1997, "Research and Conceptual Design of a Rotary Press for the Fast Compaction of Powdered Materials," paper submitted to 2nd ICMH and 15th ICAW International Conference, Beijing, China. (5 pages, 6 figures.)

Lin, Y. Y., March 1997, "The Educational Benefit of Designing a 250-Ton Hydraulic Press for Compaction of Coal Logs," proceedings of the 32th ASEE Mid-West Section Conference, Columbia, MO.





NOTES:

1. TOP AND BOTTOM PISTON HEADS SHOULD BE ALIGNED WITH MOLD CENTER LINE WITHIN R0.025".
2. TORQUE PRE LOAD ON EACH OF THE COLUMN NUTS(T300-00-01)=5000 ft-lb.
3. WHEN ASSEMBLE ITEM #10, T300-00-06, MAKE SURE THAT THE SIDE WITH A 3/8-16UNC-2 SCREW HOLE ON IT FACES DOWN.
4. DETAILS OF TOP CYLINDER MAY CHANGE(AS OF Feb 3, 97).

No.	PART NAME	QTY	DWG. NO.	MATERIAL
39	PLAIN WASHER	64	3/4 N	STEEL STANDARD
38	CLAMP (Voss Industries INC)	2	TCS-1200(DIA=12)	STAINLESS STEEL(Purchased)
37				
36	CYLINDER DIA=12 STR=26	2	MILWAUKEE CYLINDER SPECIAL ORDER	
35				
34	PLAIN WASHER	16	5/8	STEEL STANDARD
33	SCREW NUT	16	2-8UN	STEEL STANDARD
32	SCREW NUT	8	1.25-8UN	STEEL STANDARD
31	SCREW NUT	64	3/4-10UNC	STEEL STANDARD
30	HEX SOCKET CAP SCREW	16	2-8UN L= 12	STEEL ASME B18.3-1986
29	HEX BOLT	8	1.25-8UN L=12	STEEL STANDARD
28	STUD-BOLT	64	3/4-10UNC L=2.5	STEEL STANDARD
27	HEX SOCKET CAP SCREW	8	5/8-11UNC L=3	STEEL ASME B18.3-1986
26	HEX BOLT	1	3/8-16UNC L=3	1040 STEEL STANDARD
25	HEX BOLT	16	3/8-16UNC L=1.5	STEEL STANDARD
24	HEX BOLT	8	3/8-16UNC L=1	STEEL STANDARD
23	BASE PLATE	1	T300-00-19	1020 STEEL
22	DRAIN PIPE	1	T300-00-18	STEEL
21	ADAPTER PLATE	2	T300-00-17	1045 STEEL
20	CLAMP RING	2	T300-00-16	4130 STEEL
19	DEFLECTOR	1	T300-00-15	RUBBER
18	COVER	1	T300-00-14	(PURCHASED WITH CYLINDER)
17	FLANGE	1	T300-00-13	1020 STEEL
16	TOP PLATE	1	T300-00-12	1020 STEEL
15	TOP SPACER	4	T300-00-11	1040 STEEL
14	TOP PISTON ROD	1	T300-00-10	4140 STEEL
13	PISTON HEAD	2	T300-00-09	4140 STEEL
12	MOLD NUT	1	T300-00-08	1035 STEEL
11	MOLD SPACER	1	T300-00-07	1035 STEEL
10	MOLD PLATE	1	T300-00-06	1020 STEEL
9	BOTTOM PISTON	1	T300-00-05	4140 STEEL
8	BOTTOM SPACER	4	T300-00-04	1040 STEEL
7	COLUMN	4	T300-00-03	1045 STEEL
6	BOTTOM PLATE	1	T300-00-02	1020 STEEL
5	SCREW NUT	8	T300-00-01	1045 STEEL
4	PISTON ASSEMBLY	1	T300-40-00	
3	DUST COVER	2	T300-30-00	
2	COMPACTION MOLD	1	T300-20-00	
1	BASE COLUMN	4	T300-10-00	

REVISIONS
DESCRIPTION
REVISION NO. 3 – 04/15/96
REVISION NO. 4 – 12/28/96
REVISION NO. 5 – 2/19/97

DRAWN Kang Xue	CHECKED Yuyi Lin	DESIGN Kang Xue Guoping Wen	SIZE A	DWG NO. T300-00-00	REV
DATE Dec 26,1996	DATE	DATE Mar 5,1996	SCALE	QUANTITY 1	

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
THIRD ANGLE PROJECTION

PART NAME
250-TON COAL LOG COMPACTION HYDRAULIC PRESS

MATERIAL DESCRIPTION

CAPSULE PIPELINE RESEARCH CENTER
UNIVERSITY OF MISSOURI-COLUMBIA
COLUMBIA, MO 65211

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 1/1/97-3/31/97)

Project Title:	Rapid Compaction of Coal Logs
P.I.:	Dr. Brett Gunnink, Associate Professor of Civil Engineering
Research Assistants:	Wei Li

Objectives of Study:

1. Explore the effect of compaction variables on the circulation performance of rapidly compacted coal logs.
2. Investigate size effects by comparing the performance of 1.9" diameter and 5.5" diameter coal logs
3. Develop model relating large and small log performance

Work Accomplished During the Period:

Mr. Wei Li continued learning how to make laboratory scale coal logs and continued developing a research plan for rapid compaction of coal logs. A fixture that allows the new self-aligning compaction mold to be used in the 300 kip rapid compaction press was completed. Mr. Li contributed to the coal log fabrication variability study conducted by Mr. Burkett. While learning to make coal logs, Mr. Li accidentally discovered that the used of the heat exchanger affected the circulation performance of coal logs significantly. After learning this Mr. Li completed small scale study of this effect.

Four batches of mixture were prepared. For all batches, the coal was Mettiki, the binder was 3% Orimulsion, the compaction temperature was room temperature, the compaction pressure was about 18,000 psi, and the compaction time was 30 seconds. First a control batch of three logs was made. After exposure to 500 psi water for 1 hour, the log were circulated in our laboratory test loop for 350 cycle with the heat exchanger turned on. Then two batches of three coal logs each were made. These logs were also exposed to 500 psi water for 1 hour and then circulated, but with the heat exchanger off. Figure 1 shows the variation in the water temperature in the test loop for operation with and without the heat exchanger on. It is clear that the temperature of the water is much higher when the heat exchanger is not used. After about 300 cycles, the water temperature in a stable 24.4 with the heat exchanger on. With the heat exchanger off, the water temperature is 35.7 °C and still rising. This rise in temperature adversely affects coal log performance. This can be seen from examining Figure 2. As can be seen form Figure 2, all logs circulated with the heat exchanger off broke after less than 300 cycles.

In contrast, none of the control logs, circulated with the heat exchanger on were broken after 400 cycles. Apparently, the elevated temperature of the water softened the coal logs and caused them to break prematurely.

Work Proposed for Next 6 Months:

Previously, we had demonstrated that we can make durable laboratory scale (1.9" diameter) coal logs using a compaction time of about 5 seconds. A paper describing this work was recently published (Gunnink and Yang, 1997). We are now somewhat redefining the objectives of this research. The future objectives are:

1. Explore the effect of compaction variables on the circulation performance of rapidly compacted coal logs.
2. Investigate size effects by comparing the performance of 1.9" diameter and 5.5" diameter coal logs, and
3. Develop model relating large and small log performance

We will meet these objectives doing the work described in the following paragraphs.

For all rapid compaction work we will use the Mettiki coal and Orimulsion binder. We will investigate the effects of varying coal top size, mixture moisture content, compaction temperature, binder concentration and log diameter. We will conduct more extensive parametric studies of these compaction variable with small diameter logs. We would like to be able to use small log performance for predict large log performance.

We will be able to begin the small diameter parametric studies immediately. We anticipate that we will begin making large diameter logs this summer. Within 6 months most of the small diameter work is expected to be completed and the large diameter work will predominate.

References

Gunnink, B.W., and S. Yang, "Rapid Compaction of Coal Logs for Coal Log Pipelines", Proceedings of the 22nd International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, Florida, March 16-19, 1997, 95-106

Figure 1- Variation of water temperature during circulation with and without the use of the heat exchanger

