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Coal Log Pipeline Research at University of Missouri

CAPSULE PIPELINE RESEARCH CENTER

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2ND QUARTER REPORT

1 APRIL TO 30 JUNE 1996

TECHNICAL PROGRESS REPORT

TO

UNITED STATES DEPARTMENT OF ENERGY

PITTSBURGH ENERGY TECHNOLOGY CENTER

JUNE 1996

DISCLAIMER

Coal Log Pipeline Research at University of Missouri

2nd Quarterly Report for 1996

4/1/96 - 6/30/96

Henry Liu
Professor and Director
Capsule Pipeline Research Center

Project Sponsors:

National Science Foundation (State/IUCRC Program)

State of Missouri (Department of Economic Development)

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

Coal Log Pipeline Consortium:
- Associated Electric Cooperative, Inc.
- Mid American Pipeline Company
- Southwestern Public Service Company
- Union Electric Company
- Williams Pipe Line Company
- Williams Technologies, Inc.
- Willbros Engineers, Inc.

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

CONTENTS

EXECUTIVE SUMMARY

During this second quarter of 1996 (4/1/96-6/30/96), significant progress has been made in the following fronts of coal log pipeline research, development and technology transfer:

1. Design of the special 300-ton coal log compaction machine was completed, and an RFP (Request-for-Proposal) was issued. Four proposals (bids) were received. Bid selection will be done in July.

   Furthermore, much progress has been made in the design of the system needed to feed coal into the coal log compaction machine, and the design of the system to remove logs automatically as soon as they are compacted. More basic research was also conducted to develop a set of equations for predicting the properties of coal logs produced by compaction. The equations will be used in the future for optimizing the design of the compaction mold and pistons.

2. Coal mixtures containing different amounts of moisture were compacted into 1.91-inch-diameter coal logs rapidly (in 6 seconds). It was found that for the Mettiki coal tested, the optimum moisture is around 8%. Under the test conditions (room temperature and 3% binders), the rapidly compacted coal logs with 8% moisture had less than 4% weight loss in 350 cycles of circulation. Logs with either more than or less than 8% moisture had greater weight loss. It is clear from this test that to make the strongest logs possible in fast compaction, the coal mixture moisture should be near the optimum value of each case. An alternative approach is to compact more slowly or to improve the drainage of water from the logs during compaction--a matter that involves mold design and piston design. Using less binder in the coal mixture is also expected to improve drainage and may enhance coal log strength.

3. Completed evaluation of the effectiveness of using wall lubricants to enhance coal log quality. Both calcium sterarate and MoS_2 were found to be effective. However, it was found that lubricants applied to the mold wall in dry-film form do not last long. This rules out the practicality of using dry-film lubricants. However, powdered lubricants appear practical because they are effective and can be easily reapplied on the mold wall after each compaction cycle.

4. It was found that when the interior of a mold is not cleaned after coal log has been compacted, the coal mixture film clinging to the wall hardens in time and form a hard crust which affects the quality of the next log to be produced. However, if the second log is produced immediately after the first, no hard crust is formed and the quality of the second log is not affected. This means that in a continuous mode of operation

such as encountered commercially, molds need no cleaning until and unless compaction has been stopped over a long time (many minutes).

5. Coal logs made with the coal crushed by the Gundlach Company were found to be better than coal logs made with the coal crushed by the CPRC's hammer mill. This is good news because it means better coal logs can be produced using coal crushed by properly selected large commercial crushers than logs produced in the past in our laboratory using coal crushed by our laboratory-size hammer mill.

6. A document has been written to standardize the test procedures for making coal logs and for testing the logs produced. The standard should help not only in getting better logs made in the future, but also in producing more uniform quality coal logs. This will make it possible for comparing future test results produced by different CPRC researchers.

7. A 320-ft-long, 6-inch-diameter coal log pipeline test facility was constructed in Rolla during this period. The facility will greatly enhance the capability of Dr. John Wilson's team in testing the 5.5-inch-diameter coal logs produced at Rolla. It will also serve as an interim facility for the Columbia campus researchers--to test their 5.5-inch-diameter coal logs before the Columbia campus will have a planned 6-inch-diameter test facility called for in an EPRI proposal. The Williams Pipe Line Company built this Rolla test facility as the company's in-kind contribution to CPRC. The Williams Pipe Line has already contributed to CPRC $15,000 in cash for this year. This additional in-kind contribution (Rolla facility) is estimated at $19,423.

8. Completed the simulation of an 8-inch-diameter, 20-mile-long coal log pipeline recirculaiting loop driven by a pump bypass. The result is needed for future design of the Pilot Plant facility in Thomas Hill. Various ways to minimize water hammer and to eliminate negative pressure in the system were investigated. These include optimal valve stroking, using surge tank, and using air chamber. The last (air chamber) was found to be the most effective.

9. Continued improvement was accomplished in the hydraulic model of HCP and CLP to predict pressure drop and capsule velocity for both single capsules and capsule train. Also, work has started to extend the analysis to sloped pipelines.

10. The EPRI-TC Proposal has been revised based on input from EPRI (Dave O'Connor) and Union Electric Company (Richard Smith). The revised proposal was submitted to EPRI in July.

11. Fifth-Year Annual Report was prepared during this period and was mailed to all sponsors.

12. An IAB (Industrial Advisory Board) meeting was held during this period, and the meeting was very productive.

13. The Southwestern Public Services Company, a progress electric utility headquartered in Amarillo, Texas, joined the Center's list of major industrial sponsors by contributing $30,000 in cash annually.

14. Completed preliminary analysis of several different systems for heating coal in commericial operation of coal log pipelines.

<u>PLAN FOR NEXT PERIOD (7/1/96 - 9/30/96):</u>

1. Select bid and award contract on coal log compaction machine. Start construction of the machine. Complete design of the coal feeding system and the coal log removal system. Start construct/purchase of the system components.

2. Complete the derivation/development of the equations needed for predicting the properties of coal logs produced by compaction. Check the correctness of the equations.

3. Conduct and complete four fast-track tasks: (a) cost estimate of using powdered lubricants (calcium stearate and MoS_2) in dollars per ton of coal compacted, (b) test of optimum pressure for making coal logs, (c) test of wear resistance of large diameter-ratio logs ($k>0.9$), and (d) ejection orientation study--whether upward ejection produces equal quality logs as downward ejection.

4. Implement the standard prepared for making and testing coal logs.

5. Make a mold alignment rig to avoid future damage to experimental molds. (Note: This is a response to three recent accidents in mold damage).

6. Study the effect of compaction temperature, pressure and binder concentration on the performance of very rapidly compacted coal logs.

7. Calibrate the 6-inch-diameter new CLP test facility in Rolla. Compare coal log degradation (wear) rates before and after pipe flanges are changed.

8. Test 5.3-inch diameter coal logs in the 6-inch Rolla facility and compare with results obtained under similar conditions for small (1.9-inch-diameter) coal logs tested in the UMC 2-inch pipeline loop.

9. Complete optimization of the use of air chamber to improve the performance of pump bypass.

10. Complete a report detailing the work on pump bypass and train separator done so far by Mr. Du under Dr. Nair's supervision.

11. Complete detailed design of the 6-inch-diameter, 3,000-ft-long pipeline test facility called for in the EPRI proposal.

12. Design the sheet-metal building needed for housing the 300-ton coal log compaction machine, the associated equipment, and essential parts of the 6-inch-diameter, 3,000-ft-long new test loop that needs to be indoor. The building will be located on the Holstein Farm of the University of Missouri-Columbia.

13. Complete hydraulic analysis of coal log train behavior in straight horizontal pipes. Complete a thesis and some publications based on the work.

14. Complete the analysis of hydraulic behavior of coal log train in sloped pipes.

15. Complete coal heating study; student submit project completion report.

INDIVIDUAL PROJECT REPORTS

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report
(Period Covered: 4/1/96-6/30/96)

Project Title: Machine Design for Coal Log Fabrication

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

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

Purpose of Study:

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

Work Accomplished During the Period:

During last three months, the final revision of the design specification of the 300-ton hydraulic press was completed. It was sent out for bid and then construction. Four companies have offered a bid. Selection will be done in July.

After the 300-ton machine specification went out for bid, the design for two components of the machine not covered in the bids has started. One is the coal log removal device and the other is the coal mixture loading device. The loading device must be able to measure, either by weight or by volume, the correct amount of prepared coal material (mixed with binder and water, heated or not heated). It must be able to load the material at the correct time and within a specified time interval so that it is synchronized with the other parts of the machine. An assembly drawing of this device is attached. The design is still in progress.

An assembly drawing of the log removal device is also attached. Two alternatives of the designs have been discussed by the Machine Design group. One alternative uses a twisted surface to unload the compacted coal logs to the conveyor belt. The other one, which is accepted as the final design, is a push-and-catch design with springs to absorb the impact energy and protect the coal logs. The log removal device will use an extension arm fastened on the feeding hopper to push the log into a conveyor belt, thus saving an actuator and associated control device.

A third task undertaken is the literature search and planning of experiments for research of advanced piston and mold-exit shape designs, which require detailed modeling of the compaction process for the coal logs. This work is Mr. Wen's Ph.D thesis topic. Finite element analysis will be used to design the best piston head profile and mold-exit shapes. Based on our experience and information, piston and mold-exit shapes affect the capping phenomenon and the quality of the compacted logs. Before more advanced shapes are designed, the 300-ton press uses a design in the bid document derived from small scale tests. Some preliminary numerical results have been obtained using the nonlinear finite element analysis software, ANSYS. For more information, please refer to attached abstract by Mr. Wen.

As a course project, Mr. Kang Xue applied optimization technique to the design of the worm gear for the rotary press, which was conceptually designed last year. The result showed that applying traditional derivative-based optimization algorithms to the design, the size of the gear set can be reduced from 689mm to 540mm. Although this investigation is not part of Xue's work assignment, the result will be useful in the future design improvement for the rotary press. The investigation clearly showed the importance of using optimization tools in a design process.

Future Plans:

For the next three months, the emphasis of the machine design group will be to complete the shop drawings and the specifications for the loading and unloading devices for the 300-ton press, so that when the machine is manufactured by the end of the year, these required accessories will have been made, and can be attached to the main structure.

The control subsystem design for the 300-ton press using a Programmable Logic Controller will be started. The design work should include selection of hardware and software programming. The purpose of designing this subsystem is that if the manufacturer for the 300-ton press charge excessively for the PLC hardware and software with the press, we can supply the hardware ($800 est. cost.) and software with small cost and effort. Another reason to carry out the PLC and control system design is that the PLC sequence will be adjusted in the future. We need to have the capability to re-program the PLC in-house.

Experimental work related to the mathematical modeling, the design of the piston shape, and mold exit shape will be arranged and started, as sonn as the two foregoing tasks are completed. Furthermore, after the coal log compaction machine is built and operational, the emphasis will be in testing and evaluating the machine performance, and to improve the system.

Publications:

Lin, Y. Y., Li, H. C., Wen, G. P. and **Xue, K.**, June 1996, "The Design of A 300-Ton High Speed Hydraulic Press for Compaction of Coal Logs," accepted for presentation and publication by the 1996 International Mechanical Engineering Congress and Exposition, Atlanta, GA. Camera ready copy available.

Lin, Y. Y. and **Xue, K.**, June 1996, "Optimal Design of Worm Gear Set for Rotary Press," CPRC Internal Report. 15 pages, 2 figures. Extended abstract based on this work is prepared for the 2nd International Conference on Material Handling (ICMH/ICAW '97 Beijing).

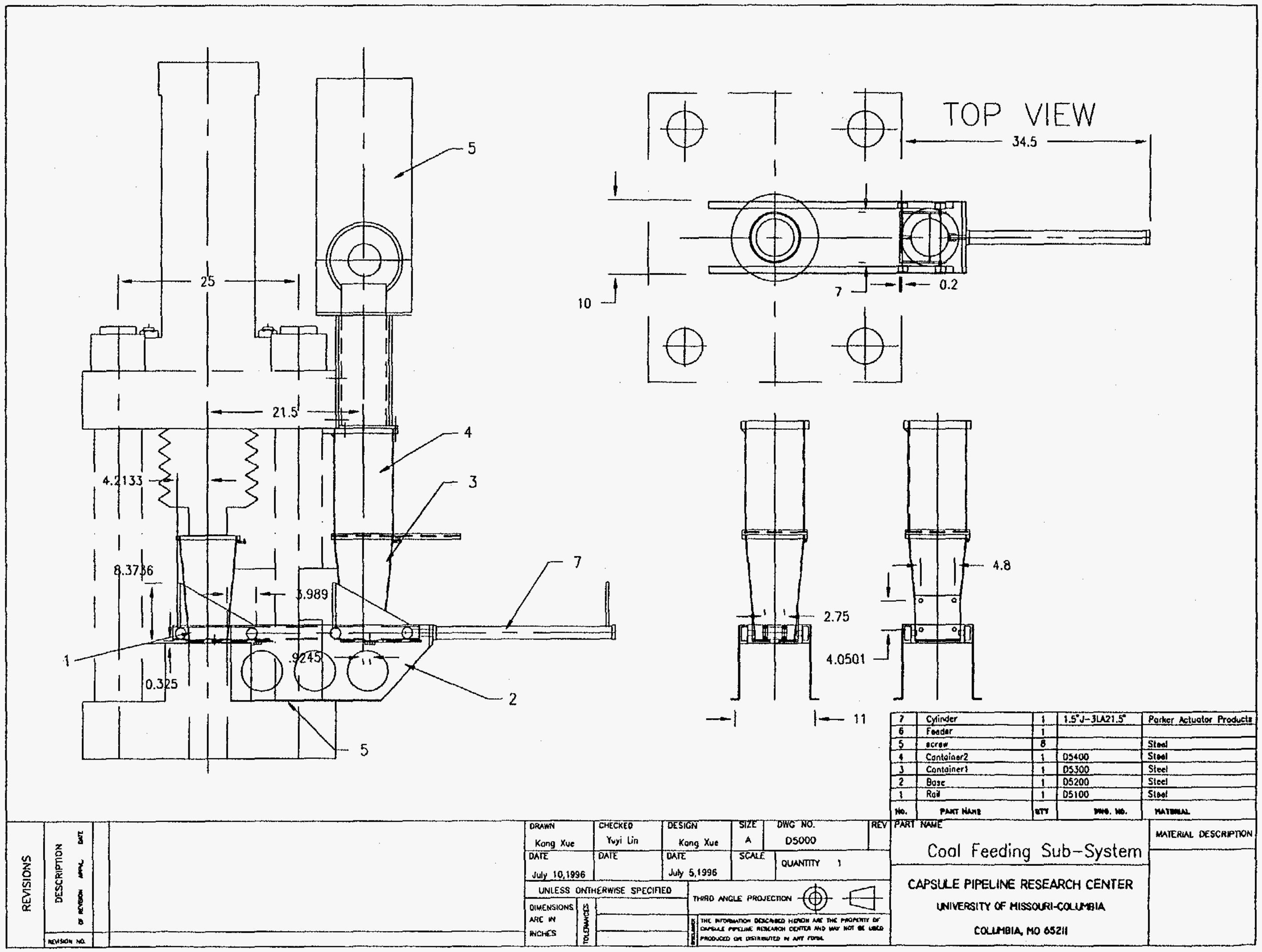
Wen, G. P., June 1996, "Optimum Tooling Profile Design and Process Modeling for Coal Log Compaction," CPRC Internal Report.

Attachment 1: Abstact of proposed research for Mr. Wen's Ph.D thesis--

A computational simulation model of the uniaxial compaction of coal in a cylinder mold will be presented using finite element methods. The nonlinear elasto-plastic compaction model can be established with commercial FEM code ANSYS, based on the material characteristics of coal which is derived from experimental data. Important aspects such as modeling of die-coal contact, the stress distribution in a pressed coal log during compation and ejection, and the elastic spring-back after compaction, etc., will be studied and compared with other compaction models in the literature. Various experiments will be performed to verify and validate the proposed computer model. The effect of mold exit shape and piston head contour on the quality of coal log will be investigated. Optimum mold design and piston head profile design can be obtained from this research. Finally, the nonlinear compaction model will be applied to the improvement of the the 300-ton coal log compaction machine.

