CAPSULE PIPELINE RESEARCH CENTER

UNIVERSITY OF MISSOURI-COLUMBIA

NSF State/Industry Cooperative Research Center

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ABSTRACT

The Capsule Pipeline Research Center is devoted to performing research in capsule pipeline so that this emerging technology can be developed for early use to transport solids including coal, grain, other agricultural products, solid wastes (including hazardous wastes), machine parts and a host of other materials and commodities.

The mission of the first four years is to focus on the coal log pipeline (CLP) technology. The Center is now near completion of its second-year research. Areas of research covered under Core Program of the second year include hydrodynamics of coal log flow, wear of coal logs in pipelines, pressure transients in capsule pipeline, pumping and control of coal log flow, fabrication and surface-treatment of coal logs, hydrophobic binder, and legal research in coal log pipeline. The Non-Core Program sponsored by the U.S. Department of Energy and the Electric Power Research Institute explores the economics and commercialization of CLP, and how to handle coal logs and treat CLP effluent water at power plants. Ten faculty members and more than 30 students from both the Columbia Campus and the Rolla Campus participated in the second-year research.

Important research findings and accomplishments during the second year include: success in making durable binderless coal logs by compaction, initial success in binderless-log, underwater extrusion, improvement in the injection system and the pump-bypass scheme, advancement in the state-of-the-art of predicting the energy loss (pressure drop) along both stationary and moving capsules, improved understanding of the water absorption properties of coal logs, better control in coal log surface treatment, better understanding of the mechanism of coal log abrasion, and completion of aspects of legal research dealing with water rights, eminent domain right, and easement right on using existing oil pipelines for coal log transport.

The second-year work also involved significant technology transfer activities including company seminars, involving companies in CLP research, preparation of a design/operational manual on CLP, issuance of a second newsletter, completion of a video tape on CLP, and presentation of research findings at several national meetings.

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EXECUTIVE SUMMARY

A. Rationale for the State/IUCRC

Capsule pipeline is an emerging technology of far-reaching implications for the nation and the world. The goal of the Capsule Pipeline Research Center is to mobilize government, industry and university resources to support a major research, development and technology transfer (RD & T) effort to improve the knowledge and the state-of-the-art in capsule pipeline so that this new technology can be used to benefit the nation, the region and the state in the nearest future.

The first four years of this Center is to focus on the RD & T of a specific type of capsule pipeline: the **coal log pipeline (CLP)** for transporting coal. Once the development of the CLP is completed in four years, the Center will then expand its RD & T program to include other types of capsule pipelines, both **HCP (Hydraulic Capsule Pipeline)** and **PCP (Pneumatic Capsule Pipeline)**. They can be used to transport grain and other agricultural products, solid wastes, machine parts and many other freight--almost anything that can be fitted inside a "**capsule**" (cylindrical container of a diameter slightly smaller than the pipe diameter.)

The reasons for concentrating on CLP during the first four years are: (1) CLP will greatly benefit the nation, the region and the state of Missouri; it is an important technology that should be developed as early as possible. (2) Once CLP is developed, the knowledge generated can be applied to other types of capsule pipelines. This means that early development of CLP accelerates the development of other capsule pipelines as well. (3) The companies supporting the Center at present consist of electric utilities, coal companies and pipeline companies. The first two groups are interested only in transporting coal, not other products. In the future, grain companies and other industries will be recruited to finance the development of the kinds of capsule pipelines for transporting grain, solid wastes and other products.

In spite of the environmental concerns (e.g. greenhouse effect) on burning coal and other fossil fuels, the nation, the region and the state will continue to rely heavily on coal for many years to come. Therefore, how to reduce the cost and the environmental impacts associated with using coal is of utmost importance to the public. The use of coal log pipelines not only reduces coal transportation cost, it also mitigates environmental impacts such as noise and air pollution, transportation accidents and so forth generated by the use of coal trucks and trains.

Due to the passage of the 1990 Clean Air Act Amendment, utilities across the nation must drastically cut down on sulfur emission from power plants. Two practical options are available to utilities in the Midwest for reducing sulfur emission. The first is to use high-sulfur local coal and spending money on scrubbers or fluidized-bed combustors to rid the sulfur from emission. The second option is to import low-sulfur coal from distant places such as Wyoming and spending money on transportation. Utilities in Missouri and other Midwestern states have used, and will continue to use, both options, depending on the type of power plants and local conditions. The CLP technology, when developed, will help Missouri to implement the Clean Air Act Amendment at the minimum cost possible, whether the state chooses to import more low-sulfur coal from the west, or to use local high-sulfur coal with scrubber or fluidized-bed combustors. The CLP technology has enormous economic value to the state.

Capsule pipeline will be a major transportation technology of the future. The Center's program will make the United States the leader in the world in this new technology. Having a lead in any advanced technology enhances national competitiveness. Furthermore, the use of CLP in the U.S. will reduce coal transportation cost, making U.S. coal more economically competitive in the world market.

B. Accomplishments and Plans

Major accomplishments of the Core Program during the second year include: success in developing a hot-water compaction process that makes durable coal logs; initial success in underwater extrusion of binderless coal logs; better control and understanding of various coal log surface treatment processes; better understanding of the nature of hydrophobic binders and the coal log abrasion (wear) mechanism in pipe; completion of the design of a coal log compaction machine for commercial production of coal logs; completion of parts of legal study dealing with water rights, eminent domain, and easement right on using existing oil pipes for coal log transport; improved prediction of the hydraulic behavior of coal logs in pipe, both under steady-state and unsteady motions; improvements on the capsule injection and pump-bypass schemes; completion of an economic study of coal log pipeline transportation of coal; completion of an end-of-pipeline study; the initiation of certain new studies in coal log wear in pipe, and slurry transport of coal logs, and the construction of the facilities for these new studies.

Collaboration with industry include: research in coal log pipeline economics (Williams Technologies, Inc.); study of computer control of a CLP system (Nova Tech, Inc.); design of a commercial size coal log compaction machine (Ramer & Associates, Gundlach Machine Company, Pro-Mark Process Systems); investigation of field test facilities (Williams Pipe Line); and extrusion of hydrophobic coal logs (Macro Tech).