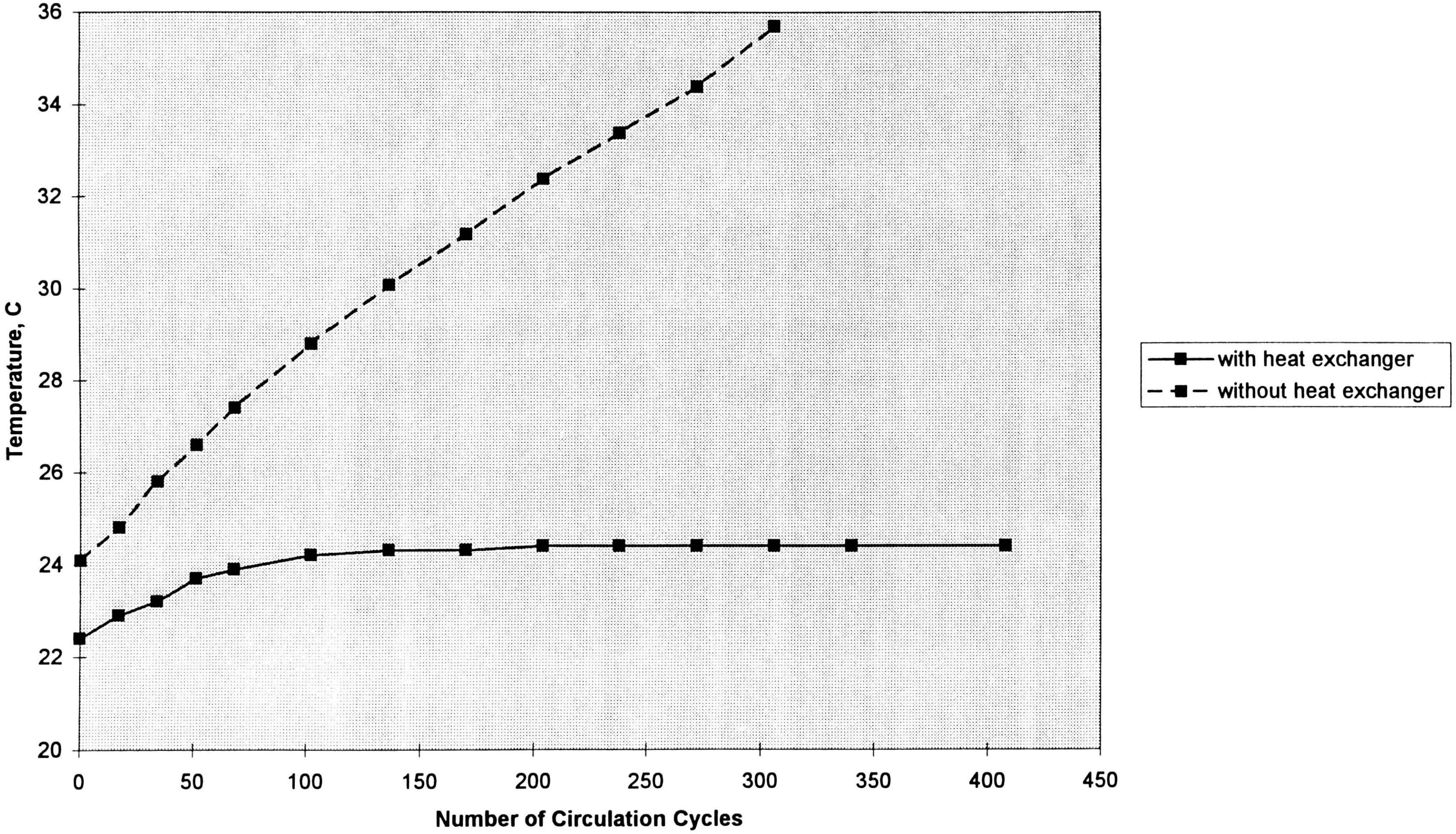
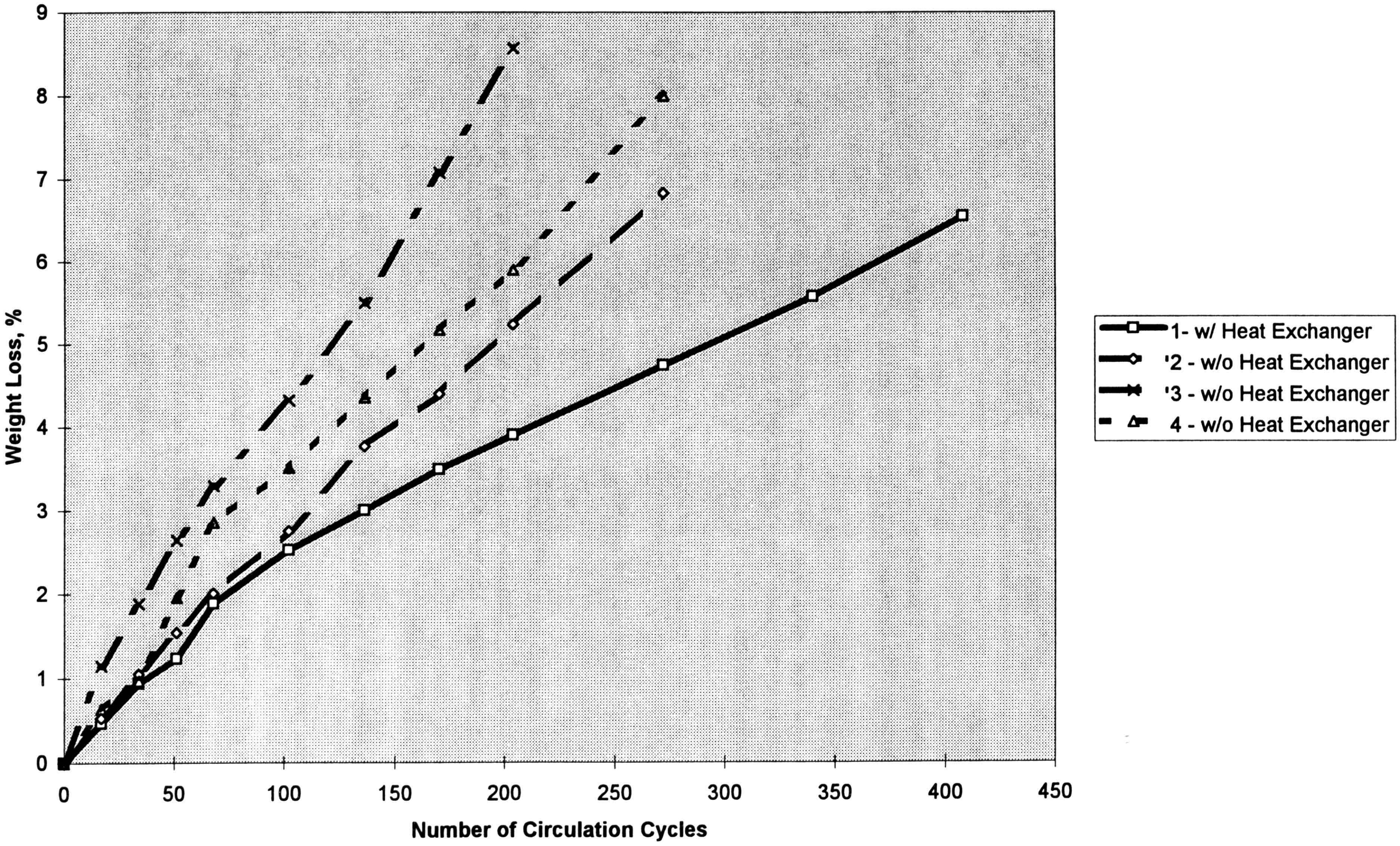


Figure 2 - Comparison of circulation test data with and without the use of the heat exchanger



CAPSULE PIPELINE RESEARCH CENTER

1997 First Quarter Report

Period Covered: January 1, 1997, through March 31, 1997

Project Titles: Coal Log Fabrication and Pipeline Transportation

Principle Investigator: Dr. John W. Wilson

Research Assistant: Bing Zhao
Nicole Pagano

Purpose of Study:

1. Develop standard test procedures for coal sample preparation and coal log fabrication and coal log characteristic measurement in order to match up the results from 1.8" and 5.4" coal logs.

2. Fabricate and test coal logs to predict the performance of coal logs for future commercialization, by examining the scale-up behavior of coal logs both in fabrication and pipeline transportation.

3. To develop a feasible method for treating and discharging effluent from the coal log pipeline.

Work Accomplished During the Period:

Coal Log Fabrication and Characteristic Tests

According to the research plan projected in the last quarterly report, 1.8" coal log characteristic tests were systematically conducted for the purpose of comparison with the tests that will be conducted on 5.4" coal logs. The test procedures and test results are summarized as follows:

A. Coal Sample Preparation

In order to effectively reveal the relationships between various test factors and eliminate the influences resulting from possible undetermined test conditions in the coal log fabrication process, the procedures for coal sample preparation and coal log compaction have been standardized so that they are in accord with the CPRC standard testing procedures. For the fabrication of 1.8" coal logs, the sample preparation procedure is described as follows:

1. The coal sample used for coal log fabrication is put in an oven, dried at least 24 hr. at over 100 °C until the moisture is removed. This eliminates the influence of moisture content on sample screening.

2. The dried sample is then screened into four groups with a top size of 30 mesh (0.6 mm in diameter), using No. 30, 50, 100, and 200 meshes of U.S. standard screens. The time for this screening is 10 min., and the portion of the sample with a particle size of +30 mesh is not used for testing.

3. The four separated sample groups are mixed in a determined fraction so that the maximum packing density of the particle distribution can be obtained. From the calculations, the coal particle distribution with the maximum packing density for a top size of 30 mesh falls into the following range:

Particle Size, mesh (mm)	Fraction, %
30 - 50 (0.600 - 0.300)	30
50 - 100 (0.300 - 0.150)	20
100 - 200 (0.150 - 0.075)	15
< 200 (< 0.075)	35
Mixture	100

4. The amount of water added for mixing the coal sample is 25% of the coal sample by weight. The water is first used to dilute the binder if a binder is used, and then the diluted binder is mixed with the coal sample at a pre-determined mixing time (variable) using a ketch mixer.

5. The amount of the mixed sample is weighed and is exactly the same for each coal log, and this weighed mixture is kept in a zip-plastic bag ready for coal log fabrication.

B. Coal Log Characteristic Test Procedure

According to a literature search and previous practice, the important factors that may affect the coal log strength and their test levels are chosen within the following range:

ksi

I. Binder concentration: 0%, 1%, 2%, 3%, and 4%.
II. Compaction pressure: 4 ski, 6 ksi, 8 ksi, 10 ksi, and 12 ksi.
III. Binder-coal sample mixing time: 1 min., 5 min., 10 min., 20 min. and 30 min.
IV. Compaction peak load time: 0 min., 0.5 min., 1 min., 5 min. and 10 min.
V. Coal log curing time: 0 hr., 1 hr., 8 hr., 24 hr., and 48 hr.