Attachment 2: Compated Coal Log Removal Mechanism Design

Attachment 3: Coal Material Loading Mechanism Design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7 Cylinder 1 1.5"J-3LA21.5" Parker Actuator Products
6 Feeder 1
5 screw 8 Steel
4 Container2 1 D5400 Steel
3 Container1 1 D5300 Steel
2 Base 1 D5200 Steel
1 Rail 1 D5100 Steel
No. PART NAME QTY DWG. NO. MATERIAL
PART NAME
Coal Feeding Sub-System
MATERIAL DESCRIPTION
CAPSULE PIPELINE RESEARCH CENTER
UNIVERSITY OF MISSOURI-COLUMBIA
COLUMBIA, MO 65211
DRAWN Kang Xue
CHECKED Yuyi Lin
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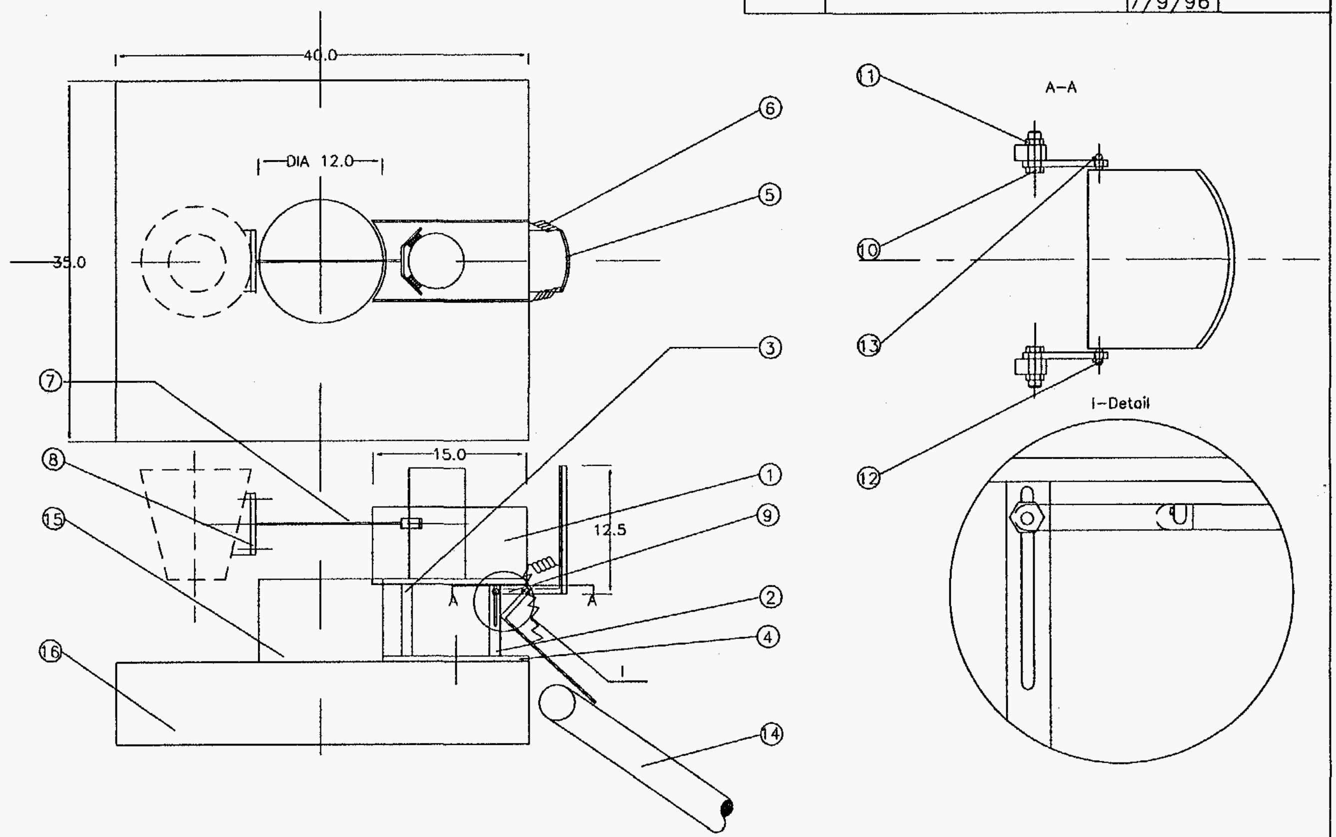

No.	Part Name	Qty.	Drawing No.	Material
16	MIDDLE PLATFORM	1	D0006	STEEL
15	MOLD GROUP	1	D2000	STEEL
14	CONVEYOR	1	D4014	ST,RUBBER
13	STOPER	2	D4009	STEEL
12	PIN	2	D4005	STEEL
11	SCREW NUT	2	3/4-16UNC	STEEL
10	HEX BOLT	2	3/4-16UNCC L=2.0	STEEL
9	SHAFT CONNECTOR	2	D4009	STEEL
8	FLANGE	1	D4008	STEEL
7	PUSHER	1	D4007	STEEL
6	SPRING	2	D4006	STEEL
5	DAMPING BOARD	1	D4005	ALUMINUM
4	FLANGE BEAM	2	D4004	STEEL
3	SUPPORT BEAM II	2	D4003	STEEL
2	SUPPORT BEAM I	2	D4002	STEEL
1	GUIDE PLATEFORM	1	D4001	STEEL

MATERIAL: STEEL	PART NAME: LOG REMOVAL ASSEMBLY	UNIT: INCH TOLERANCES .X ±.1 .XX ±.05 .XXX ±.010	
DRAWN BY: H.C. LI	Capsule Pipeline Research Center	QUANTITY	
CHECKED BY: Dr.LIN		DWG No.	D4000
DESIGNED BY: H.C. LI			

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 4/1/96-6/30/96)

Project Title: Very Rapid Compaction of Coal Logs

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

Research Assistants: Shiping Yang

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

Work Accomplished During the Period:

Work during the past quarter focused on investigating the effect of coal mixture moisture content of the circulation performance of rapidly compacted coal logs (compaction time ≈ 6 seconds).

All logs were made at room temperature with 3% Orimulsion binder. Table 1 summarizes other experimental conditions common to the rapid compaction coal logs that were made during the past quarter.

In order to both make coal logs rapidly and with reasonable control over the final compaction pressure, a two step compaction process was used. A low pressure, high displacement step was completed operating the compaction press under displacement control. Then a high pressure, low displacement step was completed operating the compaction press under load control. The controller voltage output and resulting compaction pressures as functions of time are shown in Figure 1.

moisture,

Figures 2 through 6 show the circulation test results for rapidly compacted coal logs made from coal mixtures with 4.4%, 6%, 8%, 10%, and 12% respectively. In these figures individual log data are shown. Figure 7 shows average circulation test data for logs made at various moisture contents and Figure 8 shows the average circulation test weight loss at 350 cycles for logs made at various moisture contents. From these data it is clear the circulation weight loss is minimized at a moisture content of about 8% and that weight loss increases rapidly at moisture contents above this optimum. We believe that at moisture contents above the optimum, excess water in the coal is not removed during compaction and that excess pore water pressures detrimental to log formation develop.

over

At moisture contents below the optimum we believe that particle to particle friction is higher due to insufficient amounts of lubricating water.

Work Proposed for Next Quarter:

During the next quarter, we will continue ~~out~~ our investigation of the circulation behavior of very rapidly compacted coal logs. We will also explore the effects of compaction temperature, pressure and binder concentration on the performance of very rapidly compacted coal logs.

Table 1 - Common fabrication and test conditions for rapidly compacted coal logs.

Coal	Mettiki coal
Particle Size	CPRC hammer mill through #30 mesh
Temperature	Room
Mold	#8 (1.91", single piece, tapered exit)
Binder	Orimulsion(70% bitumen+30% water)
Binder Concentration	3% Orimulsion
Moisture	4.4% initial moisture
Aspect Ratio	1.68-1.70
Compaction Style	Floating mold
Precompaction	175 psi (500 lb)
Compaction Pressure	About 20,000 psi (57,000 lb)
Compaction Time	2min, 30s, 20s, 15s, 12s, 6s,5s
Ejection	Right after compaction
Water Absorption	1 hour @ 500 psi
Circulation	350 cycles @ 85% theoretical lift-off velocity

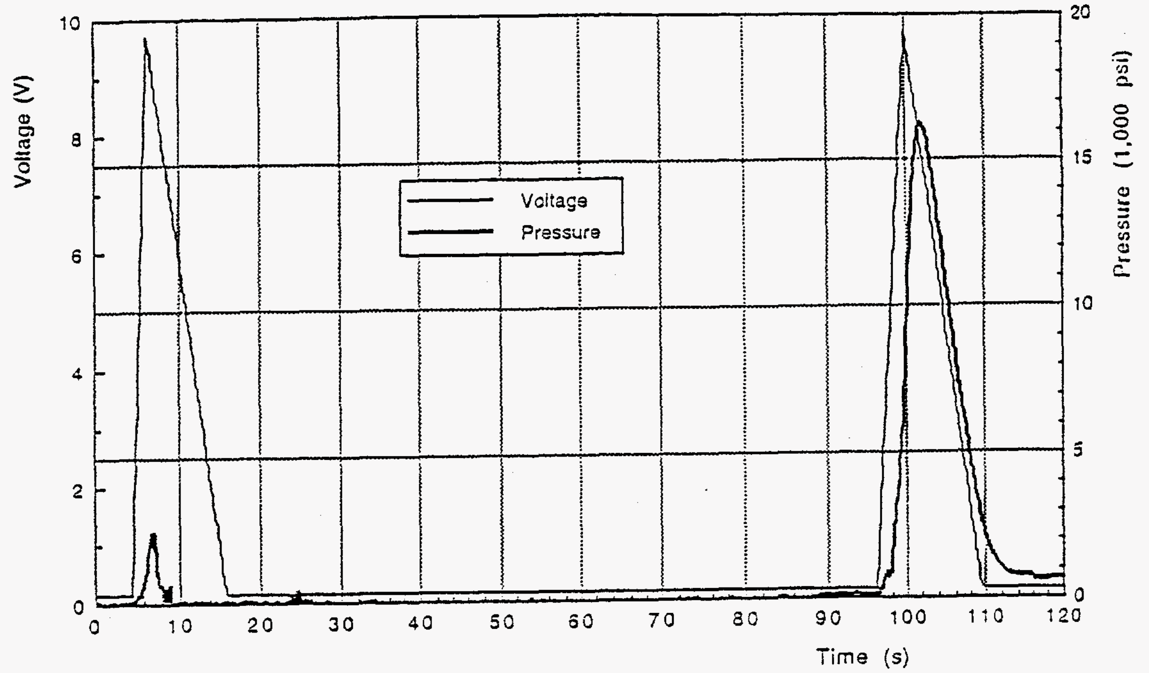

Figure 1 - Typical controller voltage output and resulting log compaction pressures for rapidly compacted coal logs.

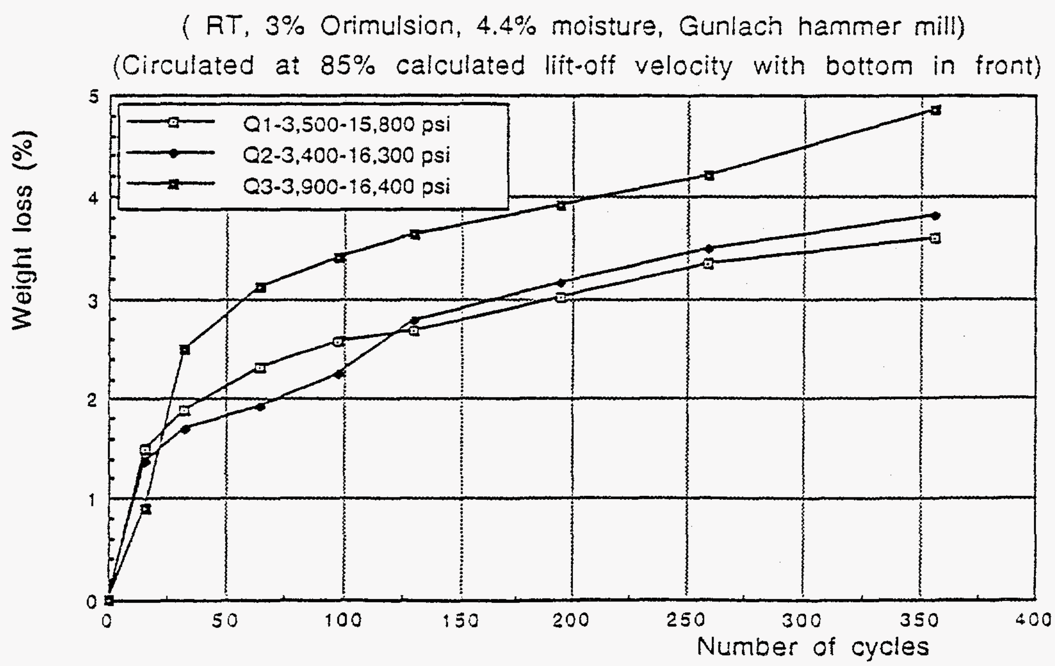

Figure 2 - Circulation test results for rapidly compacted coal logs with 4.4% moisture.

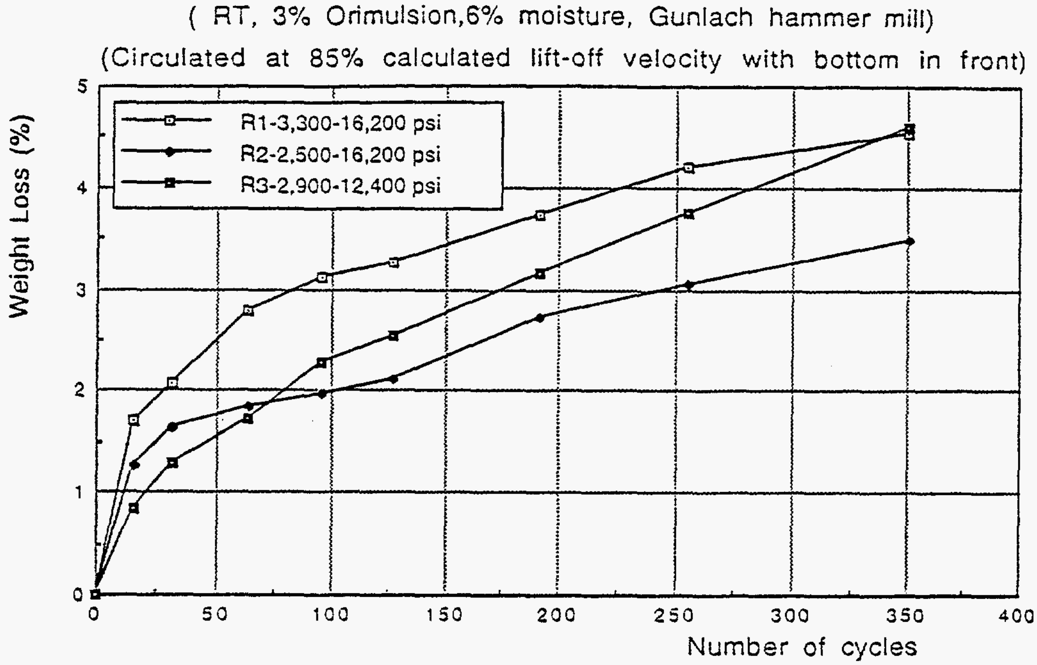

Figure 3 - Circulation test results for rapidly compacted coal logs with 6% moisture.

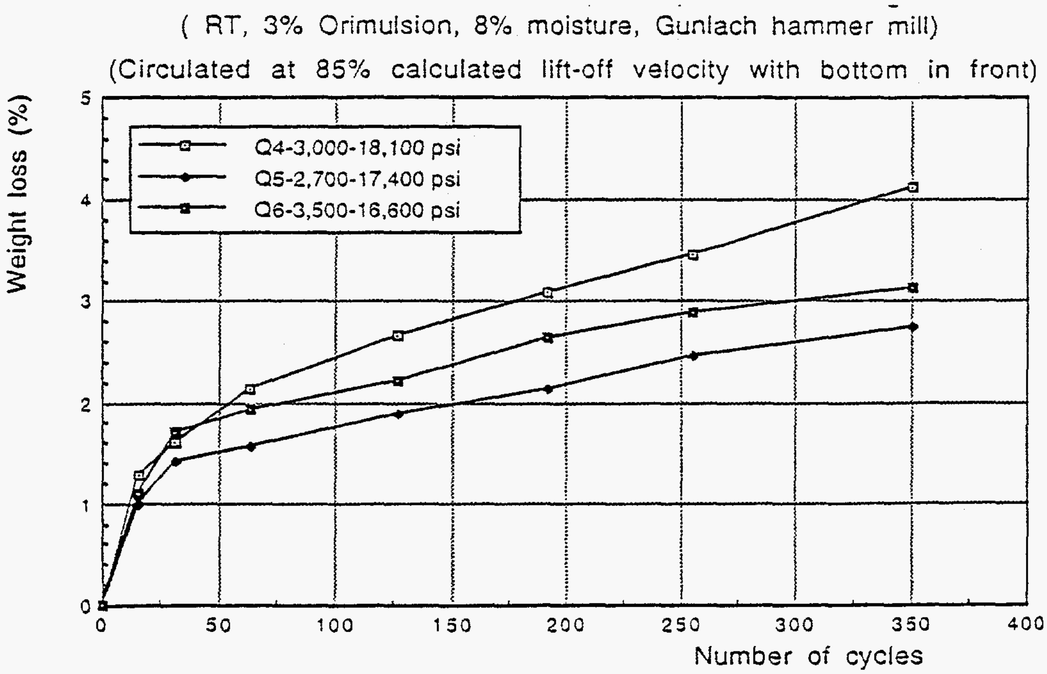

Figure 4 - Circulation test results for rapidly compacted coal logs with 8% moisture.

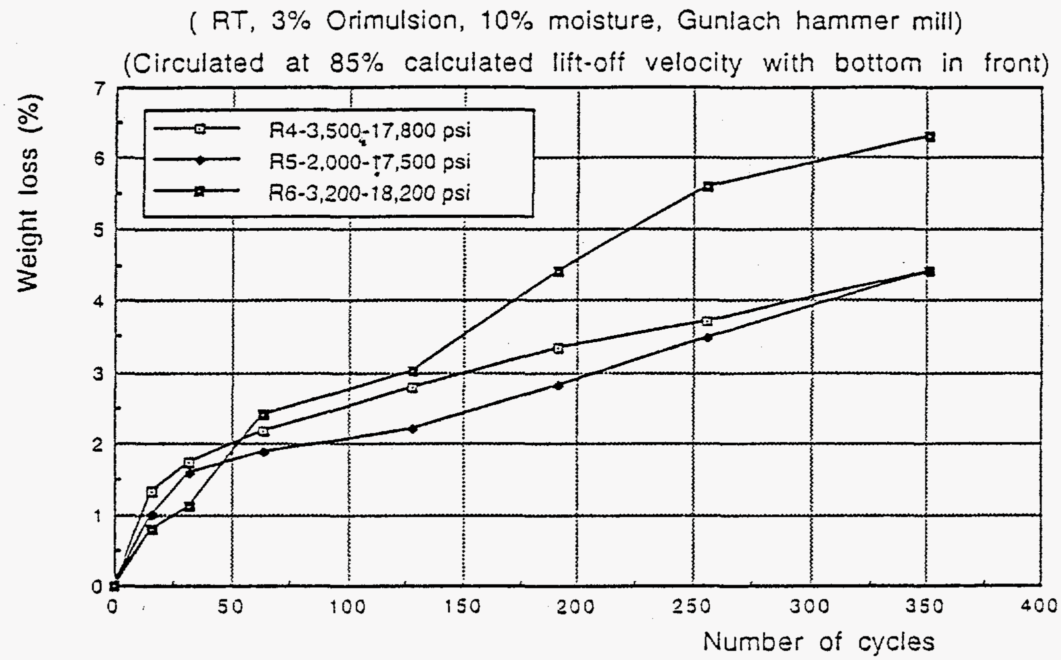

Figure 5 - Circulation test results for rapidly compacted coal logs with 10% moisture.