Technology transfer activities include: company seminars, preparation of manual of practice of CLP, completion of a high quality video tape on CLP and distribution of 50 copies of the tape to interested companies/organizations, publication of a newsletter (distributed 1,500 copies), publication of a Center program brochure (distributed 1,500 copies), publication/presentation of papers at national/international conferences and journals, and receiving national media coverage.

The plan for the third year is to complete most of the projects initiated in the first and second years, and to start making and testing large (7-inch-diameter) coal logs based on knowledge gained from our current small-scale testing. New projects will also be initiated on drag reduction in CLP, ram type extrusion of coal logs, and testing of large logs in an 8-inch pipe loop several miles long to assess the amount of wear of coal logs in commercial pipelines.

RESEARCH PROGRAM

A. Plan

The Center's research program is planned to accomplish the stated goal which is to complete the development of the CLP technology for commercial use in four years. To attain this goal in four years, and with the Center being the only institute in the nation engaged in CLP and HCP research, all the unknown areas and unsolved problems pertaining to CLP must be studied simultaneously. This calls for a wide range of research projects, and the mobilization of a large number of faculty and students from different fields.

Unlike ordinary academic research which is unsolicited and initiated by individual researchers, the Center's research program is carefully planned and designed by the Center Director with input from individual faculty members, the Industry Advisory Board, and technical consultants--especially the Williams Technologies, Inc. which is serving as the Center's Principal Consultant. This approach in research planning is necessary in order to accomplish the stated mission of the Center.

The research performed by the Center can be classified into nine broad areas (**thrusts**) as follows:

B. Research Thrusts

1. Hydrodynamics of CLP

Many areas of the hydrodynamics of CLP remain either unexplored or inadequately explored. This includes prediction of energy loss, capsule lift-off, capsule velocity, capsule train behavior, effect of slopes and bends on capsules, abrasion of coal logs in pipeline, capsule pumping and injection, and so forth. This research is led by Dr. Henry Liu, Professor of Civil Engineering, who is an expert in hydrodynamics. The hydrodynamics of CLP must be clearly understood before one can design an appropriate CLP system and expect to operate it without difficulties. This shows the justification of the hydrodynamic research.

The main emphasis of this area during the second year was development of hydraulic equations to predict the behavior of capsule motion in pipe, including incipient velocity, energy loss and capsule drag and lift. This resulted in an M.S. thesis by Richards and several publications by Liu and Richards listed under hydrodynamics study in Appendix 1: Individual Project Descriptions. A new project was initiated to study the various modes of coal log wear in pipe, a project that will continue into the third year. The third year will also include some large-scale testing, and the assessment of the effectiveness of drag reduction agents for CLP.

2. Unsteady and Transient Flow in CLP

The operation of CLP requires periodic closing and opening of valves, and startup and shutdown of pumps. This generates pressure surges, whose effect on the coal logs, pipes, valves and pumps, must be carefully evaluated. The evaluation can be done by using a specific mathematical technique called the "**method of characteristics**" commonly used for analyzing water hammer effects. The outcome of this research is to develop a technique (equations and computer program) that can be used to analyze the behavior of coal logs and the pressure waves in a coal log pipeline under various operational conditions such as pump startup, shutdown, valve switching at both the intake and at pump bypasses (booster stations). Such a technique and analyses will enable us to improve and optimize CLP system design and operations. Dr. Charles Lenau, a water hammer expert, is heading this research with the help of two Ph.D students. A theoretical model has been developed to predict the unsteady motion of coal logs in pipe caused by water hammer. A test loop has been built this year for verification of the predictions based on the theoretical model. Data are being collected to check the model predictions. This work will continue into the third year.

3. Coal Log Manufacturing

Several promising ways to make good coal logs are being investigated simultaneously. These include binderless underwater extrusion, hot-water compaction of binderless high-strength coal logs, making hydrophobic coal logs, and compaction of binderless dry logs of moderate strength. Five faculty members (Gunnink, Lin, Luecke, Marrero, Wilson), one post-doctoral fellow, one research associate and eight students worked in this area during the second year.

The reason that this area is given greatest emphasis at present is due to the necessity of this research area, and the insufficient current knowledge and know-how in making good economical coal logs. Two-to-three years of intensive research in this field is required before we can expect to produce the kind of coal logs suitable for long-distance, hydrotransport through pipelines. Good progress has been made in this area over the last 12 months. Dr. Gunnink's group has succeeded in using a hot-water drying process to produce binderless logs that maintain their strength in high-pressure water and that passed a durable-log abrasion test. Dr. Lin's group was able to extrude binderless logs that retain strength in high-pressure water. The plan for next year is to make large logs and test them in a large pipeline. A ram type extruder will also be tested for making coal logs.

4. Coal Log Surface Treatment

The high-strength logs produced so far are perhaps good enough for hydraulic transport through a commercial pipeline over a distance of hundreds of miles. However, such logs produced have high water content (about 20%), and have a density in the neighborhood of 1.3 gm/cc which is too heavy for large logs in large commercial pipelines because they require a lift-off velocity greater than 10 ft/sec. The density of the logs can be reduced to 1.05 without losing much strength for dry logs with water content in the neighborhood of 3-5%, and that would reduce the lift-off velocity of large logs to within 10 ft/sec. However, such dry logs must have an impermeable surface or else the logs would absorb water in pipe, lose strength, and break up in pipe. This shows the importance of research on surface treatment of coal logs. Success in surface treatment research will not only result in a lighter log, it will also be possible to transport logs through pipe while maintaining the logs' dryness, thereby giving the logs a higher heating value, consuming less water for transport, and eliminating the need for drying coal logs at power plants. This describes the motivation of this study.

Three methods of surface treatment are being investigated: using coal slurry to seal the surface pores of dry logs, coating the surface with an impermeable material such as wax or asphalt, and heat treatment of coal log surface. These investigations will take another year before one can say for sure whether they are feasible.

Related to surface treatment is a study to determine the permeability and water absorption properties of coal logs.

This study is directed by Dr. Marrero and Dr. Luecke, with the help of four graduate students and three undergraduates.