All other factors are kept as constants, including: particle size distribution, initial moisture content, water absorption time and condition and curing condition. 25 sets, consisting of a total of 75 1.8" coal logs, were made for investigating characteristics of coal logs made under various conditions. The uniform test procedures for coal log fabrication and various index measurements are described as follows:

1. The Orimulsion binder used for coal log fabrication was diluted using water before it was mixed with coal. The binder dosage was considered as variable No. I, ranging from 0% to 4% of the coal sample by weight.

2. Constant loading and unloading rates were used for coal log compaction. The compaction pressure was variable No. II, varying from 4,000 psi to 12,000 psi.

3. Binder-coal mixing time before compaction was considered as variable No. III, and ranged from 1 min. to 30 mins. The same amount of mixed sample was always used for different sets of logs.

4. Compaction peak load time was variable No. IV (level from 0 to 10 mins.).

5. After a coal log was taken out of the compaction mode, the weight, dimensions, and moisture content of the log was measured, the log was then left on a bench for curing test. The curing time was variable No. V, and varied from 0 to 48 hrs.

6. After curing, the coal log was weighed and then put in water (no pressure) for water absorption tests.

7. After the 24 hrs. water absorption test, the final weight, dimensions, and moisture content of the coal log was measured.

8. The splitting tensile strength of the coal log was conducted immediately after the water absorption test and referred to as the coal log characteristic strength index. The test was conducted as required in the Standard Test Method for an intact rock core specimen.

C. Test Results and Analysis

Table 1 summarizes the test results conducted of 1.8" coal log characteristic tests. The main output from the tests includes three indexes: tensile strength, specific gravity, and moisture content, i.e.:-

T.S.: Splitting tensile strength of a coal log after the water absorption test.
S.G.: Specific gravity of a coal log after the water absorption test.
M.C.: Moisture content of a coal log after the water absorption test.

The effect of various factors (five varied factors) on these three indexes, are discussed here and analyzed as follows:

1. The compaction pressure used to fabricate coal logs is the most important factor to affect coal log characteristic strength (tensile strength) among the five investigated factors. The

strength index almost linearly increases (see Fig. 1) with a slope of 1 to 5 when the pressure varied from 6 Ksi to 10 Ksi and when the other factors were kept at the middle values. After that point, the increase in rate in the strength gradually reduces. This suggests that the compaction pressure range of 6 to 10 Ksi can be used to effectively adjust the characteristic strength of coal logs.

2. There is an obvious strength difference between coal logs made using Orimulsion binder and without using any binder. A significant improvement in the coal log tensile strength (increase of more than 50%) was achieved when the binder percentage was increased from zero to 1% (see Fig. 2) and the other factors were kept at the middle values. On the other hand, when the binder was continuously increased from 1% to 4%, the strength index did not vary very much (from 31 psi to 36 psi). Another important effect of using a binder is on reduction of the final moisture content of the coal logs, and a noticeable moisture reduction was obtained even with only 1% binder (see Fig. 3).

3. Compared to the importance of pressure and binder, the other three factors, sample mixing time, compaction peak load time, and curing time, appeared secondary in improving the characteristic strength index of coal logs. These three factors can be considered as assisting variables for adjusting the coal log characteristic strength.

4. The curing time factor, showed a strong influence on reducing the final moisture content and decreasing the specific gravity of the coal logs (see Fig. 4 and Fig. 5). This finding will be important and helpful for increasing the output of a CLP system.

Coal Log Pipeline Effluent Treatment, Handling, and Discharge

A meeting with representatives from UMR Environmental Compliance was held on February 3, 1997. During this meeting a plan of action was developed to proceed with the pilot scale operation of the pipeline. The environmental related objectives, priorities, and goals for the project are outlined as follows:

1. Provide regulatory setting and direction for the pilot scale operations so that research can continue unhindered.
2. Define the applicable regulations.
3. Document all project activities.
4. Maintain compliance.

The meeting minutes are attached.

Although the pipeline was not operational during this period due to weather conditions, a sample simulating the possible effluent from the experimental coal log pipeline at UMR was prepared and shipped to MD Chemical and Testing for analyses on March 10, 1997. The sample was analyzed for volatile organic compounds, semivolatile organic compounds, metals, phenols, and cyanide based on the Priority Pollutant List. The results of these analyses will be utilized during development of the sampling and analysis plan for the remainder of the experiments to be carried out in the pipeline test loop.

The simulated effluent sample was developed according to the calculations below which assumes 15 percent log loss for 12 logs with 2 percent binder by weight. Fifteen percent log loss is a rough estimate of the log losses during early experimental trials of the CLP, final implementation will have significantly lower log losses. Table 1 presents the values of coal and binder necessary to mix one liter of the aforementioned simulated effluent. Five liters of simulated effluent was prepared and shipped to the laboratory for analyses. Due to difficulties in measuring the small quantities of binder used, a range of possible concentrations mixed and sent to the laboratory is presented in Table 2. The differences in concentration of the binder can primarily be attributed to balance accuracy during sample preparation.

Table 1: Simulated Effluent Concentrations of Coal Fines and Orimulsion® Based on Log Loss (wt.)

Mass of Coal Log	Concentration Orimulsion® by Weight	Percentage Lost by Weight	Mass of Log Particles Suspended in Water	Concentration of Coal Log in Water	Concentration of Binder in Water per Log		For 12 Logs	
(g)			(g)	(g/l)	(g/l)	(mg/l)	Coal Fines (g/l)	Orimulsion ® (mg/l)
3500	0.02	0.15	525	0.216	4.32E-03	4.32	2.59	51.9
Constants:								
	Volume of Pipeline (*l*)	2429						

Table 2: Range of Simulated Effluent Concentrations of Coal Fines and Orimulsion® Produced on March 10, 1997

Volume of Water	Mass of Coal	Mass of Orimulsion®	Concentration	
(*l*)	(g)	(mg)	Coal Fines (g/*l*)	Orimulsion® (mg/*l*)
5.2	12.9	300	2.5	58
5.0	13.0	400	2.6	80

Lab facilities are being prepared to perform analyses of several water quality parameters including but not limited to, pH, conductivity, and various metals. Additionally, requests for personnel and equipment possibly available through other departments at UMR and UMC is ongoing to aid in cost reduction of several of the other cost intensive analyses such as volatile organic compounds.

Sampling and analysis plans (SAPs) for lab scale water quality experiments are being developed. These experiments will be used to evaluate different remedial technologies, if required. Additionally, these analyses will be used to evaluate the changes in water quality dependent on coal log fabrication and various water to coal log ratios within the pipeline. The draft SAP will be reviewed and comments and suggestions incorporated into the final document

Draft standard operating procedures (SOPs) are being developed for sample collection, storage, and analysis for data quality objective (DQO) Levels II, III, and IV. The draft document will be reviewed and comments and suggestions incorporated into the final document.

Future Plans:

Work planned for the next quarter includes:

1. 2" coal log pipeline degradation test: Fabricate and conduct 1.8" coal log pipeline degradation tests in a 2" pipeline loop at UMC, so that the lowest distance-weight loss of coal logs can be obtained by optimizing the affected factors. The factors selected for the pipeline tests include: coal log characteristic strength index, coal log aspect ratio, and water flow velocity.
2. 5.4" coal log characteristic tests: Repeat the major experiments of the 1.8" coal log characteristic tests on 5.4" coal logs, and attempt to define a correlation between them by comparing the test results.
3. Bringing the CLP back online.
4. Installation of transducers and a data acquisition system for the CLP.
5. Completion of SAPs and SOPs.
6. Perform analyses on CLP effluent. If possible, determine a correlation between log loss and contaminant concentrations.

Table 1 1.8" Coal Log Test Data

Test	Varied Factors					T. S.	S. G.	M. C.
No.	I	II	III	IV	V	psi		%
1	1	1	1	1	1	55.80	1.2310	5.99
2	2	2	2	2	2	51.48	1.2327	6.51
3	3	3	3	3	3	36.45	1.2029	7.63
4	4	4	4	4	4	16.31	1.2440	12.11
5	5	5	5	5	5	10.06	1.2971	17.95
6	1	2	3	4	5	43.66	1.2947	11.39
7	2	3	4	5	1	32.58	1.1963	4.78
8	3	4	5	1	2	30.90	1.1831	4.20
9	4	5	1	2	3	21.41	1.1697	9.04
10	5	1	2	3	4	26.12	1.3190	13.88
11	1	3	5	2	4	35.33	1.2789	8.84
12	2	4	1	3	5	21.13	1.3046	15.79
13	3	5	2	4	1	15.22	1.1338	6.30
14	4	1	3	5	2	46.23	1.2004	5.50
15	5	2	4	1	3	26.66	1.3143	15.13
16	1	4	2	5	3	24.99	1.2453	11.08
17	2	5	3	1	4	18.87	1.2984	15.57
18	3	1	4	2	5	50.18	1.2794	9.54
19	4	2	5	3	1	46.49	1.1953	3.39
20	5	3	1	4	2	20.65	1.2756	13.44
21	1	5	4	3	2	20.88	1.1804	5.49
22	2	1	5	4	3	50.04	1.2469	6.18
23	3	2	1	5	4	40.87	1.2657	12.18
24	4	3	2	1	5	27.63	1.2970	15.95
25	5	4	3	2	1	15.11	1.2462	13.10