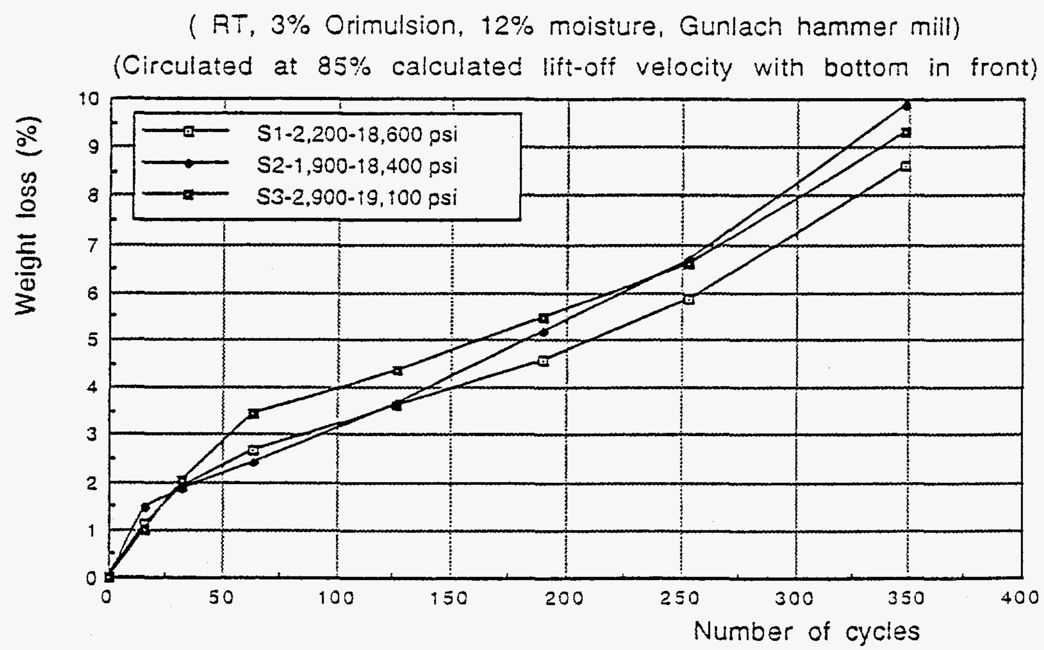

Figure 6 - Circulation test results for rapidly compacted coal logs with 12% moisture.

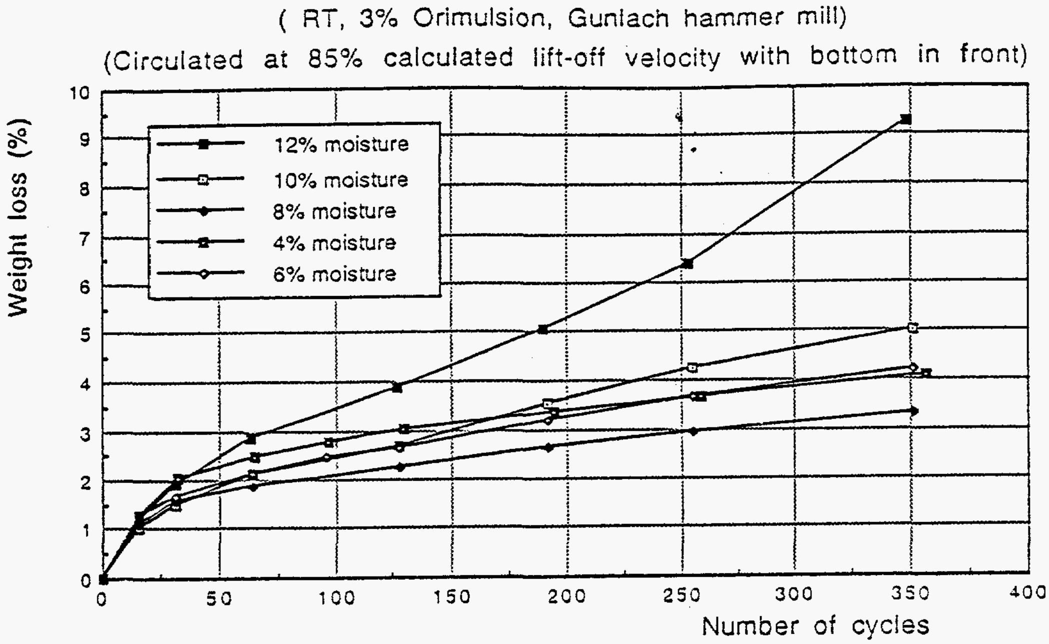

Figure 7 - Average circulation test results for rapidly compacted coal logs with various moisture contents.

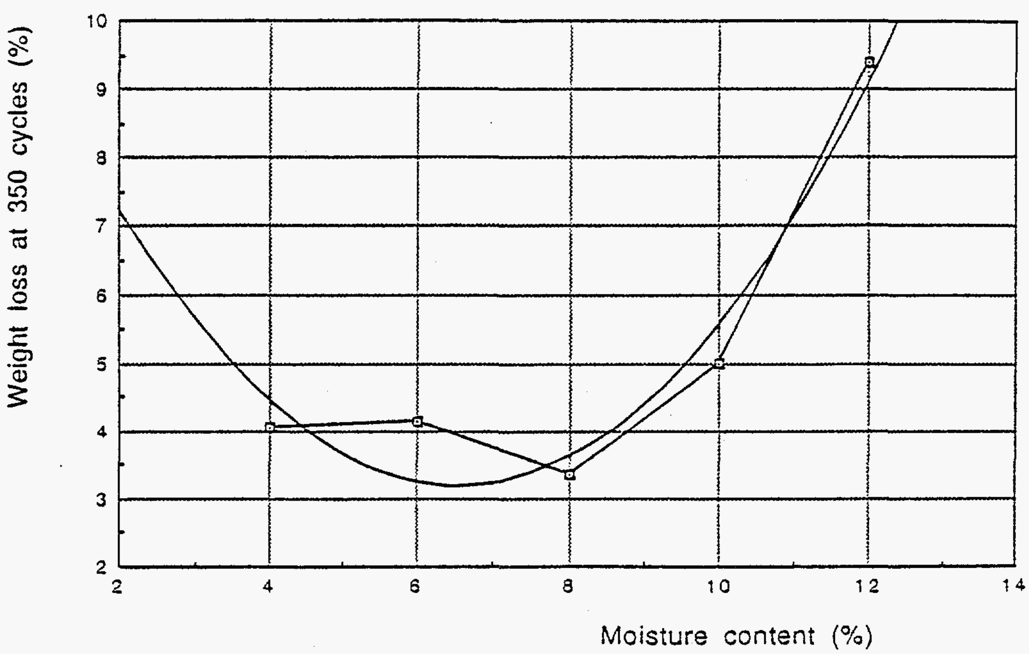

Figure 8 - Average circulation test weight loss after 350 cycles for rapidly compacted coal logs with various moisture contents.

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report

(Period Covered: 04/01/96-06/31/96)

Project Title: **Fast-track experiments**
Principal Investigator: Yin Li
Co-Investigator: Dr. Henry Liu
Research Assistants: R. Gorde, B. Tao, and C. Yates
Purpose of Study:

1. Lubricant Endurance Life
To investigate the endurance lives of calcium stearate powder, MoS_2 powder, and MoS_2 dry film in the application of coal-log compaction

2. Effects of Mold Cleaning
To study the effect of mold surface cleaning on coal log quality.

3. Particle Size Distribution Effects
To investigate the effect of particle size distribution (under the same top size) on coal log quality.

4. Standard and Testing Procedures in Laboratory for Coal Log Fabrication
To standardize the methods for fabricating and testing coal logs; to minimize uncertainties in coal log manufacturing and test procedures; to serve as a manual for training new research assistants.

Work Accomplished during the Period:

1. Lubricant Endurance Life

The mold surface was pretreated by first degreasing and then sand-blasting the surface. After the pretreatment, calcium stearate powder was first tested for lubricating the mold surface. Logs were compacted and the ejection force (or friction force) were measured for use as an indicator for the endurance life of the lubrication. The experiment was stopped once the ejection force reached that of the unlubricated mold. Following calcium stearate powder, MoS_2 powder and MoS_2 films were tested. A total of 47 coal logs were made. All logs were made at room temperature, 18,149 psi peak pressure and 6 minute loading-6 minute unloading without holding. A project completion report was submitted (Li et al., 1996a).

Major conclusions:
1. The endurance life is one compaction cycle for calcium stearate and about five to ten cycles for MoS_2 powder. However, the effectiveness of lubrication was reduced considerably after the first two cycles in the case of MoS_2 powder.

2. The endurance life of MoS_2 films--Dow Corning 321 Dry Film and E/M Perma-Slik Solid Film are similar and no more than two compacting cycles (Fig. 1). It was noticed that the film was scratched severely by coal particles after one compaction cycle.

3. Coal logs made in solid film cases (both Dow Corning and E/M films) were more stable than those made in powdered lubricant cases. Only one coal log broke in the Dow Corning Film case, and none of the coal logs broke in the E/M film case.

2. Effects of Mold Cleaning

Mettiki coal crushed by the Gundlach Company to - 30 mesh was used to prepare the coal logs. A total of 12 coal logs were compacted using an unlubricated, stainless steel mold (Mold No. 8). Six coal logs were compacted in a clean mold in which the mold was cleaned using hot water after compacting each coal log. Another six coal logs were compacted under the same conditions but without cleaning of the mold in between. All logs were made at room temperature, 18,149 psi peak pressure and 6 minute loading-6 minute unloading without holding. A project completion report was submitted (Li et al., 1996b).

Major conclusions:
1). There is a difference in the average weight loss of coal logs between cleaning of the mold after each compaction and without cleaning (Fig. 2).

2). The results of this experiment indicate that compacting coal logs continuously without cleaning the mold may not introduce major effects on coal log quality for the given unlubricated mold. But if the process is stopped long enough to allow the particles to dry on the mold surface, cleaning of the mold before restarting the process is necessary to maintain the coal log quality.

3). There is a positive correlation ($r = 0.541$) between the coal log diameter before water absorption and coal log weight loss. Fig. 3. indicates that coal logs compacted without mold cleaning tend to have larger coal log diameters or larger radial expansion than those compacted with mold cleaning. In addition, coal logs with higher radial expansion may suffer higher weight loss. The reasons that cause the difference are not clear at this time. It is expected that friction during compaction and ejection and surface strength of coal log may play a role here.

4). The analysis of variance and correlation analysis used in this report are simple and effective in revealing useful information on factors related to coal log quality. Without such tools, it is very difficult to identify the correlation between weight loss and radial expansion because of the relatively low sample correlation coefficient.

3. Particle Size Distribution Effects

The particle size distributions of Mettiki coal crushed by the CPRC hammer mill, the Gundlach Company and the Retsch cross-beater mill were measured. They are shown in Table 1. The comparison of these particle size distribution to that of maximum packing density is given in Figure 4. The difference in coal log quality produced by 12 minute compaction and using the CPRC hammer mill crushed coal and the Gundlach Company crushed coal was studied by Tao and Li. The difference in coal log quality produced by 30 second compaction and using the

Gundlach Company crushed coal and the Retsch Cross-Beater Mill crushed coal was investigated by Li and Yates. A report on preliminary results was submitted (Li et al., 1996c).

Table 1. Particle size distributions of coals crushed by different crushers (Mettiki coal)

No. Mesh	Size (mm)	CPRC hammer mill* (%)	Gundlach Company* (%)	Retsch Cross-Beater-Mill (%)
30-40	0.600-0.425	6.46	3.84	1.12
40-50	0.425-0.300	16.56	6.74	6.18
50-60	0.300-0.250	30.56	9.26	13.47
60-80	0.250-0.180	13.52	14.33	31.88
80-150	0.180-0.104	16.79	25.20	20.77
150-200	0.104-0.075	7.69	10.22	19.88
200-Pan	0.075-0.000	8.42	30.41	6.6
Total		100.00	100.00	99.90

Major conclusions

1. Coal particle size distributions from different crushers are different. Coal crushed by the CPRC hammer mill contents 77% particles that are smaller than 0.3mm while 93% for coal crushed by the Retsch cross-beater-mill and about 90% for coal crushed by the Gundlach Company.

2. For slow compaction, the coal logs made with the coal crashed by Gundlach Company gave better wear resistance than those made using CPRC hammer mill crushed coal (Fig. 5).

3. For 30 second compaction, no difference in weight loss has been found between the coal logs made using coal crushed by Gundlach and the Retsch cross-beater-mill (Fig. 6).

4. Standard and Testing Procedures in Laboratory for Coal Log Fabrication

The first draft of the document (Li, 1996d) has been completed. The draft is now being reviewed by CPRC faculty. A second draft will be prepared based on the comments received.

Future Plan:

The following experiments has been delayed due to lack of man power and training of new students on 30 second compaction. During next quarter, these experiments will be conducted using 30 second compaction:

1. Pressure Effects

Previous experimental results indicate that over pressure can cause cracking and capping. To test the effectiveness of pressure levels between 13,816 to 18,149 psi so that we will have a better idea on how to select the compaction pressure at different conditions. In this study, we will test MAPCO coal with an unlubricated surface condition, room temperature, with 0, 1, 2, and 3% binder and 8% moisture at seven pressure levels (13816, 15357, 16753, and 18149). Three logs will be made and tested for each run. A total of 48 logs will be made and a final report will be submitted.

2. Diameter Ratio Effects

To investigate the log diameter ratio effect on coal log wear resistance, coal logs will be made from Mettiki coal using three molds with different diameter: 2.18″, 1.91″, and 1.75″. A total of 9 coal logs will be compacted at room temperature and with a binder concentration of 3.0%. The surface condition of the mold will be an unlubricated, stainless-steel mold. The peak pressure will be 18,000 psi. Wear resistance will be used to assess the log quality. Previously, comparisons were made between only the 1.75″ and 1.91″ logs. The new test will include 2.18″ logs, thereby extending the test to larger diameter logs than done previously.

3. Ejection Orientation Effects

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

References:

Li, Y., B. Tao, and H. Liu. "Lubricant Endurance Life", Project completion report, July 5, 1996a.
Li, Y., B. Tao, and H. Liu. "Effects of Mold Cleaning", Project completion report, May 15, 1996b.
Li, Y., B. Tao, C. Yates, and H. Liu. "Particle Size Distribution Effects", Report on preliminary results, June 6, 1996c.
Li, Y. 1996d. *Standard and Testing Procedures in Laboratory for Coal Log Fabrication.*

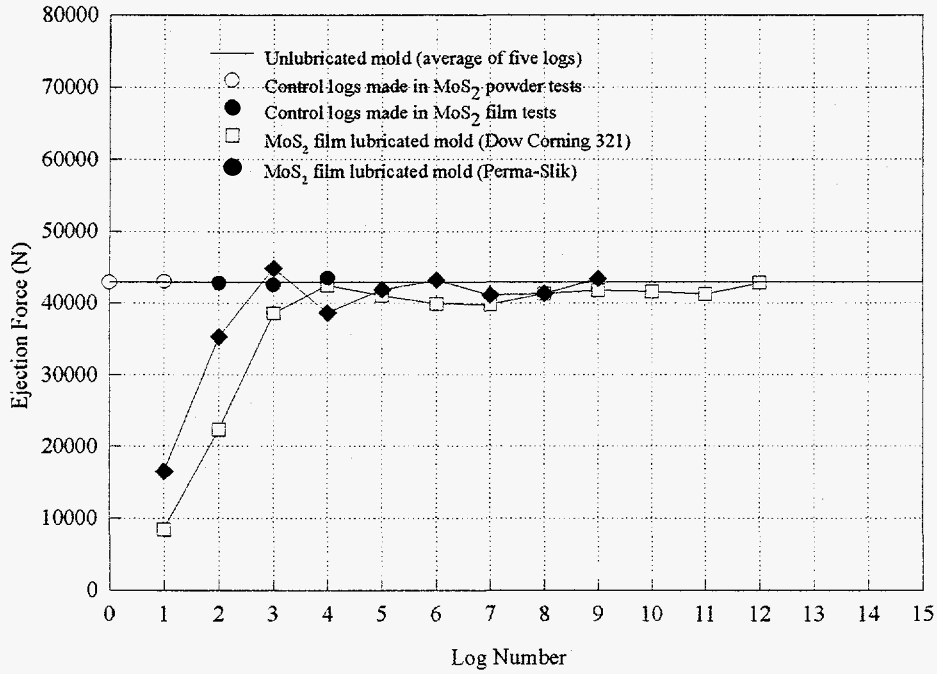

Figure 1. Ejection force with MoS_2 film lubrication

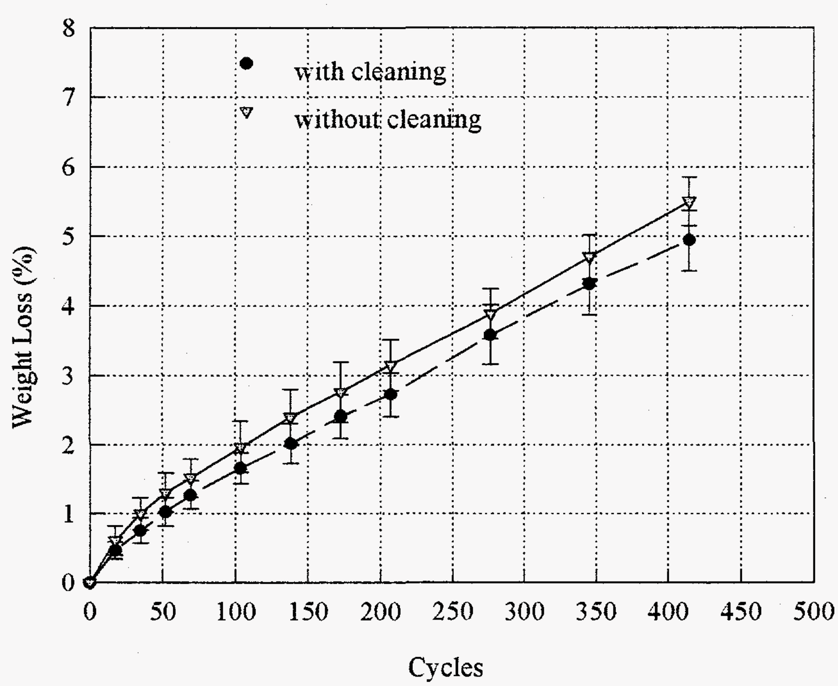

Figure 2. Weight loss of coal logs compacted with and without mold cleaning (1% Orimulsion; room temperature; 18,149 psi peak pressure).