5. Coal Log Machine Design

Conventional briquetting and extrusion machines cannot make good coal logs and cannot make them fast enough. It is important that a special machine be designed to make good logs at a fast rate -- the purpose of this study. Dr. Lin, with the help of two students, is working in this area. At present, machine design is focused on a compaction machine. A second-stage design is underway. This will be completed during the second year. Note that meaningful machine design depends on a good understanding of the coal log manufacturing process. Therefore, the machine design work must follow coal log manufacturing study. Whenever there is a new manufacturing process developed or breakthrough, the machine design must be changed. Haste in machine design will not be productive.

The plan for the next year is to test certain design concepts and components, and to build a small-scale model of the commercial-size machine designed in order to determine problems and areas of improvement. Dr. Lin will also design an underwater extrusion machine during the next year.

6. Automatic Control of CLP System

Automatic control is a must for CLP systems. Operation of any future commercial CLP system, including the injection, pumping and ejection of coal logs, can best be controlled by a centralized computer interacting with microprocessors or small computers scattered at different locations to control individual components such as a booster station or an injection station. Because coal log pipelines operate quite differently from ordinary liquid or gas pipelines, the control hardware and strategies are also very different. This calls for the design of the hardware and the control strategies for operating CLP systems.

It should be realized that proper control of a CLP system depends not only on proper use of signals derived from transducers and use of computers, it also depends on a good knowledge of the hydrodynamic behavior of coal logs and the flow. Many hydrodynamic equations must be included in the computer software for controlling the coal log pipeline. For this reason, the hydrodynamic group and the control group members work closely together in their research. Dr. Satish Nair, Assistant Professor of Mechanical Engineering, (MAE) is heading the automatic control research area. Dr. Nair is also the director of the Automatic Control Lab of the MAE Department.

The next year will focus on developing a mathematical model for controlling the operation of CLP, and to select the proper hardware and software for automatic control.

7. Legal Research

The legal research is to identify legal and institutional obstacles that may impede the future implementation of coal log pipelines, and to suggest ways to remove or reduce such obstacles. Subjects under legal research include water rights, eminent domain rights, the right to cross railroads, conversion of ordinary oil or gas pipelines to coal log pipelines, and others. Dr. Peter Davis, MU Professor of Law, is heading this research. Good progress has been made in this research in the last two years, but the research must be extended for at least another year before all the legal questions can be answered or clarified. The work for the next year includes procedure for pipeline to acquire right-of-way across federal land, possible use of highway right-of-way for coal log pipelines, constraints on water rights transfers, regulation on brackish water use and disposal, etc.

8. Economic Research

The economics of coal log pipeline is not only an important subject itself, it also affects the direction of technical research and developments. For instance, in an economical study completed by Liu in 1993, it was found that the economics of CLP depends greatly on the amount of binder used in fabricating coal logs. The binder amount must be less than approximately 3% by weight or else the coal logs produced would not be economical. Based on that finding, we have adjusted our coal log manufacturing research on making logs with less than 3% binder, or better yet without any binder--the binderless process.

The completion of the 1993 economic report does not mark the end of the need for further economic study. New problems were discovered, such as how to best compare coal log transportation costs with future rail tariff increase. The issue will be studied by Robert Zuniga as part of his M.S. thesis, under the direction of Dr. Jim Noble of the Industrial Engineering Department.

9. End-of-Pipeline Study

On the power plant end of a coal log pipeline, how must the logs be handled (i.e., dewatered, dried, crushed, stored and transported to boilers), and how should the effluent water be treated before it is discharged into natural streams or utilized at the power plant, is of strong interest to utility companies. Therefore, it is necessary to perform some research in this area.

This research was supported by a Non-Core contract from EPRI (Electric Power Research Institute); the research was completed in 1992. A report was issued, and key findings of this study were published and reported at several technical conferences. Dr. John Wilson and Dr. Thomas Marrero were co-directors of this project. This area need not be studied during next year unless new problems are discovered which justify further studies. It will be revisited later when a TC Project is negotiated between EPRI and interested utility companies.

C. Research Projects

Depending on the complexity of the tasks involved, each research thrust area described before may contain one or more than one project, each of which is led by a faculty member with the help of one or more than one student. Some projects also have the help of a post doctoral fellow or research associate. **Table 1** is a listing of all the projects, the Principal Investigator (P.I.) of each project, and the purpose of each. More about each project is described in Appendix 1.

D. Non-Core Program

The Non-Core research program is closely tied to the Core program, and in certain cases, coincides with the goal and tasks of the Core program. They simply provide additional resources to support the needed research, development and technology transfer (RD&T) activities of the Center. The only reason that they are called **"Non-Core"** is their funding mechanism. Instead of being a four-year support such as provided by the NSF, State of Missouri and industry (the CLP Consortium), the Non-Core program consists of short term grants or contracts for lesser amounts than each Core contribution. Nonetheless, they are as valuable as Core program on a per-dollar basis.

The two Non-Core projects completed during the second year operation of the Center are a two-year grant of $80,000 from the Energy Related Inventions Program, U.S. Department of Energy **(DOE)**, to study the commercialization of CLP, and an 8-month contract from the Electric Power Research Institute **(EPRI)** -- the end-of-pipeline study. They are listed in **Table 2.** A new non-core project funded by DOE Pittsburgh Energy Technology Center is expected to start in May 1993. This project provides additional money to study the same nine areas of the Core Program, plus a study of slurry suspension of coal logs. Other proposals have also been submitted which may result in additional non-Core projects.