T. S. - Splitting Tensile Strength of a coal log after the water absorption test.

S. G. - Specific Gravity of a coal log after the water absorption test.

M. C. - Moisture Content of a coal log after the water absorption test.

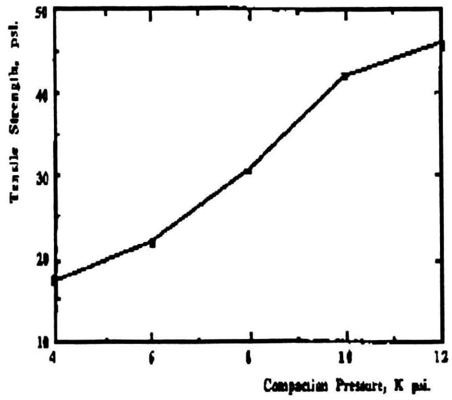


Fig. 1 Tensile Strength vs. Compaction Pressure

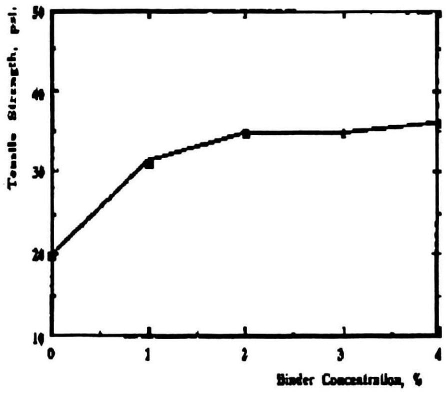


Fig. 2 Tensile Strength vs. Binder Concentration

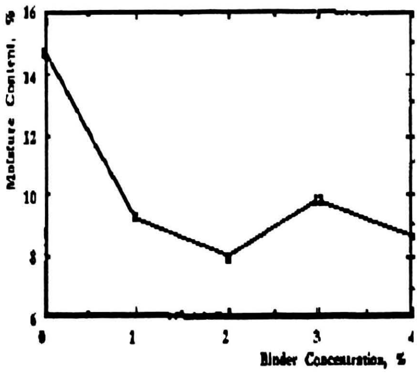


Fig. 3 Moisture Content vs. Binder Concentration

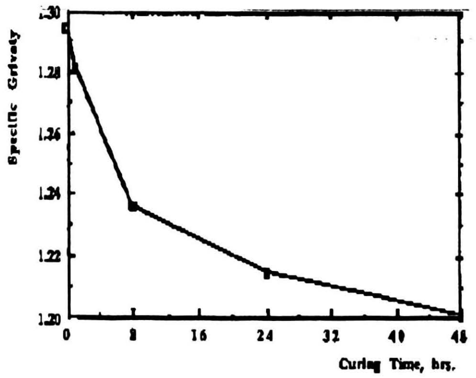


Fig. 4 Specific Gravity vs. Curing Time

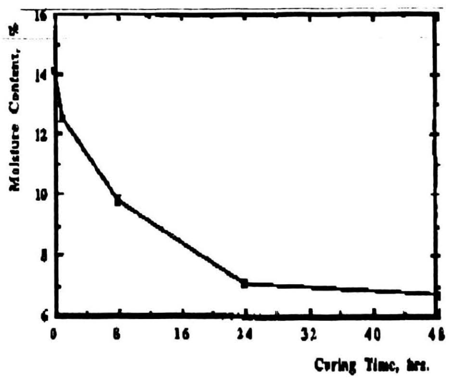


Fig. 5 Moisture Content vs. Curing Time

Coal Log Pipeline: Effluent Treatment, Handling, and Discharge
Environmental Compliance Meeting
Minutes

Date: February 5, 1997
1:30 PM
Location: Environmental Management
108 Campus Support Services
University of Missouri - Rolla
Attendees: Suha Aksoy, UMR Mining Engineering Department
Nicole Pagano, UMR Mining Engineering Department
Paul Sherod, UMR Environmental Management

A very productive meeting was held between Environmental Management and UMR CPRC. There was a substantial exchange of information, ideas, and suggestions. The following is a summary of the topics reviewed and discussed.

Ms. Pagano outlined the goals of the project and the various scales which are under consideration. Differences in regulatory setting between bench, pilot, and commercial scale operations are expected. The priority is to provide regulatory setting and direction for the pilot scale operation so that research can continue unhindered. The bench and commercial scale operations will be considered as deviations from the pilot scale.

Following discussion of goals, Ms. Pagano outlined projected experiments for evaluation of pilot scale operations. The projected experiments and analyses are attached with the expected data quality objective (DQO) level indicated. Mr. Sherod stated that a yet to be determined number of samples will be required for analyses by a certified laboratory for compliance. The required DQO level may be Level IV for these samples. Any other samples for project evaluation can be run at a DQO level deemed applicable by the project team. Since the possible regulated substances are known from the MSDS sheets on Orimulsion®, the required analyses should only include tests for these substances. Mr. Sherod will consult with Ms. Powell and potentially Missouri Department of Natural Resources (MDNR) to determine the required analyses and DQO level for compliance.

During discussion of the above, the issues of contamination levels of the coal log pipeline (CLP) effluent were discussed. Preliminary figures indicate that the CLP effluent may contain contaminants (most likely volatile organic compounds (VOCs)) which may exceed regulatory levels. There are three possible scenarios which are outlined below:

> *Case I: CLP Effluent Concentrations Exceed Regulatory Levels Immediately*
> Mr. Sherod pointed out the salient fact that if these levels exceed the surface discharge limits for the State, a secondary containment system and a spill prevention, control and countermeasures (SPCC) plan will likely be required. Obviously, this would have significant cost impacts to the project, subsequently this should be evaluated first to consider the viability of the project.
>
> *Case II: CLP Effluent Concentrations Exceed Regulatory Levels at an Undetermined Coal Log to Water Ratio*
> If the effluent in the pipeline does not exceed these regulatory limits until used for a given length of time (or certain volume of logs are run) then the best alternative may be to discharge the effluent prior to exceeding these limits and use fresh water for further runs. Although secondary containment would not likely be required in this case, a SPCC plan would probably be required.

Case III: CLP Effluent Concentrations Do Not Exceed Regulatory Levels
This is obviously the best case situation but is not expected.

Effluent from Cases I or II will be used to evaluate potential treatment technologies. Pending these findings, the preferred final disposal would be surface discharge if possible.

Mr. Sherod and Ms. Pagano concurred on the importance of documenting all activities and plans appropriately. Ms. Pagano will continue to draft a sampling and analysis plan (SAP) and standard operating procedures (SOPs) for the project. Additionally, Ms. Pagano will draft a SPCC plan to meet the required regulatory standards. These documents will include required site activities (log book, decontamination procedures, etc.) and documentation to meet applicable regulations.

In view of the implications of Case I, the projected lab tests will focus on evaluating the worst case scenario first. Mr. Aksoy and Ms. Pagano plan to take samples of the Orimulsion® and diluting with water to concentrations expected in the CLP for analysis. After evaluation of these samples, a conclusion may be drawn regarding which case is applicable.

Ms. Pagano outlined plans to test potential remedial technologies to treat effluent. These methods include, but are not limited to the following:

- Solids removal/reduction for recycling of water (pilot & commercial scale)
    - Bag filters or other mechanical methods
    - Chemical methods
- pH adjustment

Mr. Sherod noted that any of these methods were acceptable for evaluation provided that only samples for evaluation were removed from the site. Any wastes, such as contents of bag filters, could not be removed unless appropriately disposed of through Environmental Management.

Mr. Sherod will forward copies of the laboratory analytical results of the samples that were collected after the accidental release of effluent from the Primary Holding Tank discovered on November 5, 1996. ~~This release was reported to MDNR along with the results. MDNR chose~~ to take no action regarding this issue.

CAPSULE PIPELINE RESEARCH CENTER
Quarterly Report
(Period Covered: 1/1/97 to 3/31/97)

Project Title: Biomass Compaction
Principal Investigator: Thomas R. Marrero,
Associate Professor of Chemical Engineering
Graduate Assistants: None
Undergraduate Assistant: Chris Yates

Purpose of Research:

To determine the technical and economic potential for biomass compaction to transport densified material by truck or railroad.

Work Accomplished:

Five types of biomass materials (alfalfa, sawdust, wood chips, cotton seed and soy bean hulls) were obtained and they were compacted using standard coal log procedures for single sided compaction. No binders or heat treatment was used; the biomass was compacted at room temperature. In addition, the handleability of the biomass logs was quantified by use of the ASTM (D-440-86) procedure, the drop test. Calculations were initiated of the cost savings for shipment of densified materials compared to raw materials.

The compaction results are presented in Figure 1. This figure shows the compaction ratios, or density ratio, which is defined as the ratio of the density of the biomass log to the density of the raw material, as received. Alfalfa has the greatest compaction ratio (≈7), and soy bean hulls the least (≈2). The biomass log densities are relatively independent of compaction pressure, from 5,000 to 20,000 psi.

The densified biomass are all handleable, or hold together, except for soy bean hulls, based on the drop test results.

The amount of energy required for compaction is about 0.2 per cent of the total energy in the log. The biomass log energy was experimentally determined (at Rolla) for three different biomass materials. The energy contents were over 7,000 Btu/lb.

Future Work:

During the next quarter at least two other biomass materials will be compacted, switchgrass and waste paper. The calculations of potential net transportation cost savings will be completed.