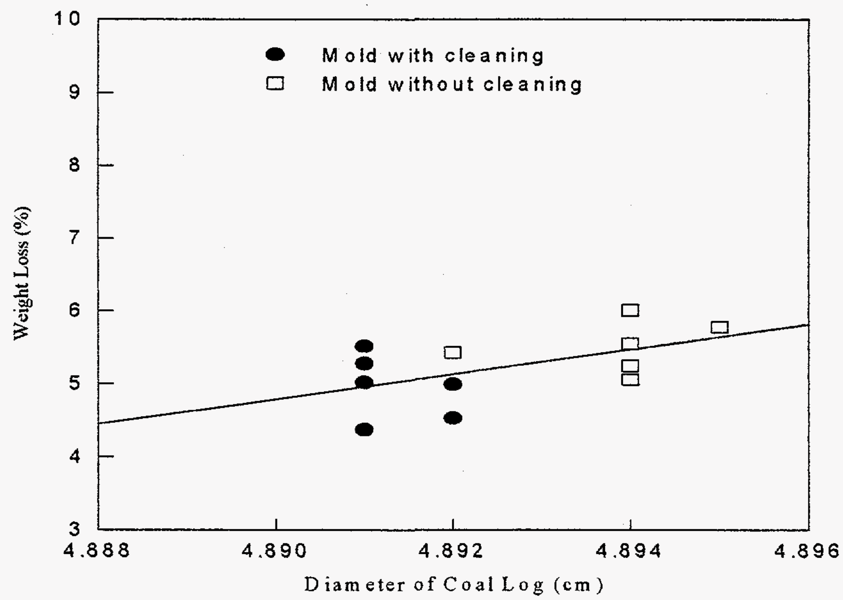

Figure 3. Correlation between weight loss and coal log diameter before water absorption (1% Orimulsion; room temperature; 18,149 psi peak pressure).

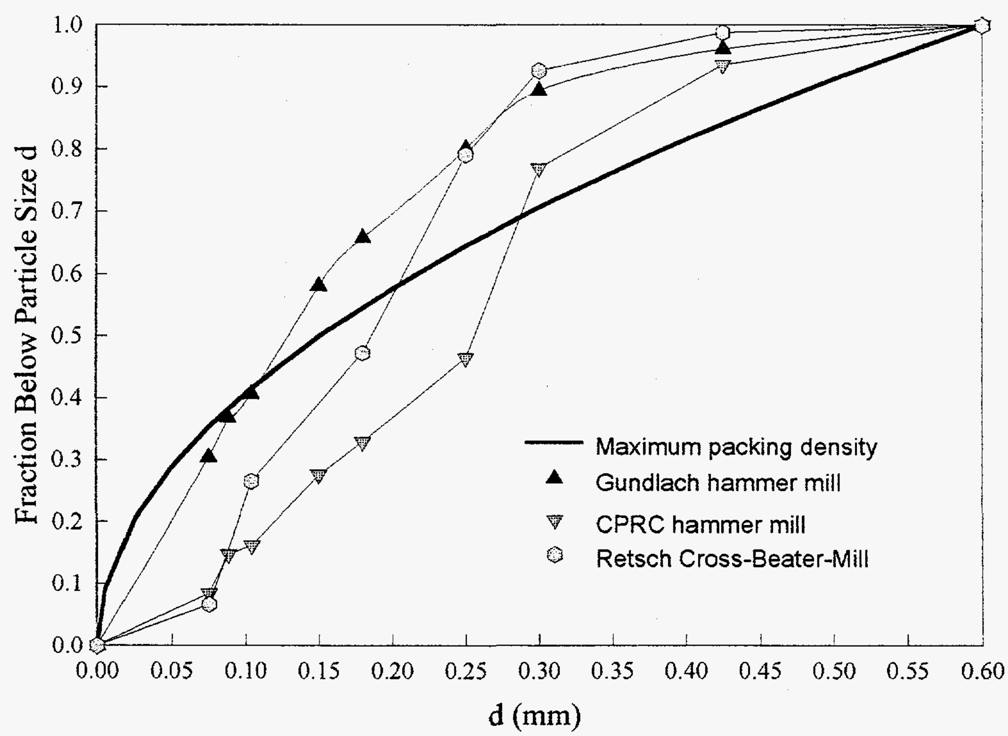

Figure 4. Comparison of particle size distributions of Mettiki coal

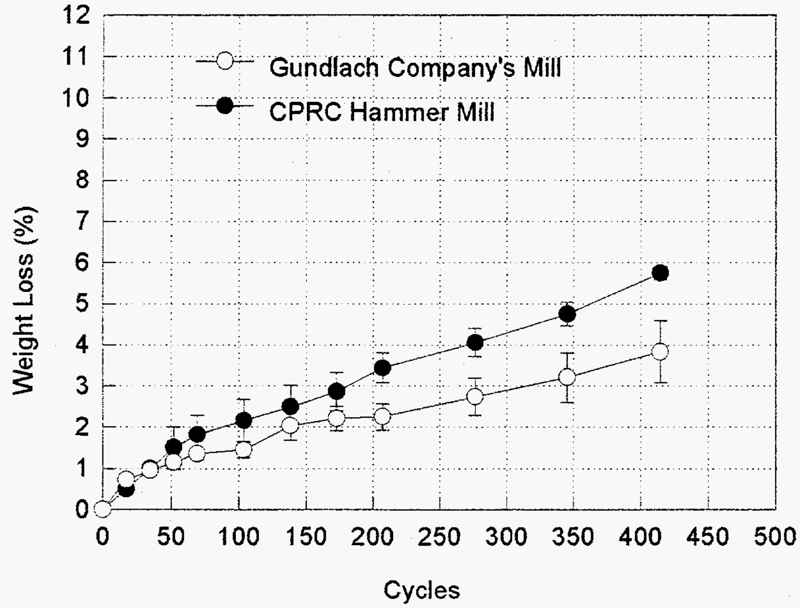

Figure 5. Effects of particle size distributions (CPRC vs. Gundlach) on coal log quality (12 munite compaction; 1% Orimulsion; room temperature; 18,149 psi peak pressure).

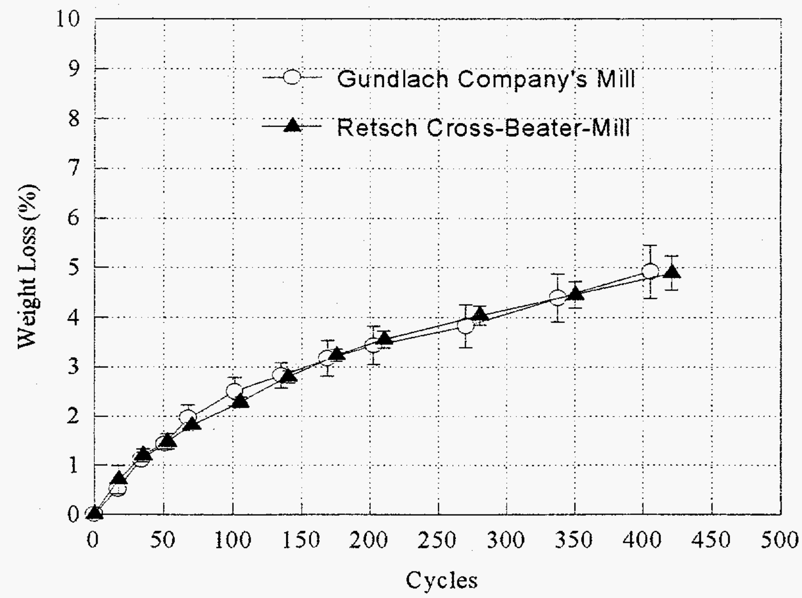

Figure 6. Effects of particle size distributions (Retsch cross-beater-mill vs. Gundlach) on coal log quality (30 second compaction; 3% Orimulsion; room temperature; 18,149 psi peak pressure).

COAL LOG PIPELINE RESEARCH PROJECT

2nd Quarterly Report For 1996

(Period Covered: 04/01/96-06/30/96)

Project Title: **Coal Log Fabrication Using Hydrophobic Binders**

Project Investigator: Dr. John W. Wilson
Co-Investigator: Dr. Yungchin Ding
Research Assistant: Bing Zhao

Purpose of Study:

In order to accelerate the commercialization of the coal log pipeline technology, the durability of commercial size coal logs is considered to be one of the most important tasks that must be evaluated through large pipeline degradation tests. In the earlier work, the performance of large coal logs were evaluated based on the basis of tumbling test results. However, the tumbling test results can only provide a relative index for the assessment of the abrasive resistance of coal logs that were made under a variety conditions. It is believed that only the pipeline degradation test can accurately reveal the true durability and abrasive resistance of coal logs. Therefore, a 6-inch-diameter, 320-ft long pipeline test loop has been planned and constructed at UMR for testing 5.3-inch-diameter coal logs.

Work Accomplished during the Period:

In the past three months, all effort of the UMR team has been concentrated on the construction of the 6" pipeline loop and the installation of necessary supplementary facilities. To date, all work on building the 6" pipeline system has been accomplished as scheduled, and the pipeline is being calibrated and tested for coal log degradation tests. The overall 6" pipeline test system is shown in Fig. 1 & 2.

The major work completed during the period includes:

Construction and installation of the main pipeline system

1. Constructed and painted the 320-ft long steel pipe loop of 6.187-inch internal diameter (Fig. 3).

2. Prepared footings and built the concrete foundation for the support of the major pieces of equipment.

3. Lined-up and installed the major pieces of equipment (Fig. 4), including:

   a. A 25 HP - Bell & Gossett 6BC series 1531 centrifugal pump (Fig. 5);
   b. Jet pump and diffuser designed and manufactured at UMC (Fig. 6);
   c. A 6-inch diameter water control valve (Fig. 7).

4. Installed and painted the 230 gal water tank (Fig. 8).

5. Connected a 6 ft long plexiglas pipe section to the pipeline (Fig. 9);

Installation and construction of the supplementary facilities

1. Assembled and constructed the 20' x 12' building to cover the major pieces of equipment (Fig. 10).

2. Installed and painted a 2000 gal water reservoir (Fig. 11).

3. Installed a 5 HP water pump and constructed the plumbing system connecting the water reservoir with the pipeline (Fig. 12).

4. Connected the 480 volt and 240 volt electric power system (Fig. 13 & 14).

5. Constructed a steel bridge walkway across the pipeline (Fig. 15).

6. Built the 2' x 180' concrete side-walk alongside the pipeline (Fig. 16).

Future Plans:

1. Calibrate the 6" pipeline system using plexiglas logs and/or aluminum logs.

2. Manufacture 5.3" coal logs under various fabrication conditions.

3. Test the 5.3" coal logs in the 6" pipeline.

4. Compare the degradation test results with small 1.9" coal logs manufactured at the UMC research laboratory under similar conditions.