Table 1. Center Projects (Second Year)

P.I.	PROJECT TITLE	PURPOSE
Dr. Davis	Legal Research in Coal Log Pipeline	To explore legal issues involved in commercialization of CLP including water rights, eminent domain, right to cross railroads, etc.
Dr. Gunnink	Vacuum Compaction of Binderless Coal Logs	To explore and optimize compaction technique for making binderless coal logs.
Dr. Lenau	Unsteady Flow in Capsule Pipeline	To study methods for prediction of unsteady flow and pressure transients generated in the operation of coal log pipelines. Verification of theory by experiment.
Dr. Lin	Design of Coal Log Fabrication Machines	To design coal log fabrication machines for commercial use.
Dr. Lin	Underwater Extrusion	To explore the feasibility of underwater extrusion of coal logs.
Dr. Liu	Economics of CLP	To study the economics of CLP and update a 1990 economic report
Dr. Liu	Hydrodynamics of CLP	To explore hitherto unexplored important hydrodynamic problems of CLP including prediction of energy loss, effects of bends, and slopes, coal log degradation in hydrotransport, etc.
Dr. Luecke	Coal Log Casing	To explore encasing coal logs with a special material to prevent water absorption.
Dr. Marrero	Surface Treatment of Coal Logs	To explore ways to treat coal logs surface in order to minimize water absorption. Treatment methods include coal slurry impregnation and heat treatment.
Dr. Nair	Automatic Control of CLP Systems	To study and design the automatic control systems needed for reliable operation of CLP systems.
Dr. Seaba	Coal Log Pipeline Using a Slurry Medium	To collect data on coal log transport in a slurry medium in order to determine the feasibility and advantage of such a system.
Dr. Wilson	End-of-Pipeline Study of CLP	To explore the handling of coal logs and effluent water at pipeline terminals located at power plants.
Dr. Wilson	Hydrophobic Coal Logs	To explore the use of special hydrophobic binders to make coal logs.

Table 2. Non-Core Projects (completed or started during the second year)

Project Title	Sponsor	Periods	Amount $
Coal Log Pipeline System Development	DOE Energy Related Inventions Program	8/24/90-6/30/92	80,000
End-of-Pipeline-Study	Electric Power Research Institute (EPRI)	1/13/92-12/31/92	50,000
Used Energy Related Lab Equip. DE-FGOG-93RL12514	DOE	1/23/93-1/22/94	1,997*
Used Energy Related Lab Equip. DE-FG21-93MC30110	DOE	12/21/92-2/21/94	6,400*
Used Energy Related Lab Equip. DE-FG09-93SR18309	DOE	1/15/93-1/15/94	1,620*
Used Energy Related Lab Equip. DE-FG06-93RL12571	DOE	12/22/92-12/21/93	4,060*
Consortium for Coal Log Pipeline Research	DOE Pittsburgh Energy Technology Center	4/1/93-3/31/96	218,000

*Acquisition Cost & In-kind valuation

The DOE Energy Related Invention grant expired on July 1, 1992. A final report was submitted near the end of 1992. The three tasks of this project were: (1) improving coal log fabrication so that adequate logs can be made with less than 8% binder, (2) constructing and demonstrating a small model of the most promising injection system for coal log pipeline, and (3) conducting an economic analysis of coal log pipeline -- improve/revise the 1990 economics report. All three tasks were successfully completed by January 1, 1993.

The EPRI grant was designated for the end-of-pipeline study -- how should coal logs reaching a power plant from a pipeline be treated at the plant, including dewatering, crushing, drying, grinding and storage. Also of interest to the project is the effluent water quality at the plant and how to treat the effluent water to meet EPA standards for discharge into streams and to meet utility standards for reuse of the water at power plants. The project was completed in January 1993.

The new DOE grant, from the Pittsburgh Energy Technology Center, is intended for supplementing the Center's existing projects, not to start new projects. Intention for providing the grant to the University of Missouri was announced in the November 10, 1992 issue of the

Federal Register. However, due to complex budgeting requirements, at the time of preparation of this report (April 28, 1993), the business officers of both DOE and the University are still negotiating a mutually agreeable contract document. It is hoped that the project can start in May.

All the Non-Core projects are also closely tied to the technology transfer program of the Center. For instance, the demonstration of a small coal log pipeline system and the economic study mandated by the DOE Energy Related Invention project are a must for technology transfer. We cannot transfer a technology unless and until it is demonstrated at least at small scale and the economics of the system is known at least approximately. The end-of-pipeline study is needed before we can transfer the technology to electric utilities. This study is also closely related to our plant visits and involvement of utility companies in our technology transfer program.

E. Publications and Intellectual Properties

Publications during the second year (9/1/92-8/31/93) are listed as follows:

Berg, D.M., Hot Extrusion of Coal Logs, M.S. Thesis, Department of Chemical Engineering, University of Missouri-Columbia, May 1993.

Chen, S.H., Effects of Particle Size, Binder Concentration and Compaction Pressure on Coal Log Properties, M.S. Thesis, Department of Chemical Engineering, University of Missouri-Columbia, May 1993.

Davis, P.N., Cress, N. and Sullivan, J.P., "Legal Aspects of Coal Pipelines in the United States -- Preliminary Findings," 18th International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, FL, April 29, 1993.

Gunnink, B.W. and Liang, Z., "Compaction of Binderless Coal for Coal Log Pipelines," accepted for publication in Fuel Processing Technology, Elsevier, Amsterdam.

Lenau, C.W. and El-Bayya, Majed, "Unsteady Flow in Hydraulic Capsule Pipeline," submitted to the Engineering Mechanics Division of the American Society of Civil Engineering, 1993.

Liang, Z., "Compaction of Binderless Coal Log Pipelines," M.S. Thesis, Department of Civil Engineering, University of Missouri-Columbia, May 1993.

Lin, Y.Y. and Wang, L.Q., Binderless Coal Log Extrusion, CPRC Internal Report (publication temporarily withheld due to proprietary information), March 1993, 14 pages.

Lin, Y.Y., Coal Log Compaction Machine Design and Estimation of Cost and Power Requirement, CPRC Internal Report (Publication temporarily withheld due to proprietary information), August 1992.

Liu, H., Zuniga, R. and Richards, J.L., Economic Analysis of Coal Log Pipeline Transportation of Coal, CPRC Internal Report (Publication temporarily withheld due to proprietary information), January 1993.

Liu, H. and Richards, J.L., "Hydraulics of a Stationary Capsule in Pipe," Journal of Hydraulic Engineering, American Society of Civil Engineers, accepted for publication in April 1993.

Liu, H., "Hydraulic Behaviors of Coal Log Flow in Pipe," invited paper for a book on freight pipelines published by Elsevier Science Publisher, submitted in May 1993.

Liu, H., "Freight Pipelines," article published in the 1993 Encyclopedia Britannica, pp. 861-864.

Liu, H. and Marrero, T.R., "Coal Log Pipeline: Basic Concept and State of Development," poster paper presented at Ninth Annual International Pittsburgh Coal Conference, Pittsburgh, PA, October, 1992.