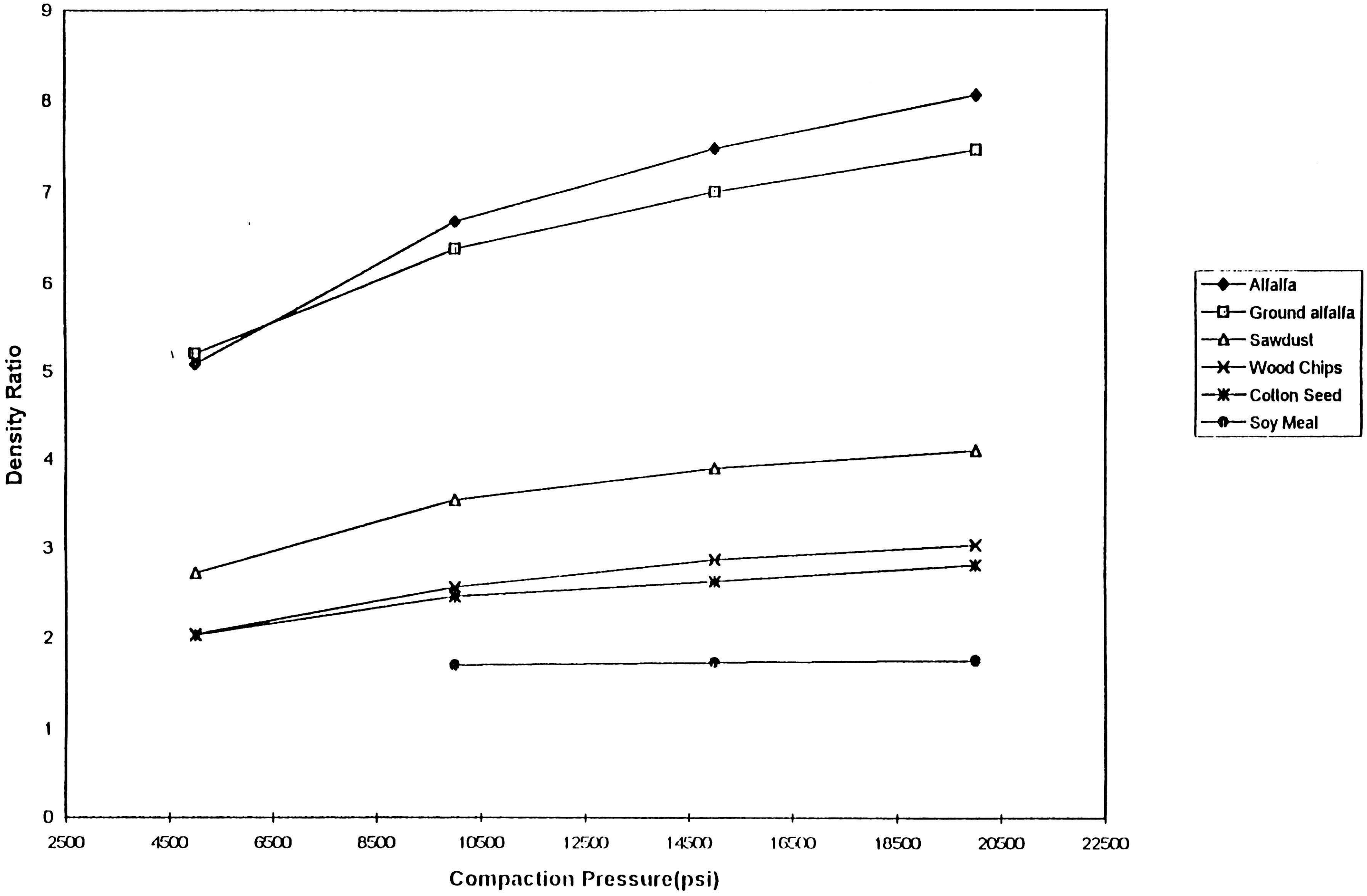


Fig. 1 Compaction Ratios (Density Ratios) of Biomass Materials

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 01/01/97-03/30/97)

Project Title: Design of a Demonstration/Test Pipeline

Principal Investigator: Charles Lenau

Co-Investigator: Henry Liu

Purpose of Study:

The purpose of the study is to design a test loop for conducting coal log degradation studies. This test loop is to have pump bypass and injection systems similar to those needed for a commercial coal log pipeline. The total length of the loop is to be approximately 3000 feet with a nominal diameter of 6 inch. The coal logs are to be produced by a machine which can produce up to 100 logs per batch.

Work Accomplished during Period:

In previous periods, the design was finalized to one that contains one injection lock, a pump bypass and an injection system. Provisions for the pressure treatment of the coal logs prier to their circulation in the loop is also included.

During the last period the writer has worked on floor layout and has collected cost for the multitude of items contained in the design. Pumps and pump seals for the five pumps required by the design have been selected. Valves and valve actuators have also been selected. A clarifier has been selected to reducing coal finds in the water before returning it to the sump. A sand drying bed has been designed to clean up the sludge discharged from the clarifier. In addition a detailed design of the diverters has been completed.

Future Plan:

The first priority will be to obtain the total cost of the project. Hopefully this can be accomplished by July 15, 1997. The second priority will be to complete detailed drawing of the project including detailed drawing of the diverters, diffusers air chambers and the Y junctions. Before final dimensions of the air chambers can be completed, new dynamic simulations are needed because some changes have been made in the design layout since the completion of the last simulations. Lastly, the specifications and document must be completed.

Capsule Pipeline Research Center
Quarterly Report

(period covered: 1/1/96 -- 3/31/97)

Project Title: Drag Reduction in Large Diameter Hydraulic Capsule Pipeline

Principal Investigator: John B. Miles
Professor of Mechanical Engineering
Co-Investigator: Henry Liu
Professor of Civil Engineering
Research Assistant: Gangwei Wu

Work Accomplished in this Period:

Efforts made on this project in the past three months focused on the issue of Polyox solution production and injection. Concentrated Polyox solution was successfully produced using the constructed tank. In addition, considerable attention was paid on how to achieve a more practical, more economical and more flexible Polyox injection design.

The Polyox production tank was built and set up in the Hydraulic Lab by MAE shop personnel according to our design. This tank, connected to a high pressure water source, employs a vacuum pump to form the desirable partial vacuum (~0.5 atm) condition for better and more efficient Polyox dissolution. When Polyox particles are injected into the vacuum tank through an injector, water is also passed into the tank through four nozzles to form a strong vortex for better agitation. After practice, a 43 gallon Polyox solution was successfully produced with the concentration of about 700 ppmw. This implied that the vacuum-aided Polyox solution production method is efficient and good enough in large scale equipment for mass solution production even without the aid of mechanical agitation.

However, one accident occurred to this tank when water was being filled into the tank for cleaning. As a result of the unanticipated high pressure from the water-feeding pump, a quick air pressure build-up in the tank and because of the insufficient capability of the air passing valve, the tank top lid was blown off on one side by the tank compressed air and was fairly bent. To prevent this from happening again, some measures were proposed and a modified tank will well serve the future experiments.

Work with respect to Polyox injection is of theoretical considerations. Two methods named as constant injection and slug injection, respectively, are suggested, considered and discussed in detail. The method of constant injection of Polyox solution aims to achieve constant injection rate by setting a proper tank air pressure corresponding to a particular experimental run. The principal disadvantage associated with this method is the concentration difference due to capsule presence. This is so, because at the moment when capsules are passing through the injection point, there is less water for the concentrates to dilute. Although the concentration difference due to capsules presence will become much less significant when capsules reach the test section as a result of mixing on their way to the test section due to turbulence, diffusion, and the velocity difference between capsule and water flow, the real concentration difference is hard to be determined either theoretically or experimentally, which may consequently put the research in a dilemma when analyzing the optimum concentration for drag reduction. This concern led to the appearance of slug injection method.

Opposed to the constant injection design in which the injection is restricted for solution to cover only 140 feet of the total pipeline, the slug injection method will allow the injection to proceed until the Polyox solution front is back to the injection point and the whole pipeline is full of dilute Polyox solution. After the injection stops, the main pipe solution will be circulated several cycles at low velocity before it is accelerated to the experimental velocity and the data acquisition begins. The main credits of the slug injection method is that the main pipe Polyox solution can be reasonably regarded as uniform. Capsule presence dose not change the concentration distribution. However, Polyox degradation exists since the solution has gone through the jet pumps several times. Consequently, only a conservative instead of the maximum drag reduction can be obtained.

Since each method owns some credits and somehow affects the on-site installation and setting-up of the injection facilities, a more practical and flexible facility arrangement and setup design was proposed to test the slug injection method first but without giving up the constant injection design.

Work Planned for the Next Three Months:

1. Relocate the Polyox production and injection tank to the Civil Engineering Freight Pipeline Research Laboratory at the University Research Park. Install the injection facilities according to the design.

2. Take data from experiments with water only, water/logs flow and water/polymer flow.

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report
(Period Covered: 1/1/97-3/31/97)

Project Title: Hydrodynamics of CLP

Principal Investigator: Dr. Henry Liu, Professor of Civil Engineering

Graduate Research Assistants: Xiang Gao (50% GRA)

Purpose of Study:

To study not-yet-explored hydrodynamic subjects important to the operation of coal log pipeline (CLP).

Work Accomplished During This Period:

Mr. Xiang Gao (Ph.D. candidate) has completed the derivation of a set of hydrodynamic equations that describe the behavior of coal logs entering and leaving a sloped pipe--see Attachment 1. He also started working on a computational fluid dynamic (CFD) model called "FLUENT" to solve the turbulent flow field around a capsule or coal log.

Future Plans:

1. Complete CFD model on flow field around a capsule. First check the validity of the model against existing experimental data on pressure variation around a stationary capsule--measurements reported by Liu & Graze in 1983 in Journal of Hydraulics Division, American Society of Civil Engineers (Vol. 109, No. 1). Once the model is verified for the stationary capsule case, it will then be used for determining the flow field around a capsule moving in pipe by a trial-and-error procedure assuming different capsule positions/ orientations until the capsule orientation/position is stable.