Figure 1. Overall front view of the 6" pipeline system

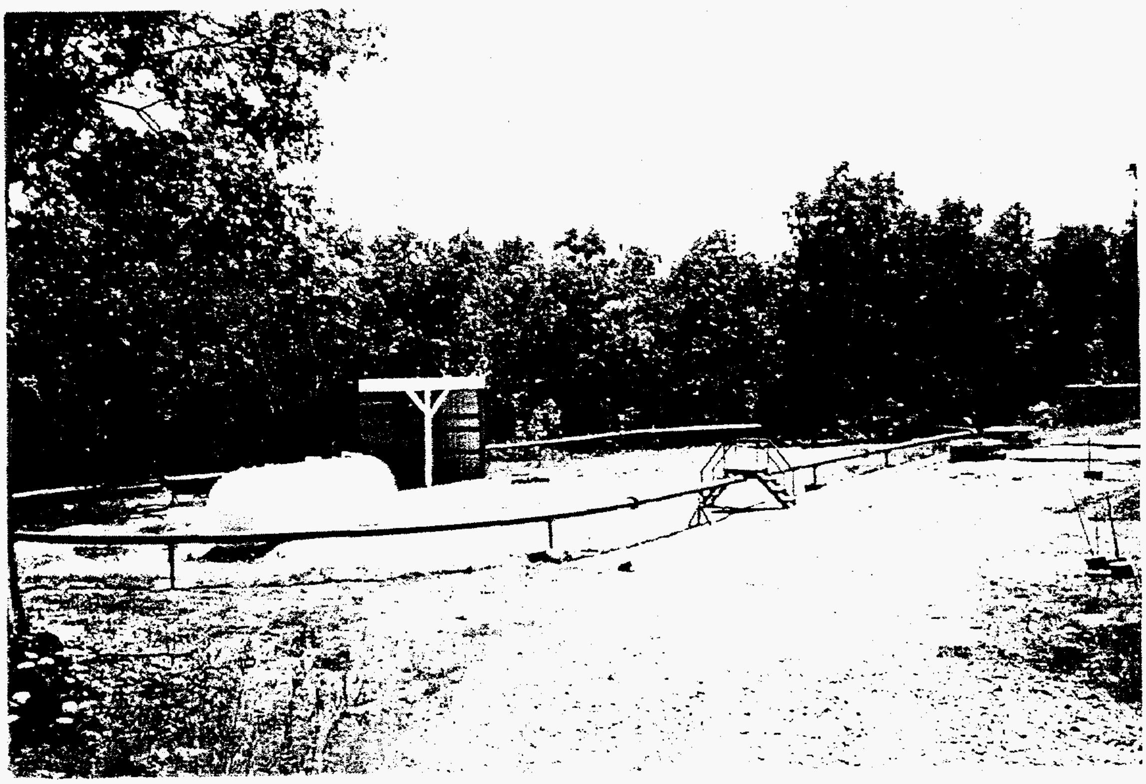

Figure 2. Overall side view of the 6" pipeline system

Figure 3. 320 ft long steel pipe loop

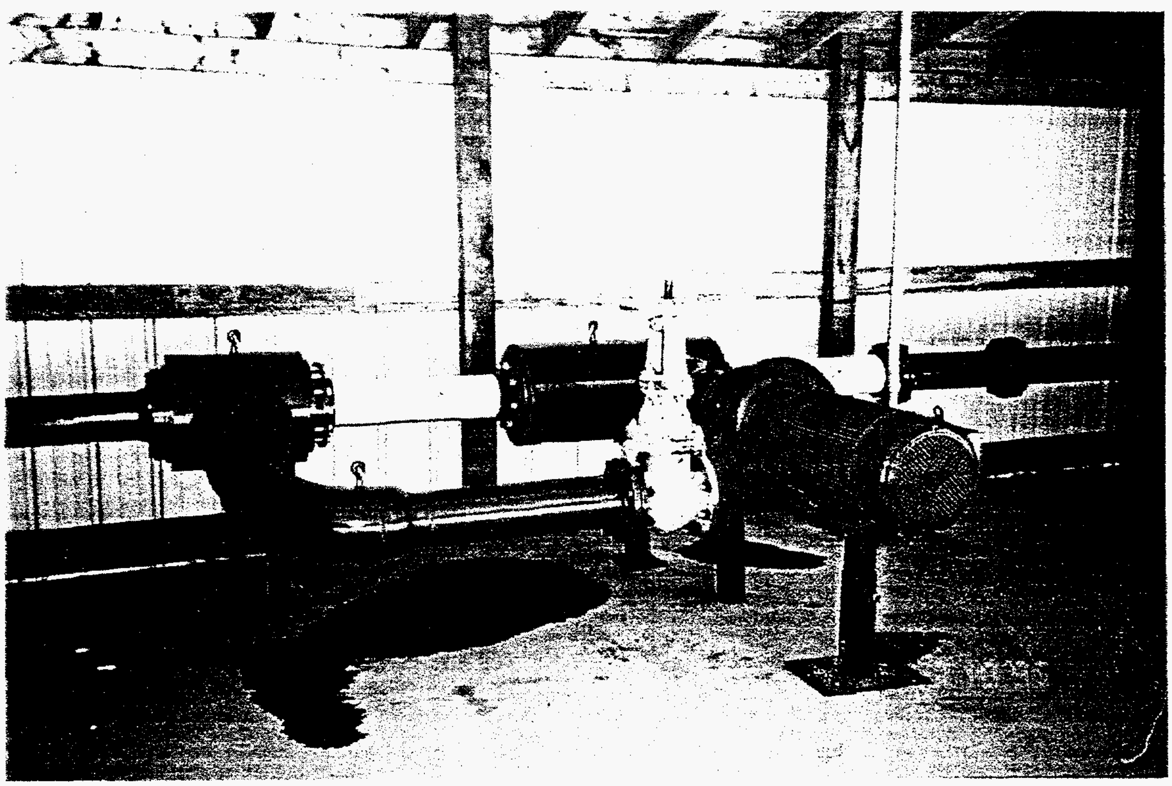

Figure 4. Pump system

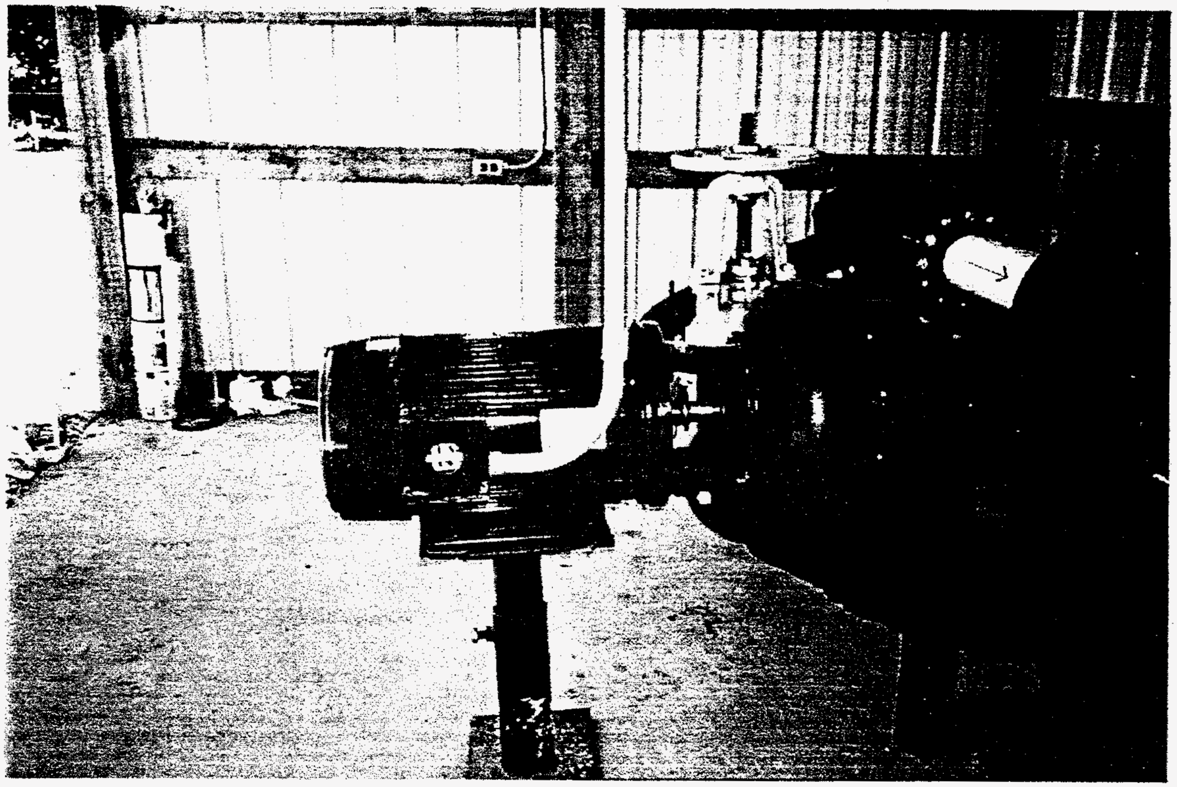

Figure 5. 25 HP centrifugal pump

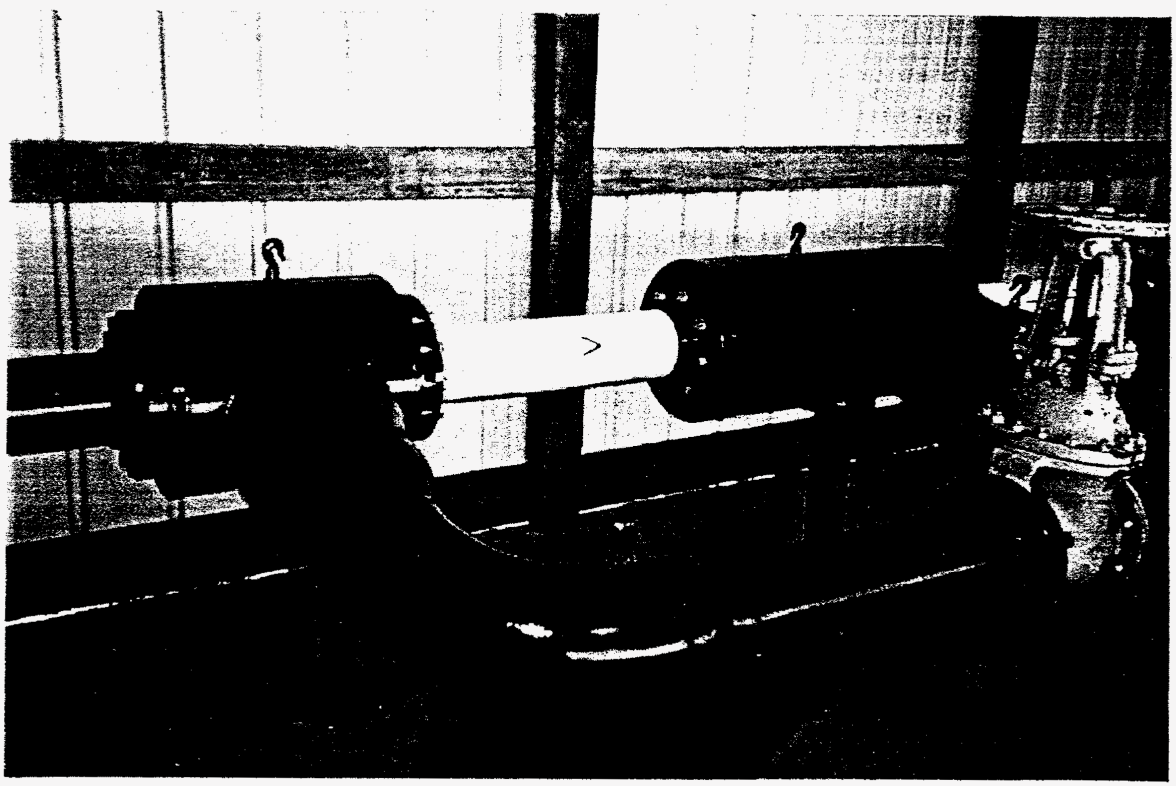

Figure 6. Jet pump & diffuser

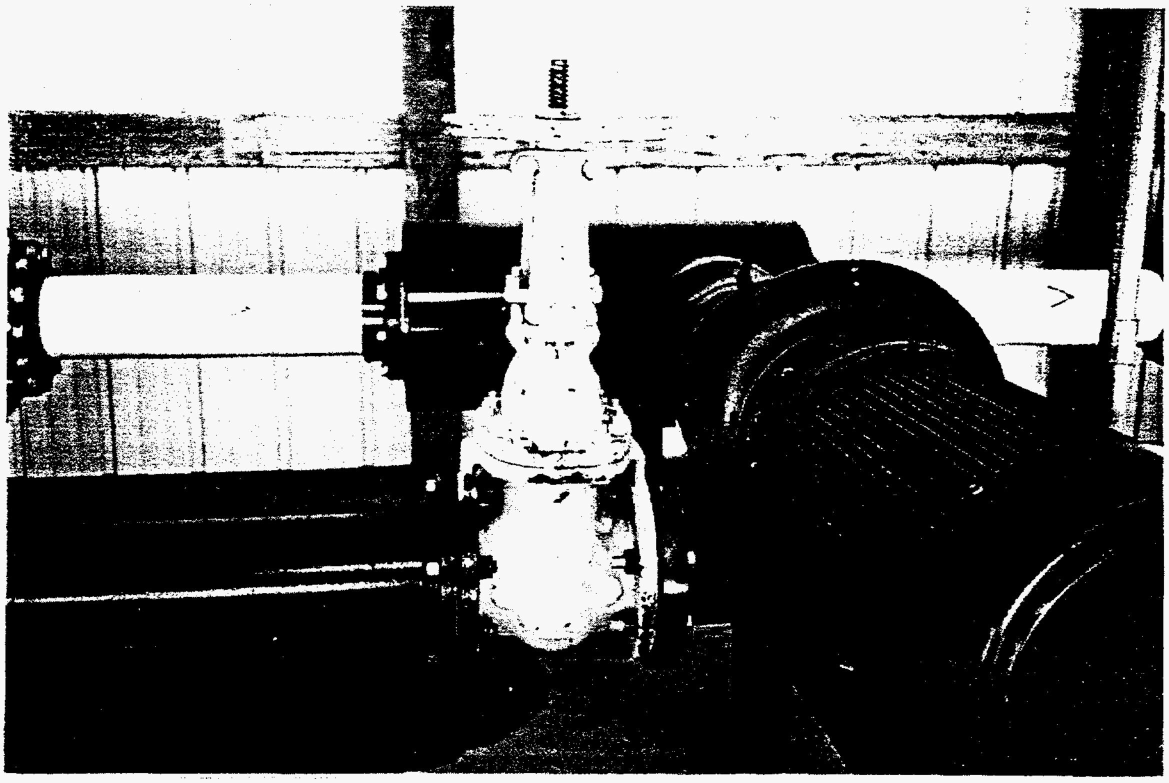

Figure 7. 6-inch diameter water valve

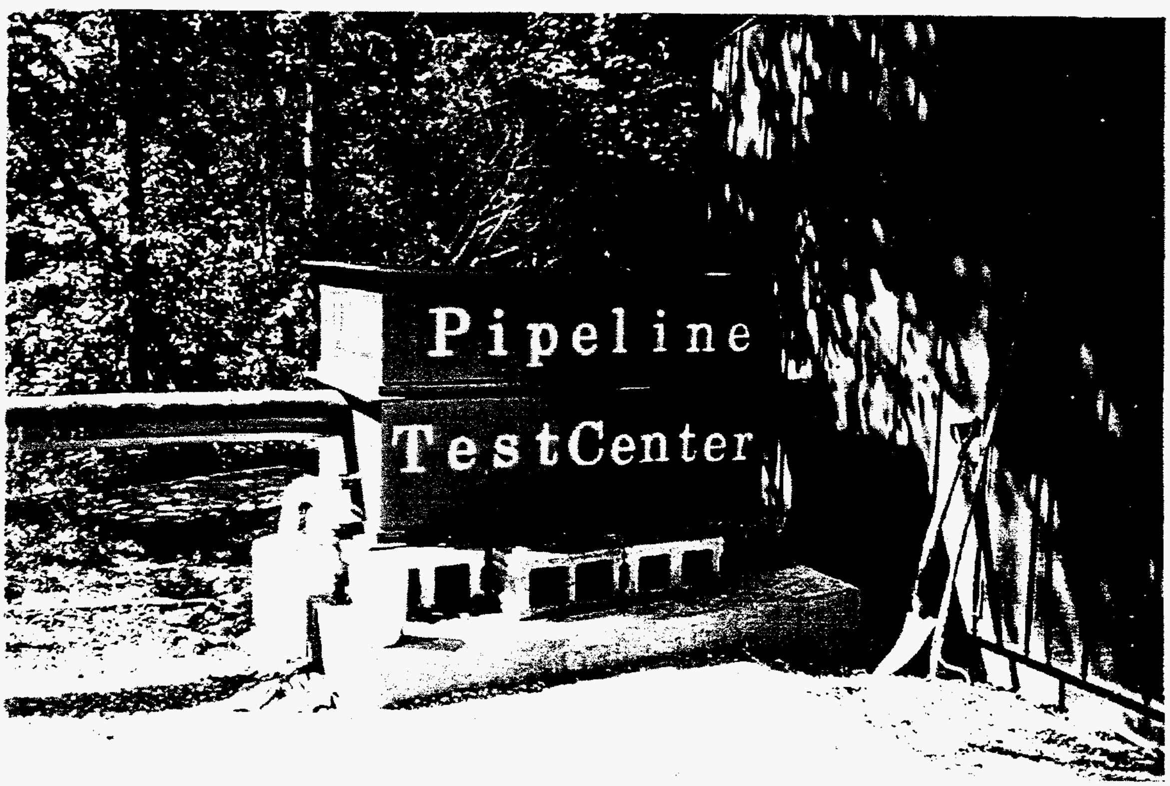

Figure 8. 230 gal steel water tank

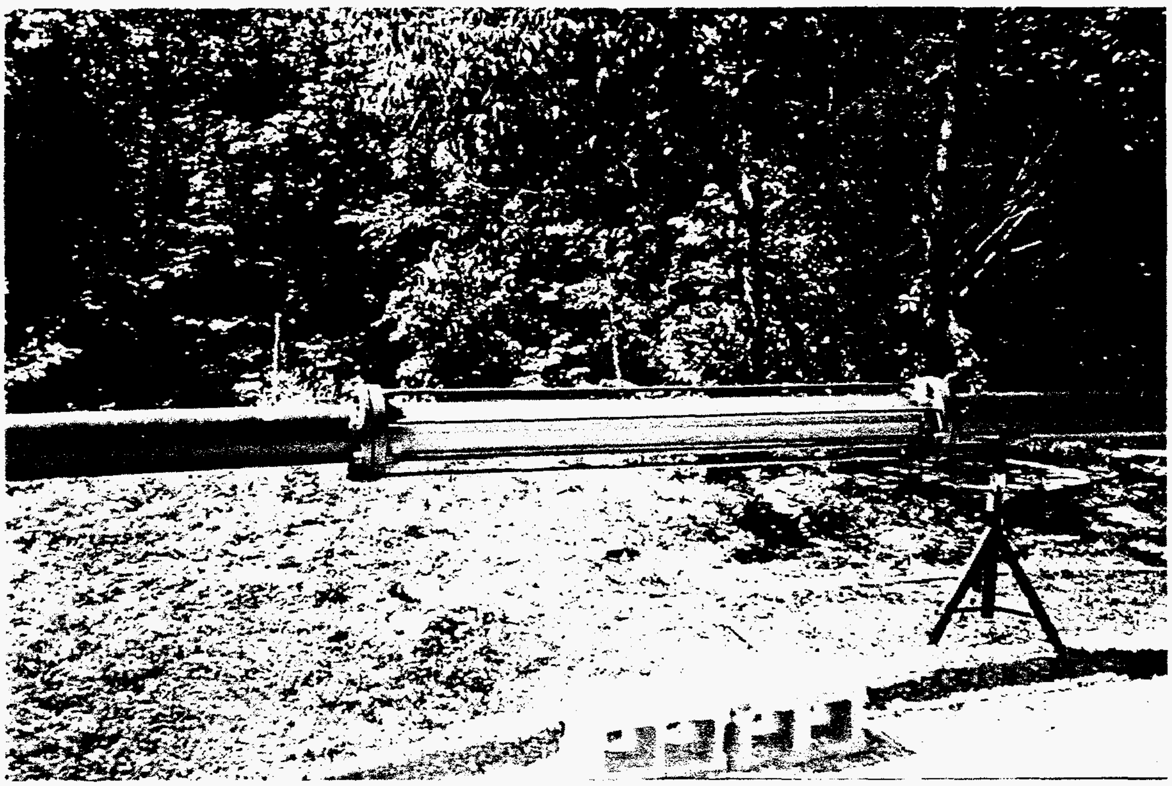

Figure 9. 6 ft long plexiglas pipe section

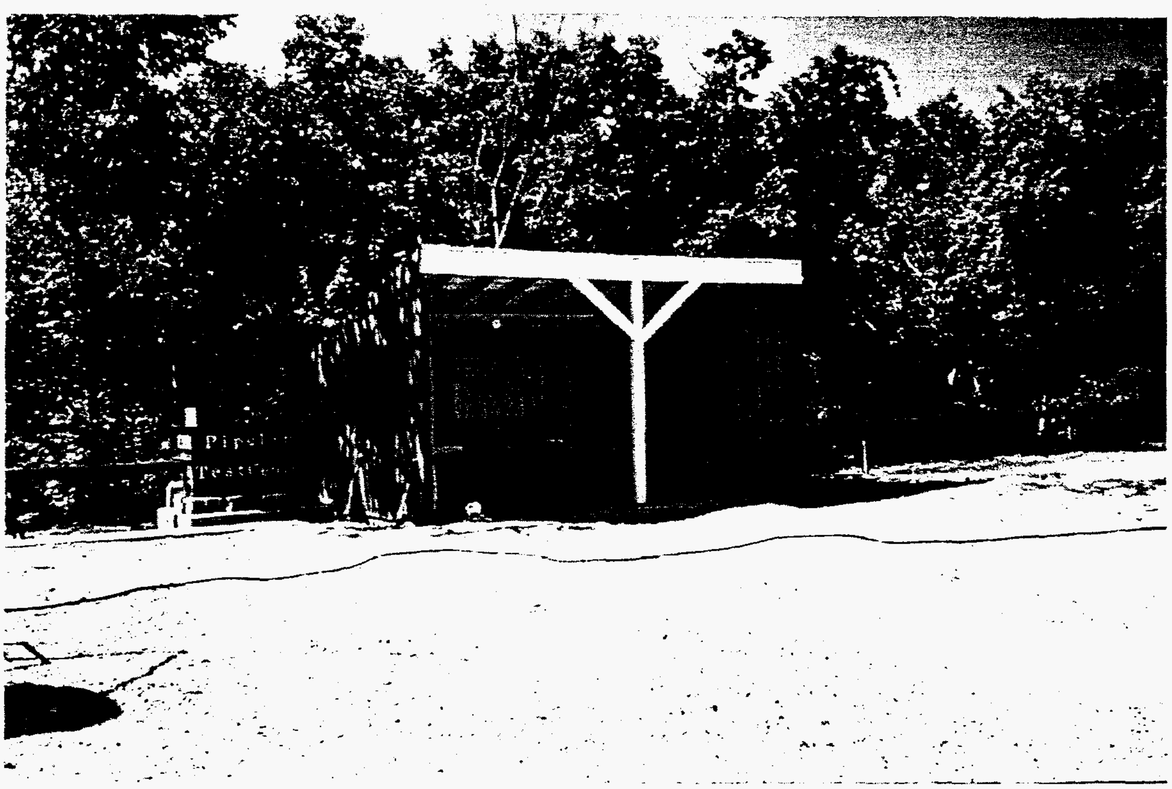

Figure 10. 20' x 12' building

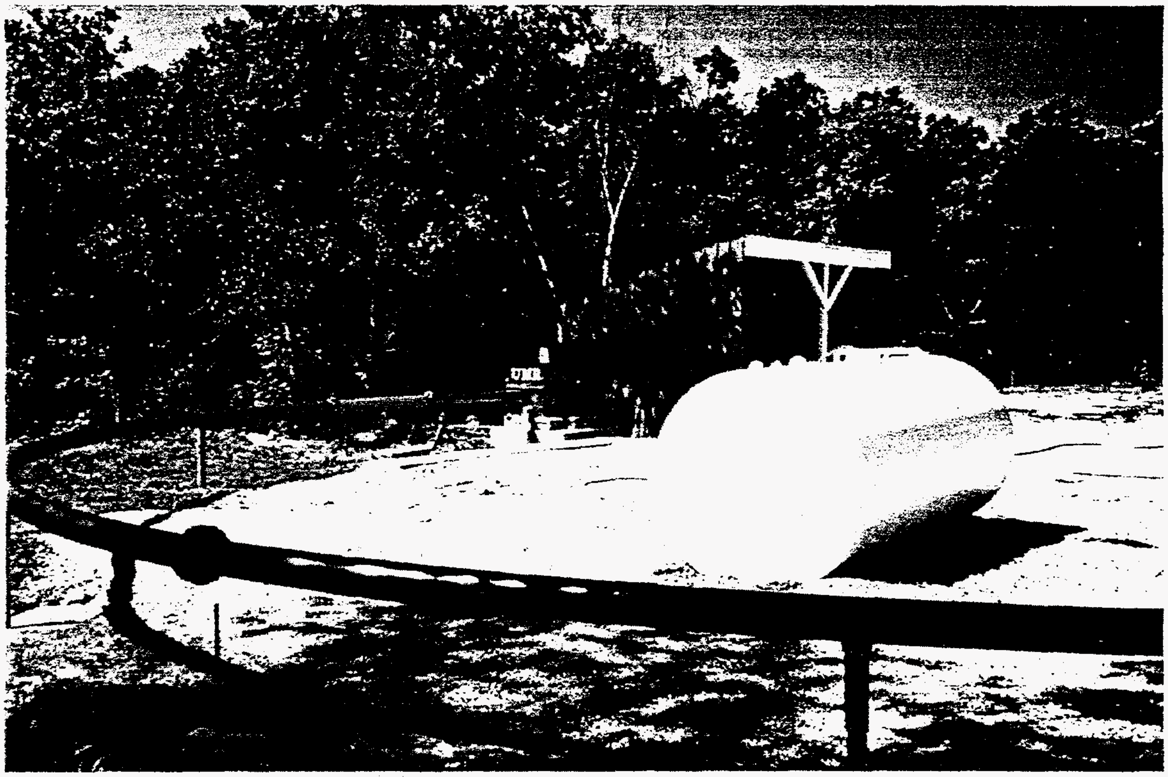

Figure 11. 2000 gal water reservoir

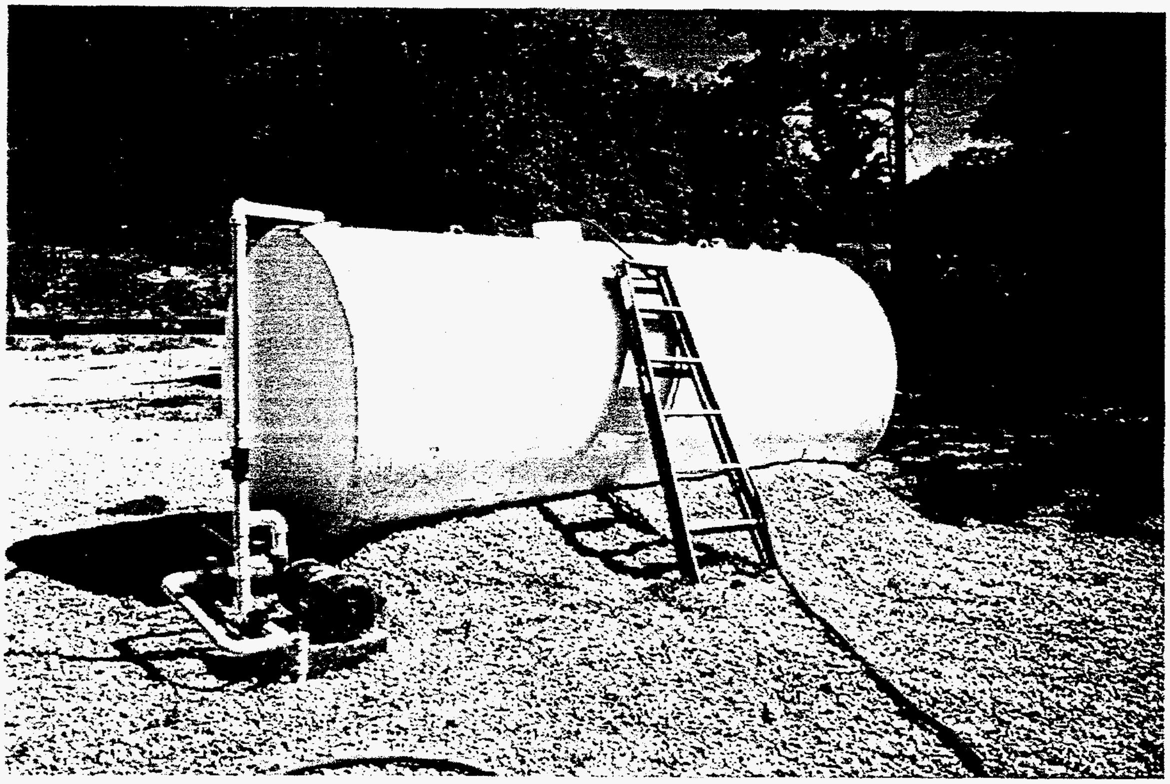

Figure 12. 5 HP water pump & plumbing system

Figure 13. Main power system

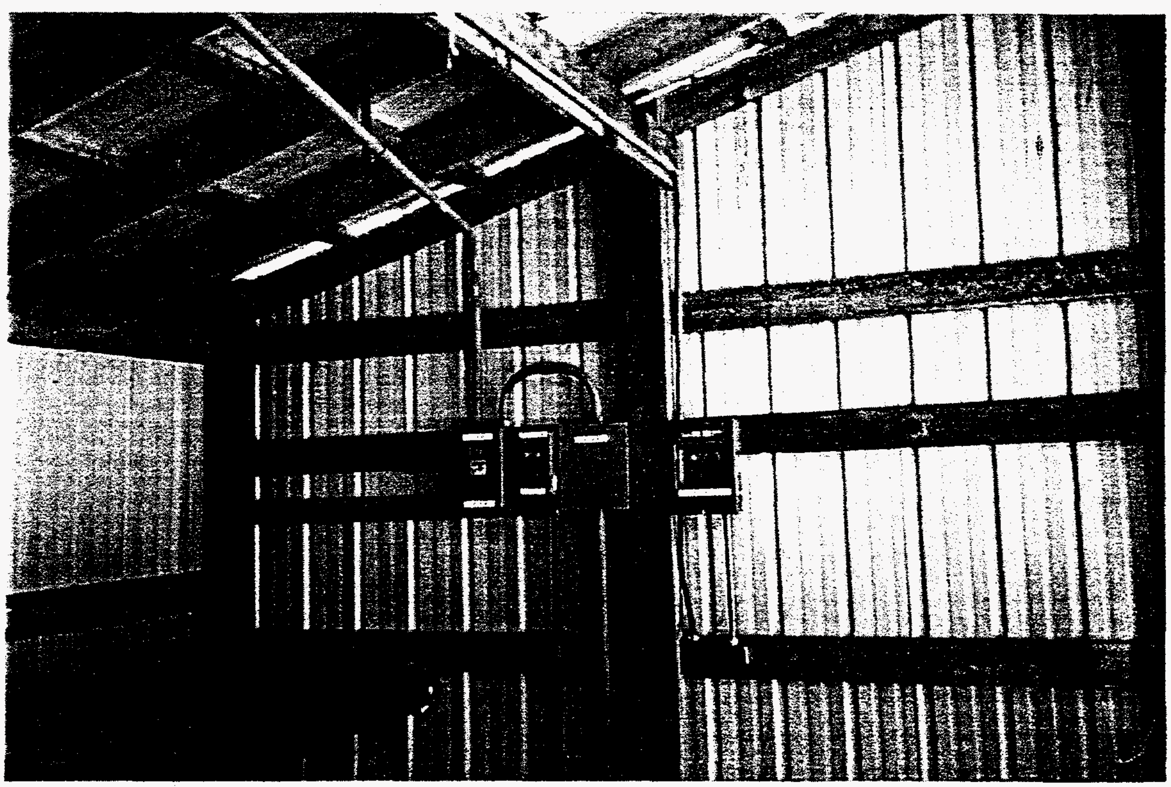

Figure 14. 480 volt & 240 volt power

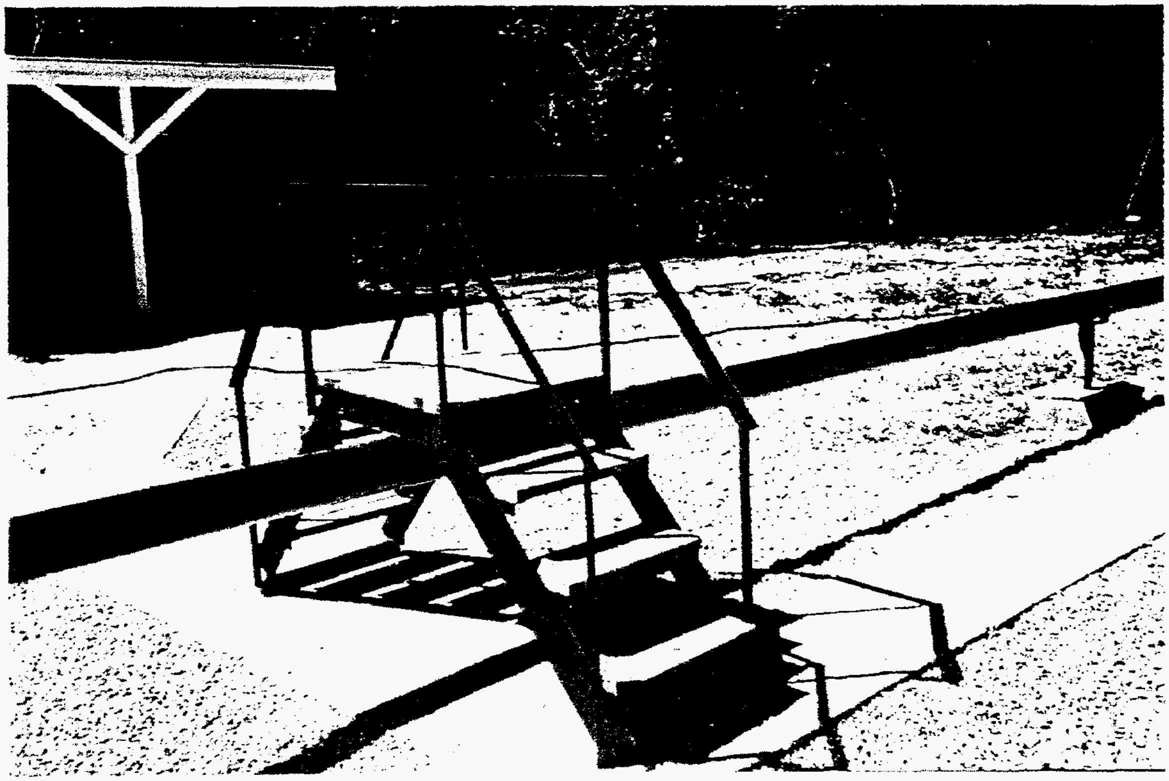

Figure 15. Steel bridge walkway

Figure 16. 2' x 180' concrete side-walk

Capsule Pipeline Research Center
Quarterly Report
(Period Covered : 4/1/96 - 6/31/96)

Project Title : Automatic Control of Coal Log Pipeline System

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

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

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

Work Accomplished During the Period :
The remaining specific tasks (for 1 Jan to 31 Aug. 1996) from the pervious quarter were : were defined as follows: (ii) Develop the simulation model of the pump bypass with a recirculating loop with valve stroking for the water-only case. Again, study transient effects; (iii) Add the train separator designed to the simulation model in (ii); (iv) Perform experiments on the small scale system and validate the observations and results in (ii) and (iii). This includes using a high-speed video recording system, a data acquisition board, getting flow and pressure sensors, etc. Modify the control program to accommodate the changes. Based on the results of the experiments, adjust the simulation program to take care of all realistic effects, including friction losses, etc.; and (v) Prepare a report of the subtasks performed.

Simulation Model of the Train-Separator

Due to the necessity of resolving the issue of whether there will be negative pressures at specific locations due to the operation of the pump bypass, and whether the associated velocity reversals would be significant, it was decided to focus much more on task (ii) than previously envisaged. This obviously would be at the cost of not performing or performing to a limited extent the other tasks, (iii) to (v), since the simulation model takes considerable time to run and the time associated with plotting and data analysis for each run is also huge. But, the importance of understanding whether the pump bypass was reliable from a detailed simulation point of view was felt to be of paramount importance by Dr. Liu and so focus was on this task only.

Specifically, a detailed simulation incorporating the pump bypass in a 20 mile test loop was developed (see attached figure which is repeated here from the previous report). It was thoroughly checked for accuracy before exercising different valve stroking scenarios for the pump bypass. The different valve closure scenarios to reduce negative pressure (and associated flow reversals) included (T below was varied from 3 to 9 seconds):

(i) linear valve closure in T seconds

(ii) instantaneous valve closure for comparison

(iii) closure with time delay between opening and closing of valve sets

(iv) different linear combinations of closure rates; closure in 50% to 95% of T

(v) strategy in (iv) + hold