Marrero, T.R., "Coal Log Pipeline Concept and Technology," Short Course on Recent Topics and Future Use of Capsule Transportation Technology, Japan Society of Multiphase Flow, Tokyo, June 1992.

Marrero, T.R. and Wilson, J.W., "Coal Log Fuel Handling and Treatment at Power Plants," CPRC Report No. 93-2, sponsored by the Electric Power Research Institute, Palo Alto, CA., January 1993.

Marrero, T.R., "Coal Log Pipeline Transportation Technology," (in the session: A New Area of Chemical Engineering Research) to be presented at the American Society of Engineering Educators Annual Conference, University of Illinois, June, 1993.

Nair, S.S. and Wu, J.P., "Theoretical and Experimental Investigation of Coal Log Pipeline Control Systems," 18th International Technical Conference on Coal Utilization and Fuel Systems, April 1993.

Phimjaichon, R., Prediction of Waterhammer in HCP Pump Bypass System, M.S. Thesis, Department of Civil Engineering, University of Missouri-Columbia, August 1992.

Richards, J.L., Behavior of Coal Log Trains in Hydraulic Transport through Pipe, M.S. Thesis, Department of Civil Engineering, University of Missouri-Columbia, August 1992.

Seaba, J.P. and Xu, G., "Slurry Suspension of Coal Logs -- An Exploratory Study," 18th International Technical Conference on Coal Utilization and Fuel Systems, April 1993.

Wilson, J.W. and Marrero, T.R., "Coal Log Pipeline Concept and Performance Characteristics," J.S. African Institute of Mining and Metallurgy. (submitted in April 1993).

During the second year, the Center has filed two Preliminary Invention Disclosures with the University of Missouri Office of Patents and Licensing. This constitutes the first step in patent application. The two disclosures are (1) "Water-Assisted Binderless Extension of Coal Logs," by H. Liu, Y.Y. Lin and L.Q. Wang; (2) "Compaction of Hot Water Dried Coal Agglomerates," by B.W. Gunnink, J. Kananur and Z. Liang. Other disclosures are expected during 1993, including the design of a large production-scale coal log fabrication machine designed by Dr. Lin with the help of a graduate student and Mr. James Ramer whose company (Ramer & Associates) is a small-business participant of the Center. When perfected and tested successfully at a small scale, an invention disclosure and a patent application will be filed on this machine design. This is most likely to happen during the third year. Meanwhile, the design will be kept confidential.

INDUSTRY COLLABORATION/TECHNOLOGY TRANSFER

A. Industry Collaboration in Research and Other Activities

Several industry participants of the Capsule Pipeline Research Center are involved in the Center's research, development, and technology transfer activities. For instance, during the past 12 months the Williams Technologies, Inc. assisted the Center in a research on the economics of CLP. The involvement was extensive; it includes providing cost data, providing frequent advice, and reviewing and critiquing the draft report. The Gundlach Company was involved in helping to provide data on coal log grinding for both the end-of-pipeline study, and the economic study. It was also involved in reviewing and critiquing Dr. Lin's coal log machine design, along with other companies such as the Pro-Mark Company and Ramer and Associates. Macrotech Inc. in Paris, Tennessee, was involved in extruding hydrophobic coal logs for Dr. Wilson's study and Novatech Inc., Kansas City, reviewed Dr. Nair's research in automatic control and provided a written critique and valuable advice.

Another important activity by companies involves the Williams Pipeline company which offered to let the Center use a 5-mile reach of its pipeline in Kansas City for coal log testing. The Company provided valuable data on this line and cooperated and assisted in a site visit.

B. Strategy for Membership Growth

It should be pointed out at the outset that there is substantial difference in the philosophy on membership growth between government sponsors (NSF and State) and our existing industry sponsors (CLP Consortium Members). While the government sponsors want the Center to grow and have more and more new members, the general feeling of our existing industry sponsors is that growth should be controlled and limited so that the Center Director and staff can concentrate on performing R&D rather than recruiting new members. Besides, too many members in a Center also becomes difficult to manage.

The Center's philosophy represents a balance between the two different positions. We feel that some growth should occur to bring in more resources to the Center so that there will be adequate resources to accomplish the stated goal of developing the CLP technology in four years. Yet, once we have reached the level of funding adequate to accomplish the Center's goal, we should no longer divert our energy and spend our time in fund raising, and should rather concentrate on research, development and technology transfer.

Based on the aforementioned philosophy, the Center Director, Associate Director, and Dr. John Wilson at UMR have actively sought to recruit new industry participants during the past year. The goal is to recruit a few additional members so that next year's support from industry can reach or exceed $250,000. This will qualify the Center for a higher level of funding from State and NSF.

The strategy used for recruiting is first to write letters or call potentially interested companies, inviting them to join. When it appears that a company has sufficient interest, the Director, Associate Director and/or Dr. Wilson will arrange to visit the company, or more preferably, invite appropriate company officials to come to Columbia for an on-site visit and meeting. As a result of such efforts, several companies are seriously considering to join. This includes TVA (Tennessee Valley Authority), EPRI (Electric Power Research Institute), Northern States Power, Southern Company Services, and other utilities. EPRI is also helping the Center to recruit some utility companies to support the Center under a Tailored Coordination (TC) Program. Some small businesses, such as the Erie Press Systems, which makes large compression machines that can be used for coal log fabrication, have also been invited. It is hoped that two or three companies will join before September 1, 1993, so that the industry matching fund for the next year will exceed $250,000. Present industry participants of the Capsule Pipeline Research Center are listed in Table 3.

C. Industry Use of Research Findings

Due to the early stage of this research, and the fact that coal log pipeline is a not-yet-developed emergency technology, industry is yet unable to use any of the findings of this research. This explains why Table 4 is not applicable to this particular Center.