2. Plan experiments needed to check the equations derived for predicting coal log train behavior on pipe slopes.

— Attachment 1 —

Hydraulics of Stationary Capsule in Sloped Pipe

By Xiang Gao (Mar. 2nd, 1997)

Introduction

Hydraulic capsule pipeline (HCP) is the transport of cargo in large cylindrical forms (capsules) in a water-filled pipeline. This concept was first actively explored in Canada in early 1960s. HCP is currently being intensively researched and developed at the Capsule Pipeline Research Center, University of Missouri-Columbia.

Relatively mature theories on the hydraulics of stationary capsule in a horizontal straight pipe have been developed by H.Liu, et al. The lift and drag on a stationary capsule in pipeline was investigated by Liu and Graze (1983); In Liu and Richards (1994), the hydraulic theory of stationary capsule in a horizontal, straight pipeline was developed, by which the pressure variation along a capsule, drag coefficient and the incipient velocity could be predicted. The tilt of stationary capsule in pipe was also studied by Cheng and Liu(1996).

Even though intensive R & D have been carried out, some questions still remain. One question is what fluid velocity can keep capsule resting on a sloped pipe. Another is how the capsule tilt will happen during start-up or restart in a sloped pipe. The purpose of this paper is to analyze the two questions on the basis of the existing research results by H.Liu, et al.

Pressure Variation and Head Loss along Capsule (Liu and Richards, 1994)

Referring to Fig.1, the flow along a capsule resting on the floor of a pipe can be divided into five regions of distinctly different flow characteristics. Sections 1 and 6 are chosen sufficiently away from the capsule so that the velocity fields at those places are unaffected by the presence of the capsule. In the region between sections 1 and 2, the convergent flow is similar to that entering a sudden contraction. The flow entering section 2 continues to converge until it reaches the *vena contracta* at section 3. Then the flow expands between sections 3 and 4. Flow separation occurs around the capsule between section 2 and section 4. In the region between sections 4 and 5, the streamlines are parallel and the flow can be considered fully developed. Then the flow starts to expand again at section 5. The flow between sections 5 and 6 is similar to that through a sudden expansion.

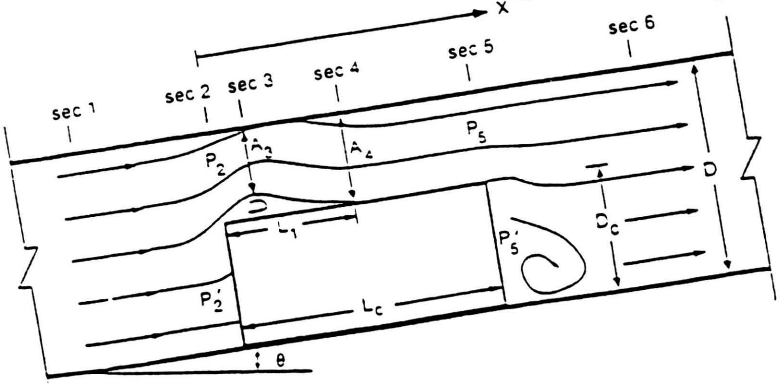


Fig. 1 Flow around Stationary Capsule in Sloped Pipe

Applying energy equation to the flow between sections 1 and 2 yields

$$p_1 - p_2 = \rho g(z_2 - z_1) + (b^2 - 1)\frac{\rho V^2}{2} \qquad (1)$$

where b = the blockage ratio, defined by

$$b = \frac{A}{A - A_c} = \frac{1}{1 - k^2} \qquad (2)$$

where k = D_c/D = the diameter ratio.

Likewise, the pressure drop between sections 1 and 3 can be

$$p_1 - p_3 = \rho g(z_3 - z_1) + (\frac{b^2}{C_c^2} - 1)\frac{\rho V^2}{2} \qquad (3)$$

where C_c = the contraction coefficient, which can be estimated from Table 1 in Liu and Richards (1994).

Applying an energy correction factor to the velocity head at section 4 and considering the entrance head-loss, the pressure drop between sections 1 and 4 can be

$$p_1 - p_4 = \rho g(z_4 - z_1) + [b^2\alpha(1 + K_{en}) - 1]\frac{\rho V^2}{2} \qquad (4)$$

where K_{en} = entrance head-loss coefficient, obtained by

$$K_{en} = \left(\frac{1}{C_c} - 1\right)^2 \qquad (5)$$

The pressure drop between sections 4 and 5 can be obtained from

$$p_4 - p_5 = \rho g(z_5 - z_4) + f_a\left(\frac{L_c - L_1}{D - D_c}\right)b^2\frac{\rho V^2}{2} \qquad (6)$$

where L_1 = the length of the flow separation zone around the upstream edge of the capsule (see Fig. 2).

Combination of (6) with (4) yields

$$p_1 - p_5 = \rho g(z_5 - z_1) + \{b^2[\alpha(1 + K_{en}) + f_a(\frac{L_c - L_1}{D - D_c})] - 1\}\frac{\rho V^2}{2} \qquad (7)$$

In a similar manner, the pressure change between sections 5 and 6 can be calculated from

$$p_5 - p_6 = \rho g(z_6 - z_5) + [1 + b^2(K_{ex} - \alpha)]\frac{\rho V^2}{2} \tag{8}$$

where K_{ex} = the exit head-loss coefficient, given by

$$K_{ex} = \alpha - \left(\frac{2b\beta - 1}{b^2}\right) \tag{9}$$

Combining (8) with (7) yields

$$p_1 - p_6 = \rho g(z_6 - z_1) + b^2[\alpha K_{en} + K_{ex} + f_a(\frac{L_c - L_1}{D - D_c})]\frac{\rho V^2}{2} \tag{10}$$

Drag coefficient C_D (Liu and Richards, 1994)

In Liu and Richards (1993), C_D was predicted from

$$C_D = C_p - 1 + b^2[\frac{k\Phi_1 + 1}{k(k + \Phi_1)}][\alpha(1 + K_{en}) + f_a(\frac{L_c - L_1}{D - D_c})] - \frac{b^2(1 - k^2)}{k(k + \Phi_1)} \tag{11}$$

where C_p = pressure coefficient, which is less than 1.0;
f_a =resistance factor for the flow in the annulus;
Φ_1 = shear stress ratio, defined by

$$\Phi_1 = \frac{\tau_p}{\tau_c} \tag{12}$$

For stationary capsule (a full eccentric annuli), the shear stress ratio may be predicted from

$$\Phi_1 = \frac{\tau_p}{\tau_c} = \sqrt{1 - (1 - k)^2} \tag{13}$$

Incipient velocity V_i (Liu and Richards, 1994)

Consider a cylindrical capsule with flat ends and a 90° edges in a pipe of an arbitrary slope (angle of incline θ) as shown in Fig.2.

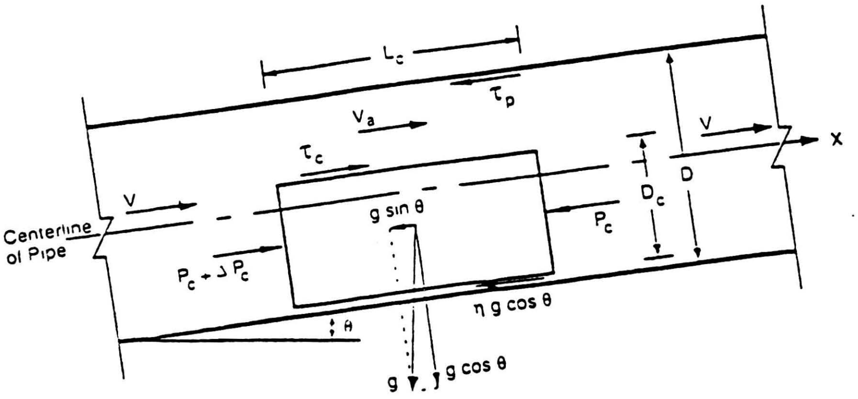


Figure 2 Forces Acting on Stationary Capsule in Slope Pipe

At impending motion (incipient velocity), the balance of these forces in the x-direction yields

$$A_c \Delta p_c + \pi D_c L_c \tau_c = A_c L_c \rho_c g \sin\theta + \eta[A_c L_c (\rho_c - \rho) g \cos\theta - C_L A_c \frac{\rho V_i^2}{2}] \tag{14}$$

While

$$A_c \Delta p_c + \pi D_c L_c \tau_c = F_D + \rho g A_c L_c \sin\theta = C_D A_c \frac{\rho V_i^2}{2} + \rho g A_c L_c \sin\theta \tag{15}$$

where F_D = drag force

Combining (15) with (14) yields

$$V_i = \sqrt{\frac{2g(S-1)L_c(\sin\theta + \eta\cos\theta)}{\eta C_L + C_D}} \tag{16}$$

Tilt of Stationary Capsule in Pipe (Cheng and Liu, 1996)

In analyzing the tilt of capsule, the forces acting on the capsule are illustrated in Fig.3. They include the lift force F_L perpendicular to the flow, the drag F_D in the flow direction, the weight of the capsule $\rho_c g A_c L_c$ which is downward, and the buoyancy in the upward direction given by $\rho\, g A_c L_c$.