The idea in trying different closure rates was to check whether an 'optimal' k for the valves could be found for energy dissipation to prevent negative pressures. After extensive simulation tests, it was determined that valve stroking strategies could not alleviate the problem, although several strategies did reduce the magnitude of the negative pressures. These simulation runs took an inordinate amount of time - note 20 miles of pipeline is being simulated. The test conditions and results are currently being documented as part of a 400 Report.

The possibility of using an air chamber upstream of the pump bypass was then investigated since this could make the valve scheduling easy. Preliminary results show that it is a good solution. This is being investigated in detail and optimized at the present time. Reducing the distances between the pump bypass stations could also help. This is an issue which should also be studied later.

Work Proposed for the Next Two Months :

(i) complete optimizing the air chamber design using simulation and thoroughly check its impact on the problems investigated.

(ii) Complete writing the various tests performed as a 400 Report and present it to the committee. An outline for the Table of Contents for the 400 Report has already been completed (expected to be more than 100 pages). This will consume a lot of time.

(iii) Based on the simulation investigations performed, write up the guidelines for the design of the large scale commercial system.

(iv) Due to the importance assigned to task (ii) of the original task list, not much work was performed on the patent application for the novel train separator sub-system developed by Nair and Du. The patent application has to be completed before Nov 96 since the design has been published in Nov 95 already. The work that had already been started and well underway will be completed in the next two months.

The SCADA system issues, etc. which were tasks beyond the ones specified in the 1 Jan - 31 Aug 96 time frame, that were outlined in the previous reports will have to be conducted at a later date.

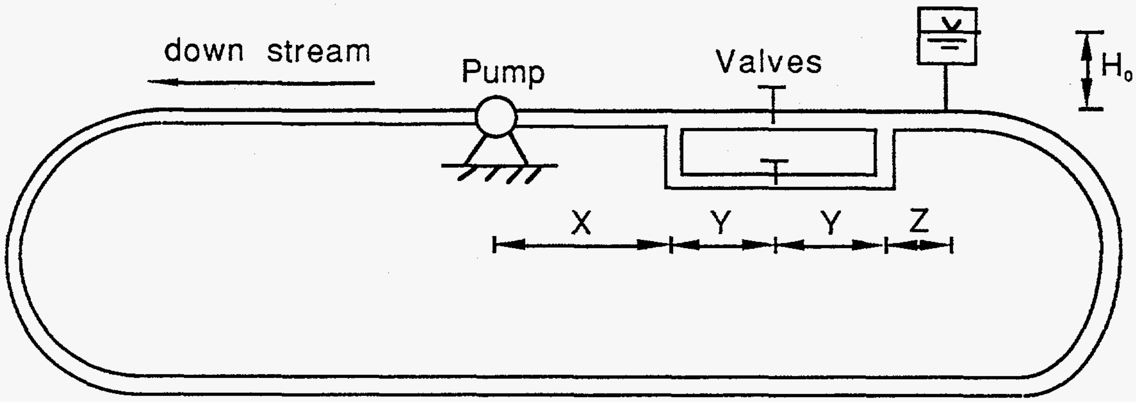

Figure 1. Simulation model for Task 12.2

g: 9.8 m/s^2

f: 0.018

ρ: 1000 kg/m^3

D: 0.2032 m (8")

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

Distance from reservoir to the two branches, Z = 10 m (32.8 ft)

Distance from the two branches to pump, X = 620 m (2034.1 ft)

Recirculating loop length: 32000 m (20 miles)

Length of bypass, 2Y = 120 m (393.7 ft)

Reservoir head, H_0 = 20 m (65.6 ft)

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

CAPSULE PIPELINE RESEARCH CENTER

Quarterly Report
(Period Covered: 4/1/96-6/30/96)

Project Title: Hydraulics of CLP

Principal Investigator: Henry Liu, Professor of Civil Engineering

Research Assistants: Xiang Gao and Wenwei Xu

Purpose of Research:

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

Work Accomplished During the Period:

Task 1: Improving model for prediction in horizontal straight pipe.

Mr. Wenwei Xu continued to work on the model to improve the prediction of capsule pressure gradient and capsule velocity for a train of capsule in a straight, horizontal pipe. Using data collected in the laboratory in a 2-inch pipe, he was able to determine: (1) the resistance coefficients f_c (for capsule) and f_p (for pipe) as a function of Reynolds number, (2) the average shear stress t_p (on pipe) and t_c (on capsule) as a function of capsule velocity V_c , and (3) the lift coefficient C_L (of capsules) as a function of capsule velocity. The result was useful in improving the accuracy for predicting capsule pressure gradient and capsule velocity in pipe. Mr. Xu is completing an M.S. thesis on this topic and will graduate in August.

Task 2: Developing a model for predicting hydraulic behavior of capsules (and coal logs) in sloped and curved pipe.

As a first step, Mr. Gao has completed the derivation of the equations needed for predicting capsule (coal log) behavior in a sloped but otherwise straight pipe. The possibility and conditions for capsule tilt in the pipe, and for capsule to slide on the pipe when the slope is steep have been analyzed.