D. Other Technology Transfer Activities

The Center's technology transfer activities of the second year are listed in Table 5, and industry-related visits are listed in Table 6. In addition to involving companies in research, the activities include preparation of design and operation manuals, company seminars, issuance of a newsletter (copy included in Appendix 2), production of a video tape on coal log pipelines (50 copies distributed to sponsors and interested parties), and dissemination of infonnation at technical meetings. Furthermore, the Center exhibited at the Mining Congress in Nevada in October, 1992, a small working model of coal log pipeline system. It has attracted great interest and generated a number of inquiries. It also exhibited and presented papers at the 18th International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, Florida, in April 1993. Also, during the second year, the Center published a number of papers as listed before, and received favorable publicity in national press -- see newspaper article attached in Appendix 2. Both help greatly in dissemination of information which is an important part of technology transfer. Finally, an article on freight pipelines was published by Dr. Liu in the 1993 Encyclopedia Britannica -- the first time any encyclopedia discussed capsule pipeline. The Capsule Pipeline Research Center was mentioned in this article -- see attachment in Appendix 2.

Table 3. Industrial Participation (Year 2)

Company	Member Category	Years of Part.	Company Size: Sm Bus	Mid-Size	Fort 500	Joint Res. Proj.	Funds Provided ($)
Arch Mineral Corp.	Principal	1,2,3		X		No	30K
Associated Electric Co.	Principal	1,2,3		X		No	30K
Bonnot Company	Sm. Bus.	1,2,3	X			Yes	5K
Coal Services Corp. (Peabody Coal)	Member	1,2,3		X		No	15K
EPRI	Non Core	1,2	X			No	50K
Gundlach Machine Co.	Sm. Bus.	2,3	X			Yes	5K
Kansas City Power & Light Co.	Principal	2,3		X		No	30K
MAPCO Transportation	Principal	2,3		X		No	30K
Nova Tech Co.	Sm. Bus.	2,3	X			Yes	5K
Pro-Mark Co.	Sm. Bus.	2,3	X			Yes	5K
Ramer & Associates	Sm. Bus.	2,3	X			Yes	5K
Union Electric Co.	Member	1,2,3		X		No	15K
Williams Pipe Line Co.	Member	1,2,3		X		Yes	15K
Williams Technologies	Member	2,3		X		Yes	15K

1. Annual fees are $30,000 for Principals, $15,000 for Members, and $5,000 for Small Business.

2. Funds listed are for Core Projects, except for EPRI (Electric Power Research Institute).

Table 4. Technology Transfer Examples

Adopting Company	Industrial Application	Technologies	Use in Company	Impact (i.e. cost saved; productivity gain; etc.)
Exxon Chemical	Advanced real time control	-Modeling nonlinear chemical processes using neural-computing	-Real time optimization for steam cracker and polymer operations.	-Improved profit margin and quality performance -Market share penetration
Texas Instrumnt	Expert (rule Based) Contoller	-AI algorithms & Data structures	-"Smart Controller" capable of controlling 30 loops with adaptive tuning	-Improved market position with new product

(THIS TABLE IS NOT APPLICABLE TO THE CENTER AT THIS EARLY STAGE)

Table 5. Technology Transfer Activities of the Second Year

1. Involvement of companies in CLP related research (Williams Technology, Inc., Macrotech, Nova Tech, Gundlach, Ramer & Associates, Pro-Mark, Bonnot, etc.)

2. Writing design/operation manual for coal log pipeline.

3. Conducted preliminary investigation of a potential site for demonstration of coal log pipeline technology (Williams Pipe Line).

4. Visited and interacted with companies for information dissemination and fund raising for the Center (TVA, Western Energy, Associated Electric, etc.).

5. Issued newsletter and mailed to potential interest groups (1,500 copies).

6. Printed a Brochure Describing Center Program Paid for by College of Engineering and mailed to interested individuals and groups (1,500 copies).

7. Made a video tape on coal log pipeline and distributed 50 copies to sponsors and special groups.

8. Prepared quarterly reports and annual reports.

9. Publication in journals and presentation at technical meetings.

10. Exhibited coal log pipeline at two important national conferences.

11. Received coverage by national press.

12. Center research covered in 1993 Encyclopedia Britannica.

Table 6. Industry Related Visits Since Completion of the 1st Annual Report

Dates	Description of Activities
7-28-92	Dr. Thomas Marrero traveled to Pittsburgh, PA to attend the 8th Annual Coal Preparation Utilization & Environmental Control Contractors Conference. Also visited Union Electric Co. in St. Louis with Dr. John Wilson to discuss EPRI projects.
8-14-92	Dr. Thomas Marrero went to University of MO-Rolla to discuss EPRI project results with Dr. John Wilson and students.
8-25-92	Dr. Thomas Marrero and Dr. Wilson visited Macrotech in Paris, TN to discuss the fabrication of hydrophobic coal logs by extrusion..
8-25-92	Mr. Michael Barron, accompanied by Mr. Kohler from Gundlach Corporation, visited the Capsule Pipeline Research Center to discuss with Drs. Henry Liu and Yuyi Lin regarding coal log fabrication machine design
9-10-92	Mr. Terry DeJaynes went to Chicago, IL to attend the International Machine Tool Show. He assessed products & equipment as well as parts & components that could be utilized to benefit the Center and made contact with numerous vendors.
9-21-92	Dr. Henry Liu went to Tulsa, OK to present a talk to the Pipeliners' Club of Tulsa and visit a research sponsor, Williams Technology, to discuss economic report.
10-01-92	Dr. Thomas Marrero attended the Particle Size Analysis Seminar sponsored by Coulter, Inc., in St. Louis.
10-09-92	Mr. Richard Viren, along with other international visitors from Ft. Leonard Wood were given a presentation of the capsule pipeline by Dr. Henry Liu.
10-13-92	Dr. Thomas Marrero attended the 9th International Pittsburgh Coal Conference and made a presentation at the Poster Session. He also made contacts with several representatives from utilities companies including Northern States Power Co.
10-19-92	Dr. John Wilson and along with Mr. Michael Holder and other University of MO-Rolla School of Mines representatives sponsored an exhibit booth that featured the coal log pipeline at the International Mining Expo '92 held at the Las Vegas Convention Center in Las Vegas, NV. Mr. Michael Holder helped assemble the coal log pipeline model. This Expo is the largest mining show in the world. More than a dozen companies requested additional information about coal log pipeline.
11-18-92	Dr. Thomas Marrero traveled to Paris, TN to visit Macrotech, Inc. to consult with representatives of that company regarding preparation of extruded coal logs and binder.