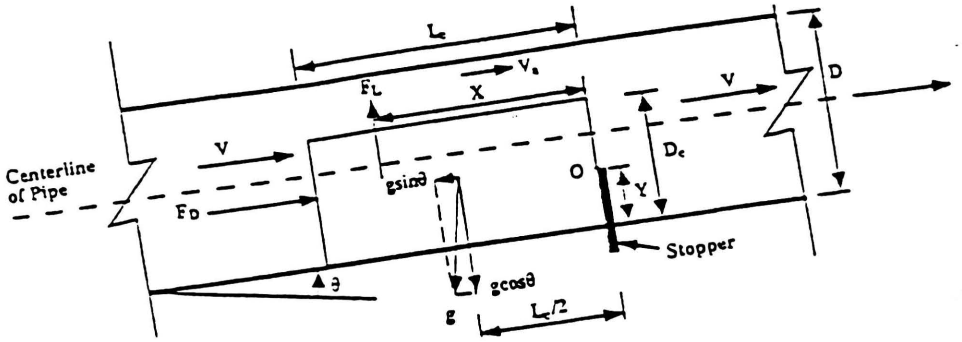


Figure 3 **Forces Acting on Stationary Capsule in Slope Pipe**

It is assumed that the pivoting point for the capsule tilt is point O in Fig.3. Based on the derivation given in Cheng and Liu (1996), the tilt velocity V_t, which is the minimum bulk velocity V that causes capsule tilt, can be predicted as follows.

When a capsule is blocked by a "stopper" with a height Y, the tilt velocity V_t is

$$V_t = \sqrt{\frac{g(S-1)L_c[a\cos\theta + (1-2Y')\sin\theta]}{C_D(0.5-Y') + aX'C_L}} \tag{17}$$

or

$$\frac{V_t}{\sqrt{g(S-1)L_c}} = F_t = \sqrt{\frac{a\cos\theta + (1-2Y')\sin\theta}{C_D(0.5-Y') + aX'C_L}} \tag{18}$$

where V_t = tilt velocity, F_t = tilt densimetric Froude number, $X'=X/L_c$, $Y'=Y/D_c$, and $\mathbf{a}=L_c/D_c$. See Fig.2 for the definition of X and Y.

For a horizontal pipe, sinθ = 0 and cosθ =1. Equations (17) and (18) reduce to, respectively

$$V_t = \sqrt{\frac{g(S-1)aL_c}{C_D(0.5-Y') + aX'C_L}} \tag{19}$$

and

$$\frac{V_t}{\sqrt{g(S-1)L_c}} = F_t = \sqrt{\frac{a}{C_D(0.5-Y') + aX'C_L}} \tag{20}$$

For the special case of a very small or non-existing obstacle, both Y and Y′ approach zero, and (17) - (20) reduce to, respectively.

$$V_{ct}=\sqrt{\frac{g(S-1)L_c[a\cos\theta+\sin\theta]}{0.5C_D+aX'C_L}} \tag{21}$$

$$F_{ct}=\sqrt{\frac{a\cos\theta+\sin\theta}{0.5C_D+aX'C_L}} \tag{22}$$

$$V_{ct}=\sqrt{\frac{g(S-1)aL_c}{0.5C_D+aX'C_L}} \quad \text{(horizontal pipe)} \tag{23}$$

$$F_{ct}=\sqrt{\frac{a}{0.5C_D+aX'C_L}} \quad \text{(horizontal pipe)} \tag{24}$$

Determining $X'C_L$ by experiments (Cheng and Liu, 1996)

Based on experimental data, Cheng and Liu (1996) found that "for capsules in practical range (k=0.75 - 0.95, **a** = 1.5 - 5), the value of $X'C_L$ depends mainly on F_{ct}, and is relatively insensitive to the variations of C_D and **a**.".

For an arbitrary pipe with an obstacle,

$$X'C_L=\frac{0.54}{F_{ct}^2}[\cos\theta+\frac{(1-2Y')}{a}\sin\theta] \tag{25}$$

For a horizontal pipe without obstacle, (25) reduces to

$$X'C_L=\frac{0.54}{F_{ct}^2} \tag{26}$$

For a given HCP, combining (26) with (24) or combining (25) with (18) can yield the value of the critical tilt Froude number F_{ct} and thus the critical tilt velocity V_{ct}. This is discussed next.

Hold-on of Stationary Capsule in Sloped Pipe

In a sloped pipe, when the slope angle, θ, is greater than the value of $\tan^{-1}\eta_1$, a certain minimum velocity of the flow, called "hold velocity", V_h, is needed to prevent the down-sliding of the capsule. This hold velocity can be determined as follows:

As shown in Fig.2, at impending motion (downward), the balance of the forces acting on the capsule in the x-direction yields

$$A_c \Delta p_c + \pi D_c L_c \tau_c = A_c L_c \rho_c g \sin\theta - \eta[A_c L_c(\rho_c - \rho) g \cos\theta - C_L A_c \frac{\rho V_h^2}{2}] \tag{27}$$

Combining (27) with (15) yields

$$V_h = \sqrt{\frac{2g(S-1)L_c(\sin\theta - \eta_1 \cos\theta)}{-\eta_1 C_L + C_D}} \tag{28}$$

From (28) and (16) the ratio of V_h/V_i should be

$$\frac{V_h}{V_i} = \sqrt{\frac{(\sin\theta - \eta_1 \cos\theta)(C_D^i - \eta_1 C_L)}{(\sin\theta + \eta_1 \cos\theta)(C_D^h + \eta_1 C_L)}} \tag{29}$$

where C_D^i and C_D^h are the drag coefficients respectively for incipient velocity (upward) and hold velocity (downward).

Compared to C_D, the quantity of $\eta_1 C_L$ is very small and can be negligible. Making the further assumption that $C_D^i \approx C_D^h$, (29) can be reduced to

$$\frac{V_h}{V_i} = \sqrt{\frac{\sin\theta - \eta_1 \cos\theta}{\sin\theta + \eta_1 \cos\theta}} \tag{30}$$

For a capsule with L_c=1.0 m and D_c=0.2 m and a pipe with D=0.232 m, the aspect ratio **a** and diameter ratio k are 5.0 and 0.862, respectively. In this case, when the static contact friction coefficient η_1 is 0.5, the ratios of V_h/V_i for various pipe angles are predicted from both (29) and (30) and shown in Figure 4. In Eq.(29), the drag coefficients C_D^i and C_D^h are calculated by the combination of (11) and (16) and the combination of (11) and (28), respectively. Figure 4 indicates that (29) and (30) yield same values of V_h/V_i for various pipe angles. Therefore, it is accurate to use (30) to predict the ratio of V_h/V_i.

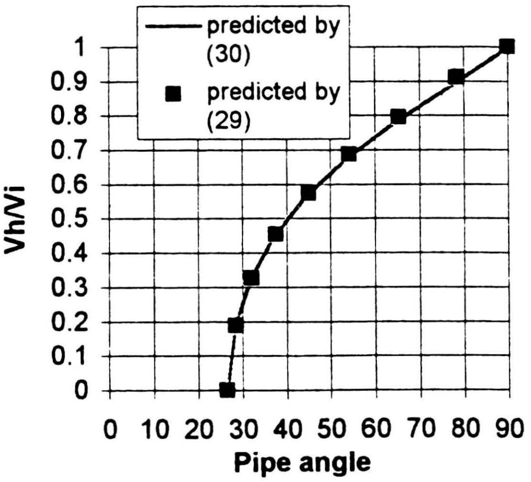


Figure 4 Comparison of Eqs.(29) with (30)

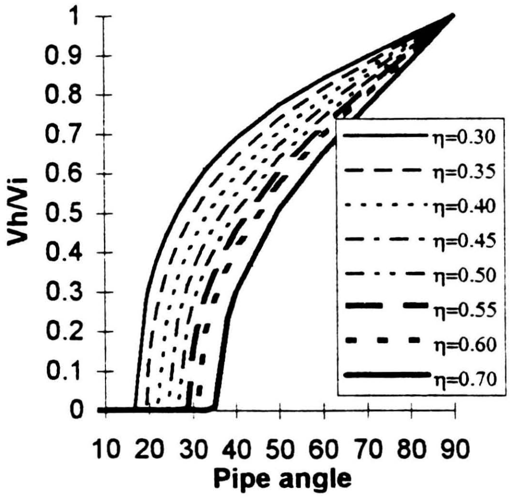


Figure 5 V_h/V_i varies with pipe angle

Critical Tilt during Start-up

When η_1 is in the range of 0.30~0.70, the values of V_h/V_i varying with θ are shown in Fig.5. For a capsule in a upward sloped pipe, when $V_h < V < V_i$, the capsule keeps stationary. For a capsule in a downward sloped pipe, $V_h \equiv V_i$, the capusle will slip down once $V > V_i$ (or V_h).

In Regime 1, as the bulk velocity has reached the incipient velocity V_i, which can be predicted from (16), the capsule starts to slide. However, when the capsule is very short or when **a** is very small, the capsule may tilt before it starts to slide. Once such a capsule starts to tilt, the pressure beneath the capsule rises, the lift force is increased rapidly, and the contact friction is reduced. This causes the capsule to slide up the slope before the incipient velocity predicted from (3) is reached. Such a phenomenon will also happen to large capsules in a pipe of large positive slopes (upward slopes).

The critical aspect ratio $\mathbf{a}_{ct}$ is defined as the aspect ratio of the capsule, below which the critical tilt will happen before slide. From the definition of $\mathbf{a}_{ct}$, the value of $\mathbf{a}_{ct}$ can be obtained by setting $V_i = V_{ct}$. From (16) and (21), the relationship between V_{ct} and V_i is

$$\frac{V_{ct}}{V_i} = \sqrt{\frac{(a\cos\theta + \sin\theta)(C_D + \eta_1 C_L)}{(\eta_1 \cos\theta + \sin\theta)(C_D + 2aX'C_L)}} \tag{31}$$

For a horizontal pipe, (31) reduces to

$$\frac{V_{ct}}{V_i} = \sqrt{\frac{a(C_D + \eta_1 C_L)}{\eta_1 (C_D + 2aX'C_L)}} \tag{32}$$

Letting $V_{ct}=V_i$, (32) yields

$$a_{ct} = \frac{\eta_1 C_D}{C_D + \eta_1 C_L - 2\eta_1 X'C_L} \tag{33}$$

It is worth to point out how C_L in (33) should be determined. In the foregoing discussions, when calculating V_i, the value of C_L was predicted based on the experiments of Liu and Graze (1982) and is normally less than 5. However, for V_{ct}, the value of C_L is predicted from (26) or (25) and is normally much larger than 5. It is suggested herein that the same value of C_L be used in predicting both V_i and V_{ct}, using $C_L=X'C_L=0.54/F_{ct}^2$ (assuming $X'=1$).