Future Plan:

During the next three months, Task 1 will be completed and Task 2 will continue. Task 2 will start to investigate the effect of pipe bends on capsule behavior in pipe.

CAPSULE PIPELINE RESEARCH CENTER
QUARTERLY REPORT

(Period covered: 4/1/96 to 6/30/96)

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

Purpose

During the last quarter the purpose of the study became more focused in order to complete the heat transfer analyses by August 31, 1996; only two systems will be evaluated: a screw conveyor and an enclosed-belt conveyor for heating crushed coal prior to compaction.

Work Accomplished During this Period

1. Started analysis of conductive heat transfer to coal particles as a function of particle size, temperature and time.

2. Initiated general equations for system design, size and power requirements.

3. Began investigation of convective heat transfer coefficients for gas-solid systems.

4. Defined two types of systems for evaluation; namely, screw conveyor and enclosed-belt conveyor; evaluations of other systems have been stopped.

5. Sent some coal samples to equipment manufactures to obtain commercial cost estimates.

Future Work

1. Complete the final report for analyses of coal heating by screw conveyor and enclosed-belt conveyor systems. This report will describe the system function, equipment size, materials of construction, safety features and utility requirements (S. Wang).

2. Summarize the available information from vendors for commercial coal heating system availability and costs (W. Burkett).

Design of a Demonstration/Test Pipeline

by

Charles Lenau

Introduction

Professor Henry Liu of the Capsule Pipeline Research Center asked me to design a 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 at least 1/2 mile with a nominal diameter of 6 inch. The pipe joints are to be welded and the interior of the joint smoothed. The coal logs are to be produced by a machine which can produce one log each 20 seconds for up to 100 logs.

Loop and Log Specifications

Because of the proposed location of the test loop facility, the maximum length of the loop is approximately 3000 ft. Excluding the injection system all pipes will have an internal diameter of approximately 6 inch. Schedule 40 steel pipe which has an interior diameter of 6.065 inch would suffice. The maximum bulk velocity is to be 10 fps which is about 110% of the log liftoff velocity.

The coal log machine has a mold diameter of 5.4 inch and can produce logs up to 11 inches in length. However, the finished coal logs may have a diameter as large as 5.5 inch because of log expansion. Based on a 5.5 inch diameter and schedule 40 pipe the maximum diameter ratio $k = D_C/D$ is 0.907. The maximum aspect ratio $a = L_C/D_C$ is 2.0. Terms D, D_C and L_C are respectively the interior diameter of the pipe, the diameter of the coal log and the length of the coal log.

Because the coal supplying the log machine is batched, there is a delay after the completion of 100 logs. Hence, each log train will contain up to 100 logs. The injection and bypass locks are designed for this train length.

Designs

At this time the writer has three preliminary designs. Here they are referenced as design 1, design 2 and design 3. Design 1 combines the injection and bypass system in order to minimize cost. For design 1 the injection and bypass systems cannot be operated simultaneously, thereby restricting flexibly of operation. Design 2 has one injection lock and the pump bypass. The two systems can be operated simultaneously, thus allowing flexibility of operation . Design 3 has two injection locks and the pump bypass. The three systems can be operated simultaneously thereby allowing greater flexibility of operation and greater injection capability then design 2. Design 2 is sufficient for the operation of the test loop with one coal log machine. However, Design 3 better demonstrates the operation of a commercial coal log pipeline.

While the three designs described above have many differences, they also share some common features. The ejection system for each design is basically the same.

Each design has one driver pump which develops the head necessary to maintain flow in the loop. For a high line fill in the loop a pump head of 369 ft is needed at a bulk velocity of 10 fps. Assuming an 80% pump efficiency a 105 hp motor will be required.

The configuration of the injection system is different for the three designs. However, during the loading of logs into a lock, the lock is isolated from the pump bypass and other injection locks and, operates the same for the three designs. Each log enters the upstream end of the lock along with the flow and is accelerated due to gravity and water flow to a velocity of about 1.1 fps. The log then travels along the lock until it comes to rest against the growing train of stationary logs at the end of the lock. In other words the log stack up at the end of the lock. Figure 1 illustrates this process. The bulk velocity in the lock will have to be about 1.9 fps in order to keep the logs moving until they come to rest against the stack. The flow passing through the annular region between the pipe wall and the stationary coal logs will create an excessive pressure drop in the lock unless the diameter of the lock pipe is greater than 6 inch. A diameter of 7 inch for the lock pipe will produce a pressure drop for a train of 100 logs of about 10 ft. However, for 6 inch diameter the pressure drop would be about 168 ft ! This large pressure drop is not possible because it would occur on the suction side of the loading pump driving it to cavitation.

design 1

Design 1 is shown in Figure 2. Table 1 shows the valve settings for different operations. Figures 3 through 8 show the flow directions corresponding to the valve settings in Table 1. During loading portion of injection, the discharge in the main loop is zero. Water is circulated from the reservoir through valves V_5 and V_9 , through the pump and returned to the reservoir via valves V_6 and V_3 . This circulation which is basically similar to that shown in Figure 1, can be used to fill pipe 2 with coal logs. After a log train is in pipe 2 pushout can begin. Water is circulated from the main loop through valves V_1, V_3 and V_8 , though the pump and back to the main loop via valves V_7 and V_{11} . If coal logs are present in pipe 1 then they are pushed out into the main loop. Bypass 1 and bypass 2 modes of operation are used to direct trains around the driver pump while maintaining flow in the main loop. Note that injection(pushout) and bypass 1 have the same valve settings. During ejection a train is diverted through valve V_2 into the reservoir. Flow is pulled out of the reservoir through pipe 1 (ejection 1) or through pipe 2 (ejection 2) to the pump and then pushed into the main loop. The ejection mode that would be used depends upon the position of any other train in the bypass system.

In design 1 the system cannot bypass a train while injection a train. In fact after a train is in the main loop the flow and the train must be brought to rest before a second train can be injected. Nevertheless it is possible to obtain a relatively high line fill with enough patients because the bypass system is complete. Another possible difficulty with design 1 is the diameter of pipe 2. Because this pipe serves as the loading pipe for the injection system it must have a larger diameter then other pipes in the system. Hence after injection pushout one can expect the coal logs to separate somewhat (i.e., the train increases in length) as their velocity increases in the main loop.

design 2

Design 2 is shown in Figure 9. This design has an injection and a pump bypass systems that can be isolated from one another. It is possible to bypass log trains at the same time the injection lock is being loaded with logs.

Table 2 show the various modes of operations. In some cases valve settings are not specified because the injection system is isolated from the pump bypass. Isolation of the injection system occurs whenever valves V_9 and V_{15} are closed. There are two modes of injection pushout. These two modes enable the system to push the train into the main loop from pipe 3 and at the same time bypass a log train. During injection pushout either pipe 1 or pipe 2 must be free of logs. The two modes of bypass operation shown in Table 2 correspond to bypass pushout of either pipe 1 or pipe 2. The four ejection modes correspond to bypass pushout of either pipe 1, pipe 2 or injection pushout from pipe 3. There are two modes for the latter case.

During injection pushout valves V_{10} remains open and the loading pump is operating. This configuration increases the bulk velocity in pipe 3 so that the pushout velocity of the logs is compatible with those in the main loop. Recall that pipe 3 has a larger internal diameter that the other pipes in the system.

design 3

Design 3 is shown in Figure 4. This design is basically similar to design 2 except there are two injection locks. This enables the system to bypass log trains at the same time the two injection locks are being filled. Because loading injection locks will be relatively slow compared to other operations, commercial system will need multiple locks to maintain high line fill. For the test loop considered here, a high line fill can be obtained over a period of time without using multiple locks. Thus, the only reason for building design 3 is to serve as a demonstration of a commercial system.

Comparison of the Three Designs

Table 3 shows the number of valves, the number diverters and the number of pumps for each design. At this time the writer does not have cost for these items. All three designs have two diverters and a driver pump. In addition design 2 has a low head loading pump. Design 3 has two load loading pumps.

The low head loading pumps in designs 2 and 3 would have to be variable speed. For design 1 the driver pump which also serves as a loading pump would have to be variable speed. For designs 2 and 3 the driver pump would have to be variable speed or an additional valve to throttle the pump discharge would have to be added to the designs.

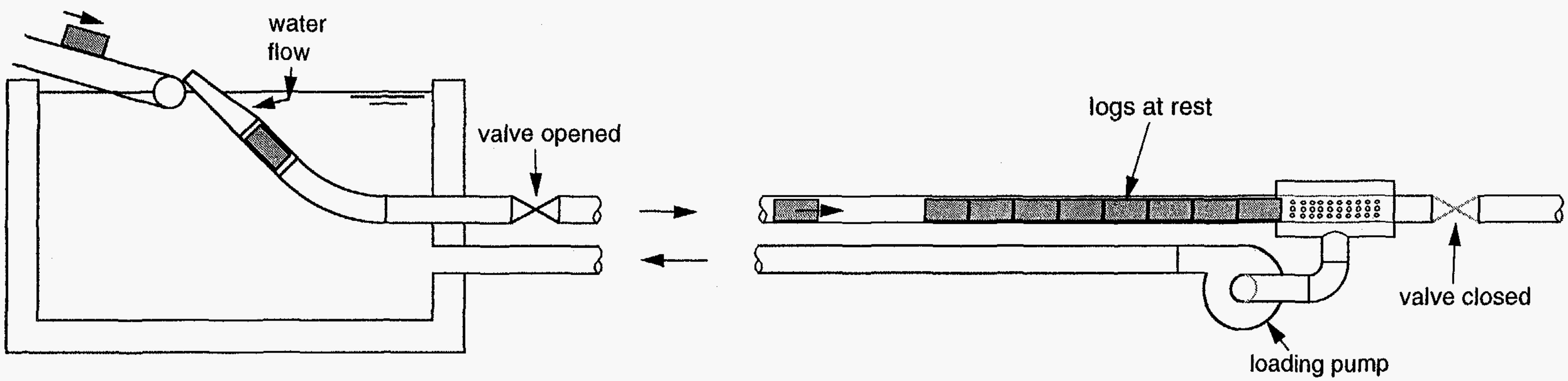

Figure 1 Loading train into injector lock

Table 1 Operation table for design 1

Operation	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}
Injection (loading)	Closed	Closed	Open	Closed	Open	Open	Closed	Closed	Open	Closed	Closed
Injection (pushout)	Open	Closed	Open	Closed	Closed	Closed	Open	Open	Closed	Closed	Open
Bypass 1	Open	Closed	Open	Closed	Closed	Closed	Open	Open	Closed	Closed	Open
Bypass 2	Open	Closed	Closed	Open	Closed	Open	Closed	Closed	Open	Open	Closed
Ejection 1	Closed	Open	Open	Closed	Closed	Closed	Open	Open	Closed	Closed	Open
Ejection 2	Closed	Open	Closed	Open	Closed	Open	Closed	Closed	Open	Open	Closed