Table 6 (Continued)

Dates	Description of Activities
12-03-92	Dr. Thomas Marrero and Mr. Bill Burkett attended the EPRI Conference on Low-Rank Coal Upgrading in St. Louis, MO. They contacted Tennessee Valley Authority while there and several other coal and utility companies.
1-15-93	Dr. Thomas Marrero and Dr. Henry Liu traveled to TVA in Chattanooga, TN to present their pipeline research project to company representatives and to solicit support for this project by encouraging them to participate as a sponsor.
1-27-93	Dr. Satish Nair, Mr. Richard Oberto, Mr. DeXiang Sun and Mr. C-Y Shieh went to Nova Tech in Lenexa, KS to meet with Mr. Aubrey Zey to critique the existing demo system of coal log pipeline at the CPRC.
2-01-93	Mr. Richard Oberto went to Houston, TX to attend a Pipeline Pigging and Integrity Conference. He established contact with various designers and developers in order to enhance future work on capsule and coal log control and sensing applications.
2-09-93	Dr. Yuyi Lin visited Mohr Corporation in Detroit, MI to inspect surplus ram extruder for possible purchase.
2-09-93	Dr. Henry Liu, Dr. Thomas Marrero and Dr. John Wilson went to Northern States Power Co. in Minneapolis, MN to make a presentation on the coal log pipeline project and to invite NSPC to join the coal log pipeline consortium.
2-93	Dr. John Wilson visited Shell Mining, Dallas, TX to discuss coal log pipeline technology with one of its executives.
3-02-93	Dr. Thomas Marrero and Dr. Yuyi Lin to Elizabethton, TN to inspect a surplus extruder for possible purchase from Great Lakes Research Corporation.
3-09-93	Dr. Henry Liu and Dr. Thomas Marrero traveled to Springfield, MO to visit Associated Electric Cooperative on coal log pipeline and present progress report on pipeline project.
3-19-93	Mr. Richard Viren, Fort Leonard Wood, brought an international contingent to the coal log pipeline laboratory.
3-22-93	Dr. Thomas Marrero went to St. Louis, MO to represent CPRC at the 6th Utility Coal Conference.
4-14-93	Dr. Henry Liu visited Williams Pipe Line Company Station in Paola, KS to evaluate an existing dual pipeline as a test site for running coal logs over a 5 mile stretch.
4-30-93	Dr. Thomas Marrero visited Extrusion Technologies, Inc. in Columbia, MO regarding plastic pipe extruders.
4-30-93	Dr. Thomas Marrero visited Rheochem Manufacturing Co., Inc. in Columbia, MO regarding the use of solid lubricants for extrusion.

INFRASTRUCTURE AND MANAGEMENT

The Center planning involves every researcher. Each week there is a meeting for each group such as the Hydraulics/Control Group, and the Coal Log Fabrication Group. Besides reporting on the progress made each week, the meetings also involve planning. Each researcher is required to reveal his (her) plan for the next week and for more distant future, and each group leader is required to tell the others about the group plans. All such plans are discussed and debated in details at such weekly meetings. Then the Center Director remarks on the course of action to be taken, and the responsible individuals carry out the plan according to decisions reached at such meetings.

Management issues are also often discussed at such weekly meetings. The Center Director seeks advice on key management issues not only from the Associate Director but also from other Center workers and the Center Evaluator (Frank Seibert) -- see Evaluator's Report. For matters involving University policies, the Center Director seeks advice from the Dean of Engineering and the Dean of the Graduate School and Vice Provost for Research. A "University Policy Committee" has been established and the Committee met once a year -- see Appendix 2.

The current organizational chart of the Center is given in Table 7. The Center Director and the Associate Director share in administrative duties. If funding increases for the third year, a manager or an administrative assistant will be hired to reduce the Director's and the Associate Director's administrative duties. That will enable the Director and the Associate Director to devote more time to research. The type of personnel associated with the Center, and the personnel characteristics (statistics) are reported in Table 8.

INDUSTRIAL ADVISORY BOARD (IAB)

The Industrial Advisory Board (IAB) consists of all the nine large companies contributing cash (minimum of $15,000 each) to the Center, plus three small companies contributing a minimum of $5,000 each year in needed services or equipment. Current chairman of the Board is John Stolwyk from Kansas City Power and Light Company. The Vice Chairman is Doug Lee from the MAPCO Company, Tulsa, Oklahoma. Both the Chairman and the Vice Chairman were elected by the members. The Board meets twice a year. The last meeting was held on October 8, 1992. A copy of the minutes is attached in Appendix 2. A key recommendation of the meeting was to use the anticipated new DOE grant to build a coal log fabrication machine. Dr. Liu fully addressed this issue, and most participants to the meeting appear to be satisfied with his response and subsequent correspondence about this matter.

The IAB plays a key role in advising the Center Director on all matters related to the Center's operation. Such advice is given not only at regular Board meetings, but in letters and phone calls throughout the year. The Evaluator's Report contained in this report addresses the interaction and relation between the Center Director and the IAB.