If $C_L=X'C_L=0.54/F_{ct}^2$, a very simple equation can be derived to calculate the value of $\mathbf{a}_{ct}$.

I. Horizontal pipe

Substituting (26) into (24) yields

$$X'C_L = \frac{0.587C_D}{a} \tag{34}$$

Substituting (34) into (33) yields

$$a_{ct} = \frac{\eta_1 C_D}{C_D + \eta_1 X'C_L(\frac{1}{X'} - 2)} = \frac{\eta_1 C_D}{C_D - \frac{0.587\eta_1 C_D}{a_{ct}}(\frac{1}{X'} - 2)} = \frac{\eta_1}{1 - \frac{0.587\eta_1}{a_{ct}}(\frac{1}{X'} - 2)}$$

Therefore,

$$a_{ct} = \eta_1(2.174 - \frac{0.587}{X'}) \tag{35}$$

If X'=1.0, (35) reduces to

$$a_{ct}=1.587\eta_1 \tag{36}$$

For a constan value of X', equation (35) indicates the following: 1) The critical aspect ratio $\mathbf{a_{ct}}$ depends only on the stationary contact friction coefficient η_1. That means $\mathbf{a_{ct}}$ has no relationship with the dimensions of the capsule and the pipe. 2) The critical aspect ratio $\mathbf{a_{ct}}$ is proportional to η_1. For coal logs, the practical range of η_1=0.513-0.569 (Liu and Richards, 1994), thus (36) yields $\mathbf{a_{ct}}$=0.814-0.903. However, in practice, **a** is greater than 1.5. Therefore, for coal logs in horizontal pipe, the critical tilt cannot happen in horizontal pipe during start-up (because **a** >1.5).

II. Inclined pipe

From (31), a_{ct} for inclined pipe can be obtained from

$$a_{ct} = \frac{C_D\eta_1 \cos\theta - C_L\eta_1 \sin\theta}{C_D \cos\theta + \eta_1 C_L \cos\theta - 2X'C_L(\eta_1 \cos\theta + \sin\theta)} \tag{37}$$

Combining (25) and (22) yields the same as equation (34), restated as follows:

$$X'C_L = \frac{0.587C_D}{a} \tag{34}$$

Therefore (34) is suitable not only for horizontal pipe but also for pipe of any slope. Substituting (34) in (37) yields

$$a_{ct} = \frac{A + \sqrt{A^2 - B}}{2\cos\theta} \tag{38}$$

where A=$1.587\eta_1\cos\theta + 1.174\sin\theta$, and B=$1.174\eta_1\sin 2\theta$.

By varying θ from -90° to +90° and assuming $\eta_1=0.5$, different values of the a_{ct} are calculated and listed in Table 1. The results are also plotted in Fig.6. Figure 6 indicates that larger positive slope ($\theta > 0$) has greater value of a_{ct}. That means for pipes with positive ($\theta > 0$) slope, even when a is larger than 1.0, the capsule may tilt before it slides.

Table 1 a_{ct} varies with pipe angle θ (note: negative angles indicate down-slope)

θ	-90°	-85°	-80°	-75°	-60°	-45°	-30°	-15°	-10°	-5°	0°
a_{ct}	0.250	0.260	0.271	0.283	0.325	0.384	0.474	0.608	0.664	0.726	0.794
θ	0°	5°	10°	15°	30°	45°	60°	75°	80°	85°	90°
a_{ct}	0.794	0.867	0.946	1.032	1.345	1.805	2.634	4.951	7.209	13.99	∞

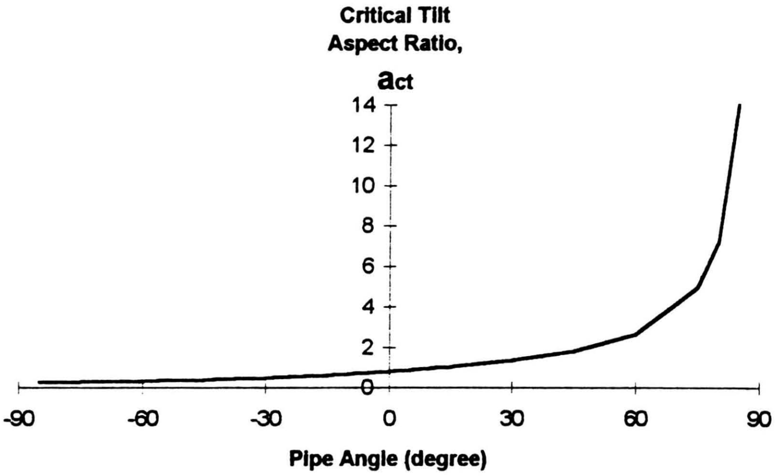


Fig. 5 Critical aspect ratio varies with pipe angle

Conclusion

In sloped pipe, the incipient velocity V_i can be predicted from equation (16). For a capsule train, the determination of f_a may be found as in Gao (1996). For upward sloped pipes, when the flow velocity is less than V_h, which can be predicted from equation (28), the capsule slides downward. Only when flow velocity is between V_i and V_h, can the capsule keep stationary in the pipe. In predicting the incipient velocity, the capsule tilt must be taken into consideration. When the aspect ratio, **a**, of the capsule is smaller than a_{ct}, which may be predicted from (38), the capsule will first tilt and then slide with the water. Under this condition, the incipient velocity should be calculated from (21). As Fig.5 illustrates, when the slope is positive ($\theta > 0$), the capsule has a stronger tendency to tilt. The reasons for this can be: 1) the tilt of stationary capsule is caused by the drastic increasing of the lift; 2) this drastically increasing lift force must be corresponding to a certain velocity (V_t) for a given pipe and capsule; 3) for the upward sloped pipe, a larger quantity of angle, θ, is corresponding to a higher incipient velocity V_i. 4) when V_t is less than V_i, the tilt of capsule will happen when the fluid velocity is above V_t. Therefore, for larger positive sloped pipe, V_i is larger and the capsule has stronger tendency to tilt. The "tilt" theory discussed above is only for single capsules. For a capsule train, the pivoting point may have many possibilities, and the tilt may be totally avoided by intercapsule contacts.

References

C.C. Cheng and H.Liu (1996). "Tilt of Stationary Capsule in Pipe" *J. Hydr. Engrg.*, ASCE, 122(2).
Liu, H., and Graze, H.R. (1983) "Lift and drag on stationary capsule in pipeline" " *J. Hydr. Engrg.*, ASCE, 109(1).
Liu, H., and Richards, J.L. (1994) "Hydraulics of stationary capsule in pipe" *J. Hydr. Engrg.*, ASCE, 120(1).
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MEETING OF THE INDUSTRIAL ADVISORY BOARD (IAB)
CAPSULE PIPELINE RESEARCH CENTER
COLUMBIA, MISSOURI APRIL 23, 1997

April 22, 1997 (Tuesday)	7:00 p.m. - 9:00 p.m.	Reception at Holiday Inn Select* Truman Room
April 23, 1997 (Wednesday)	8:00 a.m. - 4:00 p.m.	Meeting Room N222/223: Joplin-Boone Room Memorial Student Union

AGENDA

TIME	**ACTIVITIES**
A.M.	
7:30	Center staff picks up guests at hotels
8:00	Meeting starts; welcome (Dr. Andy Blanchard, Engineering Research Director)
8:05	Self introduction of participants
8:15	IAB Vice Chairman (Hank Brolick) presides over meeting and welcomes participants
8:20	NSF Official (Dr. Joy Pauschke) addresses participants
8:30	Center Director reports highlights of progress and important activities
9:00	Report on progress in coal log machine construction (Ted Gundlach)
9:20	Report on work performed by Williams Technologies, Inc. (Henry Brolick)
9:40	Report on coal log pipeline route analysis from Wyoming to Texas-- Feasibility of Using Abandoned ETSI Route (Wasp).
10:00	Coffee Break
10:15	Faculty Presentation of Research Progress (see next page for details)
12:00	Luncheon and election of new IAB Chair** (Frank Seibert)
P.M.	
1:00	Research Plan (Henry Liu)
1:30	Business Meeting, Financial status and plan, EPRI Project, Industry Involvement, DOE involvement, Pilot Plant Project, etc. (Henry Liu).
2:30	IAB Executive Meeting (Hank Brolick)
4:00	Adjourn

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[*] Holiday Inn Executive Center has changed name to Holiday Inn Select recently.

[**] As in the past, IAB Chair is re-elected once a year. There is no term limit for this position.

PRESENTATION BY SELECTED FACULTY MEMBERS

TIME	SUBJECT	FACULTY
10:15-10:30	Coal Log Machine Design Study	Yuyi Lin
10:30-10:45	Standard Coal Log Tests	Bill Burkett
10:45-11:00	Rapid Compaction of Coal Logs	Brett Gunnink
11:00-11:15	Coal Log Research Conducted on Rolla Campus	Nicole Pagano
11:15-11:30	Drag Reduction in 8-Inch-Diameter Capsule Pipeline	John Miles
11:30-11:45	Compaction of Sawdust and Other Biomass	Tom Marrero