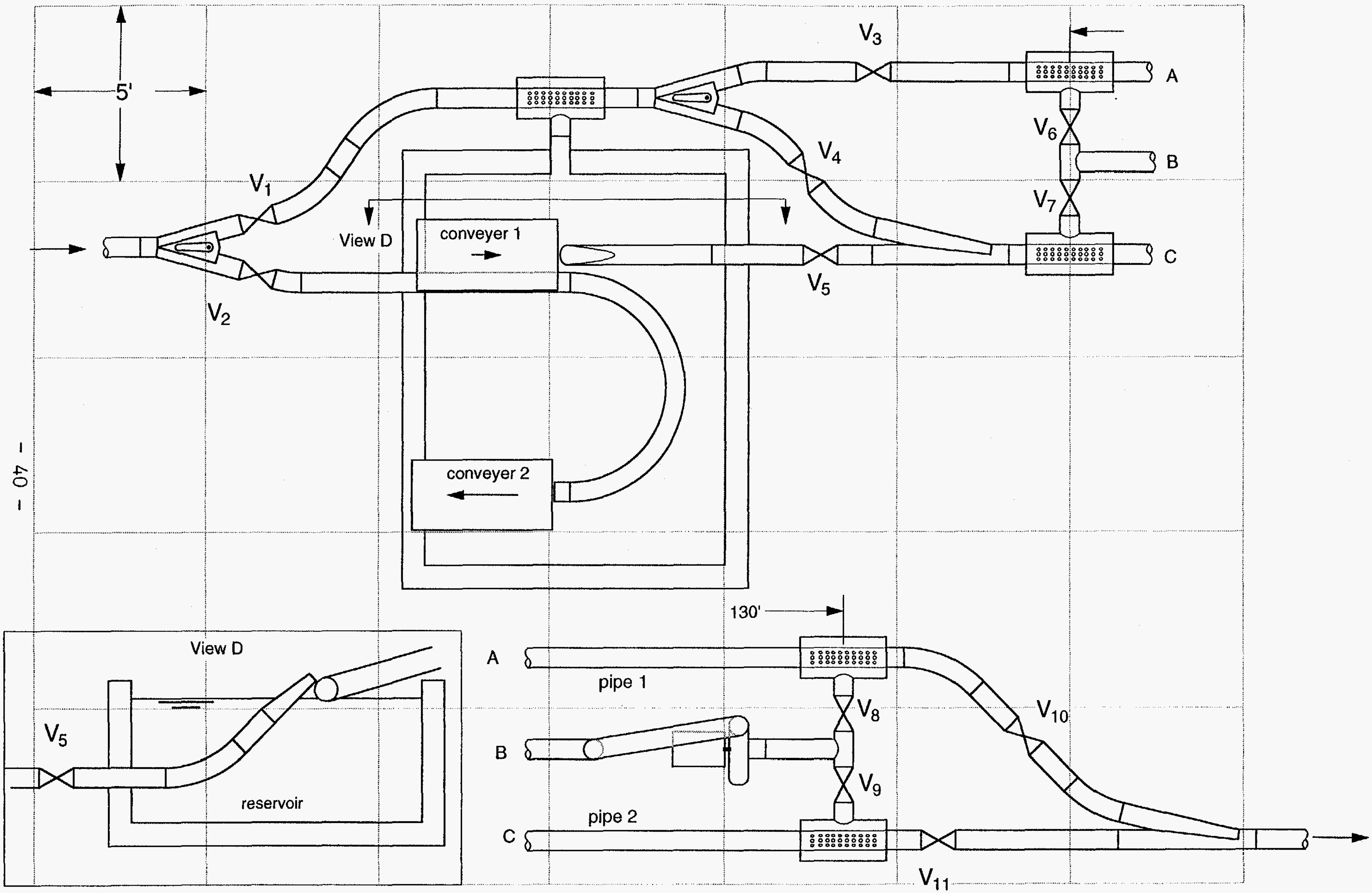

Figure 2 Design 1

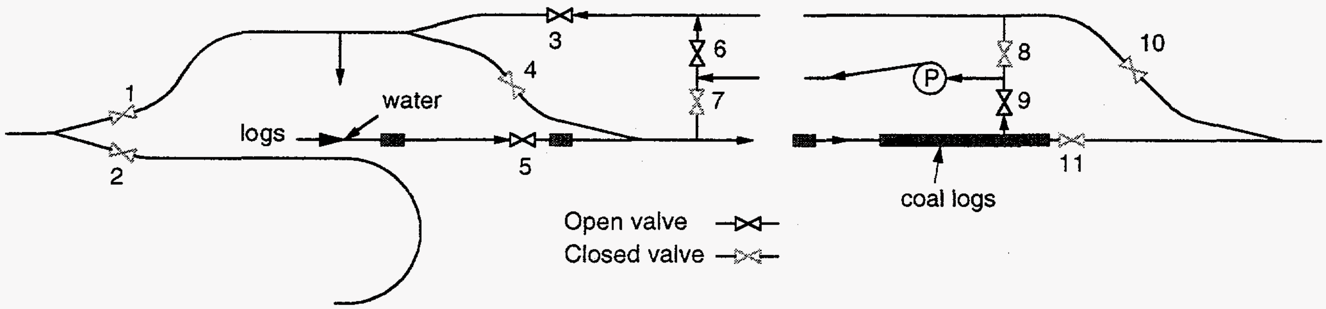

Figure 3 Injection(loading) for design 1

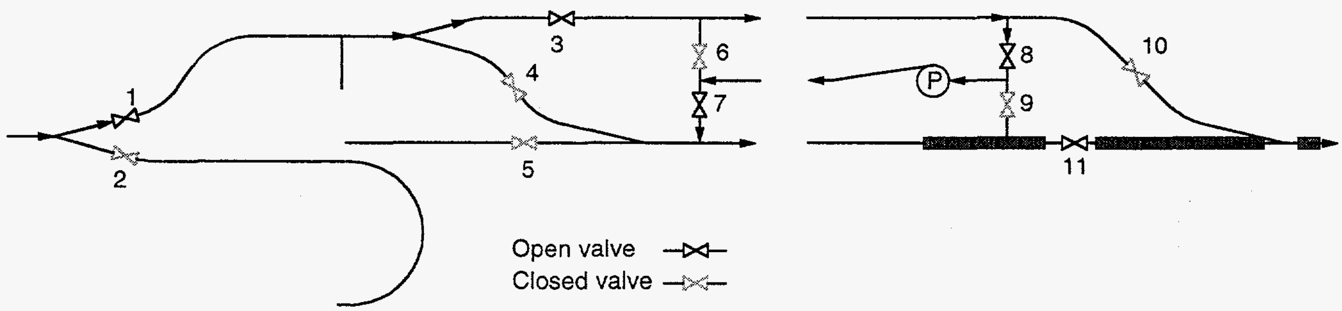

Figure 4 Injection(pushout) for design 1

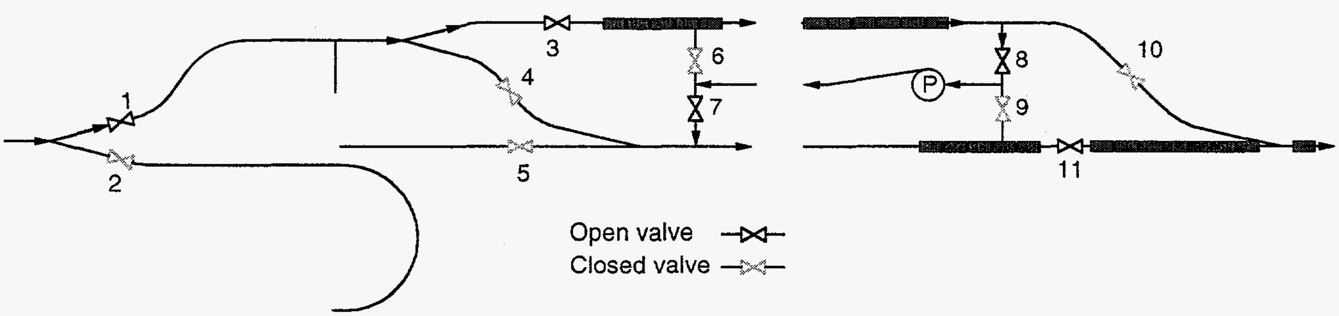

Figure 5 Bypass 1 for design 1

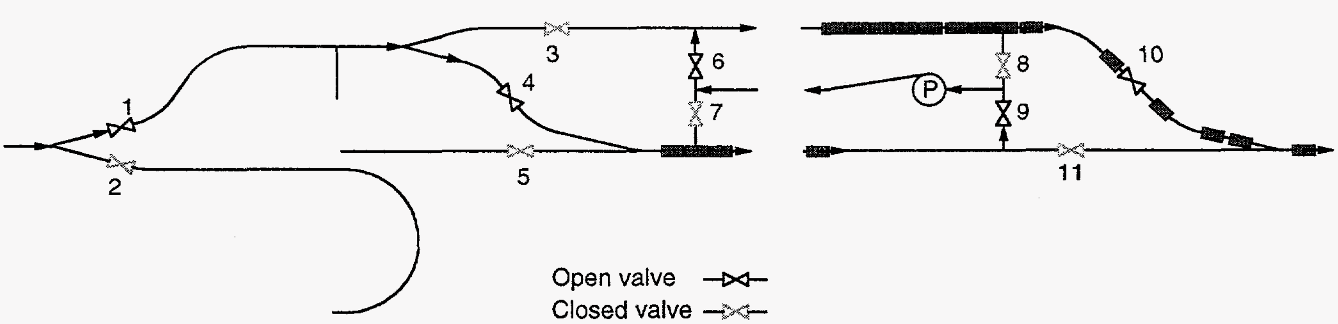

Figure 6 Bypass 2 for design 1

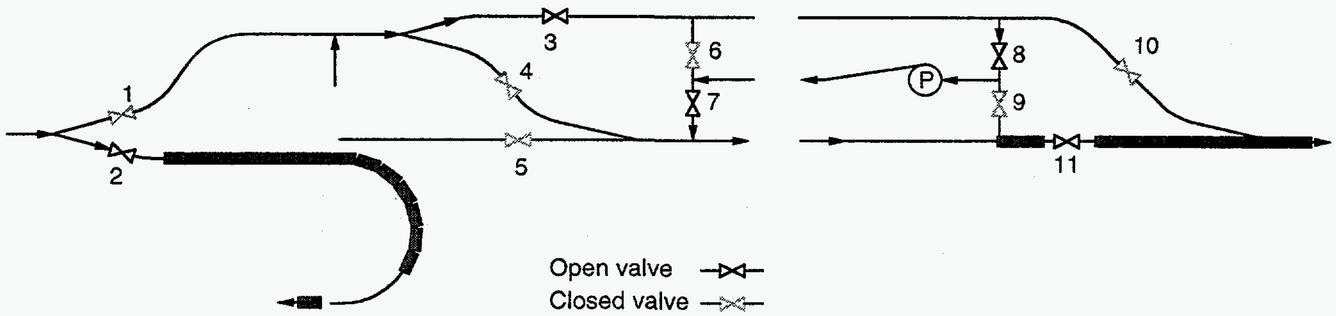

Figure 7 Ejection 1 for design 1

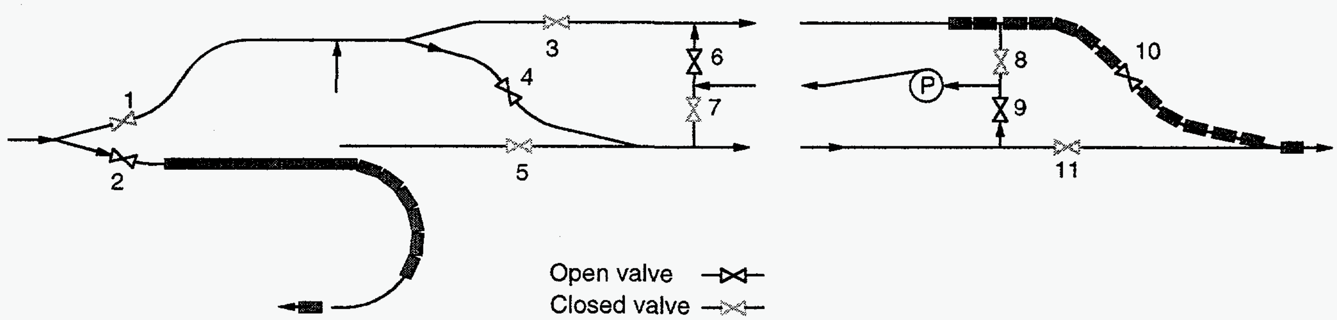

Figure 8 Ejection 2 for design 1

Table 3 Comparison of Designs

Design	Number Valves	Number Diverters	Number Pumps
design 1	11	2	1
design 2	15	2	2
design 3	20	2	3

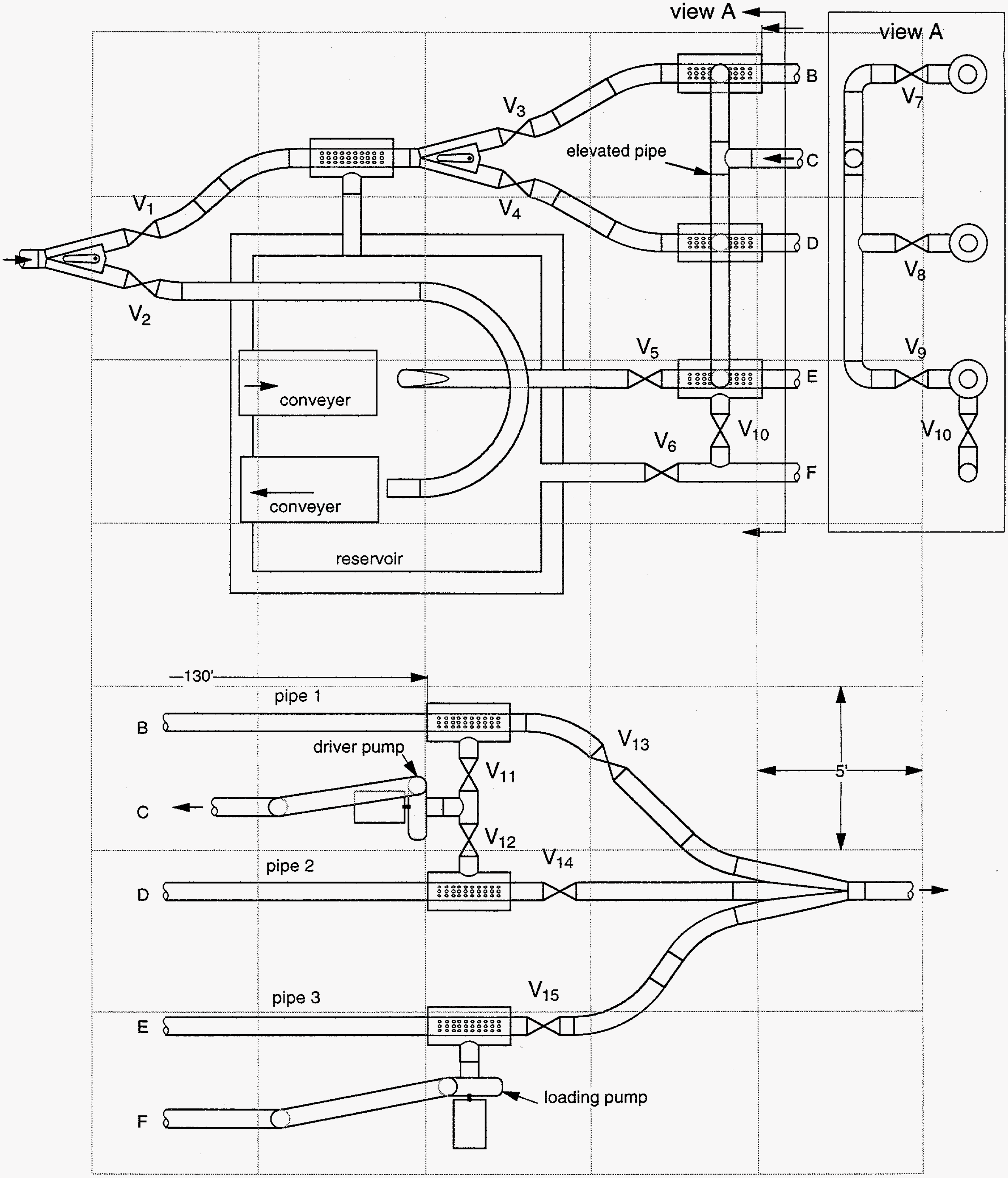

Figure 9 Design 2

Table 2 Operation table for design 2

Operation	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}
Injection(loading)					Open	Open			Closed	Closed					Closed
Injection(pushout)	Open	Closed	Open	Closed	Closed	Closed	Closed	Closed	Open	Open	Open	Closed	Closed	Closed	Open
Injection(pushout)	Open	Closed	Closed	Open	Closed	Closed	Closed	Closed	Open	Open	Closed	Open	Closed	Closed	Open
Bypass	Open	Closed	Open	Closed			Closed	Open	Closed		Open	Closed	Closed	Open	Closed
Bypass	Open	Closed	Closed	Open			Open	Closed	Closed		Closed	Open	Open	Closed	Closed
Ejection	Closed	Open	Open	Closed			Closed	Open	Closed		Open	Closed	Closed	Open	Closed
Ejection	Closed	Open	Closed	Open			Open	Closed	Closed		Closed	Open	Open	Closed	Closed
Ejection	Closed	Open	Open	Closed	Closed	Closed	Closed	Closed	Open	Open	Open	Closed	Closed	Closed	Open
Ejection	Closed	Open	Closed	Open	Closed	Closed	Closed	Closed	Open	Open	Closed	Open	Closed	Closed	Open

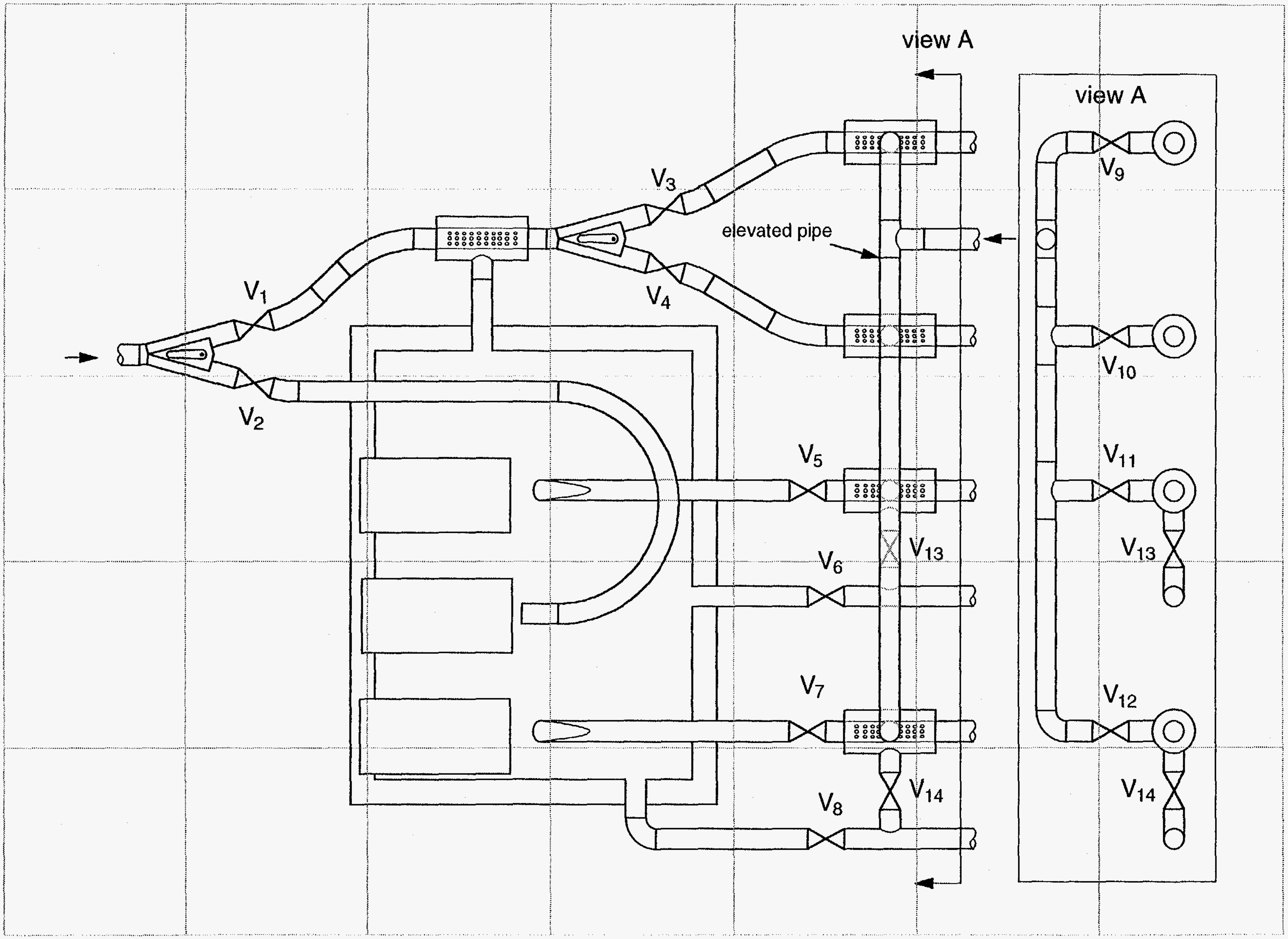

Figure 10 design 3 (page 1)

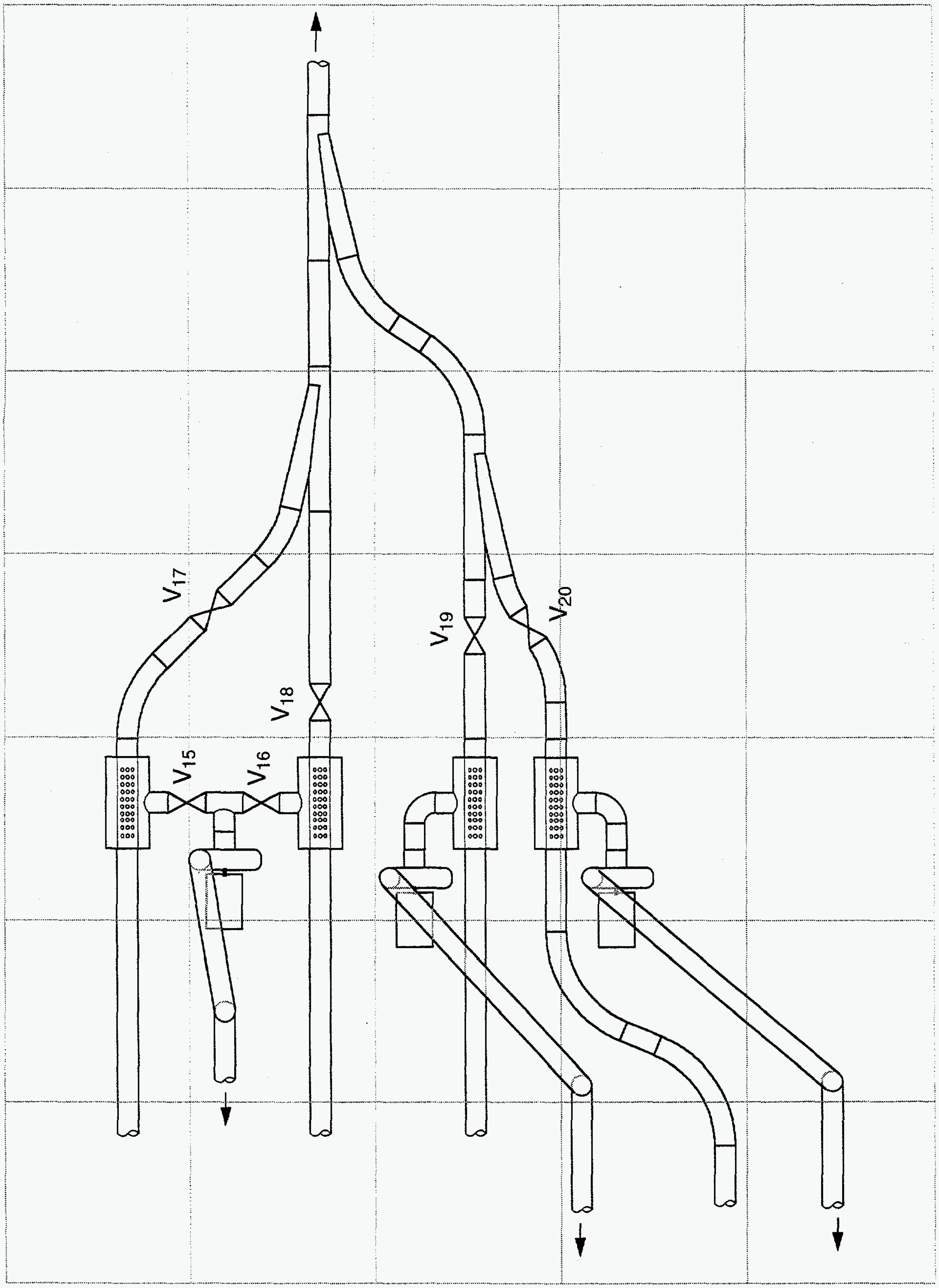

Figure 10 design 3 (page 2)