Table 7. Organizational Chart of Capsule Pipeline Research Center

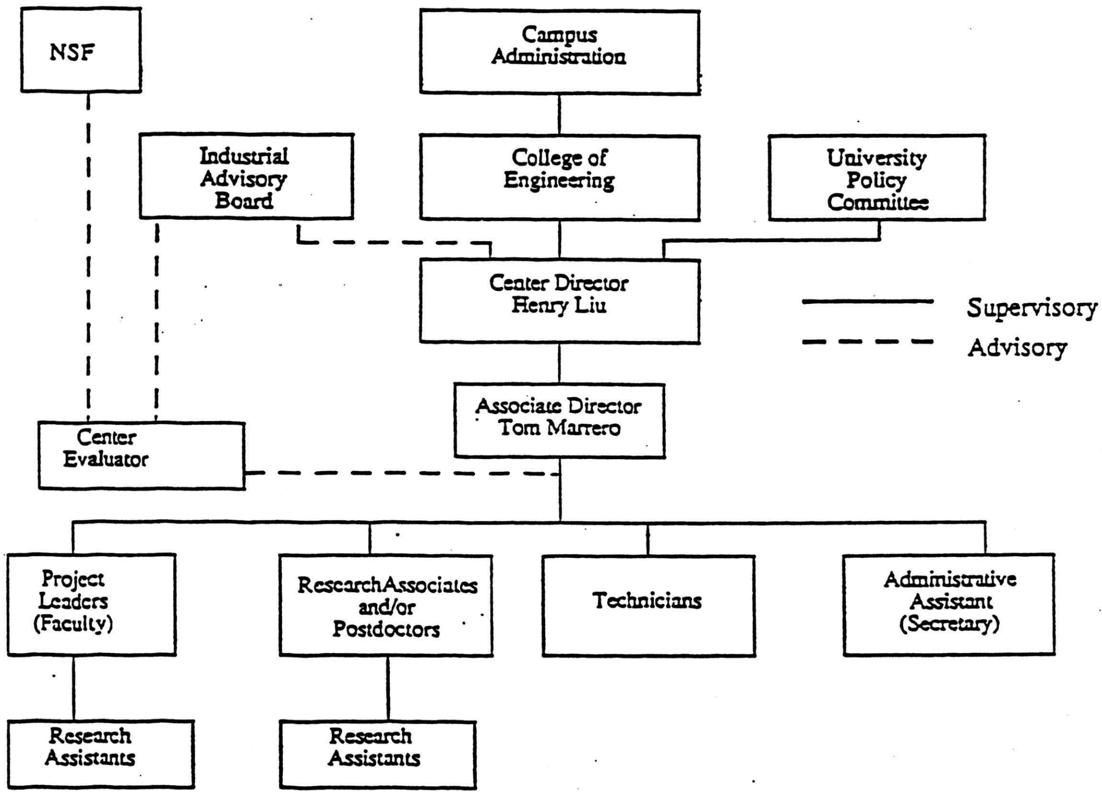


Table 8: STATE/IURC: PERSONNEL - YEAR 2

	#	Sex M	Sex F	Minority Stat.[1] 1	2	3	4	5	Disabled	Disciplines
Faculty	10	10	0	0	3	0	1	6	1	Engineering & Law
Research Staff[2]	1	1	0	0	0	0	0	1	0	Engineering
Visiting/Foreign Faculty[3]	2	2	0	0	1	0	0	1		Engineering
Industry Researcher[4]	0	0	0	0	0	0	0	0	0	None
Post Doc	1	1	0	0	1	0	0	0	0	Mining
Management/ Administration	2	0	2	0	0	1	0	1	0	None
Technical Staff	2	2	0	0	0	0	0	2	0	Engineering
Students: UG	10	8	2	0	0	1	0	9	0	Engineering
MS	14	12	2	0	9	0	1	4	0	Engineering & Law
PhD	4	4	0	0	3	0	0	1	0	Engineering

[1] (1) Native American; (2) Asian or Pacific Islander; (3) Black, not of Hispanic origin; (4) Hispanic; (5) White, not of Hispanic origin.
[2] Faculty level persons employed directly by State/IUCRC, not on regular faculty.
[3] Visits of 1 week or more.
[4] Industry research working at Center.

CONTRIBUTIONS TO STATE AND LOCAL ECONOMIC DEVELOPMENT STRATEGIES

The center must succeed technically before it can contribute to the state, region and the nation. Once the coal log pipeline technology is developed through the Center's R & D program, the technology can be used to transport any type of coal over both long distances and relatively short distances.

Approximately, 70% of Missouri's electricity is generated from coal. Most of the coal used in Missouri is imported from Illinois, Iowa, Wyoming and other states, involving transportation distances longer than 100 miles, sometimes even longer than 1,000 miles. The cost of coal transportation is high. For instance, each ton of low-sulfur coal sold in Wyoming, excluding transportation cost, is only $4 to $5. When transported to Missouri by train, the cost rises to $20 approximately. This means 3/4 of cost of Wyoming coal used in Missouri is transportation cost. Even for coal mined in Missouri and trucked to Missouri power plants within a distance of 100 miles, the transportation cost is still about $8 per ton. From an economic analysis of CLP conducted by Liu in 1993, the use of CLP instead of train (for long distance) and truck (for short distance) can cause savings of the order of $3 per ton. For a single 20-inch-diameter coal log pipeline which transports 18 million tons of coal per year, the savings accomplished is close to $50 million dollars per year. This shows the huge cost savings that can be accomplished by using coal log pipelines in Missouri. Because a dollar saved is as good as a dollar generated, the economic value of coal log pipelines to Missouri and neighboring states is enormous.

Furthermore, because coal log pipeline technology is developed in Missouri, the state will be the nation's and the world's leader in the coal log pipeline technology. A new industry will be generated in Missouri which will provide design, construction and consulting services not only to Missouri but also to other states and nations on coal log pipelines. This again provides economic development to Missouri, and can generate thousands of new jobs in the state.

SUPPORT, FINANCIAL MANAGEMENT & BUDGET

Data on industrial support are shown in **Tables 9 and 10**. As to the next year's state matching fund, the Missouri Department of Economic Development has included $200,000 in its budget, and the Senate has approved the budget. Another $50,000 needs to be requested under the 1995 F.Y. budget for the period 7/1/94-8/1/94 so that a total of $250,000 will be provided for the third-year operation of the Center (9/1/93-8/31/94). Final decisions on the State budget shall be made shortly.

Industry matching fund is not yet certain at this stage, but there is a strong likelihood that at least two new companies will join, bringing the industry matching funds to over $250,000 for the next year.

The Functional Budgets for the current year and the next year are given in **Tables 11 and 12**. The request for NSF's matching funds for the next year is made on NSF Form 1030.

Table 9. Industrial Support and Characteristics (Second Year)

Company Name	Size L/M/S	Foreign[1] Y/N	In state Mfg on R&D site Y/N	"Core" Cash Support[2] $k	"In-kind" Support $k	Total "Core" Support $k	"Non-Core" Cash Support $k
Arch Mineral Corp.	M	No	No	30	0	30	0
Associated Electric Cooperative	M	No	Yes	30	0	30	0
Bonnot Co.	S	No	No	0	5	5	0
Coal Services Corp.	M	Yes	No	15	0	15	0
EPRI	M	No	No	0	0	0	50
Gundlach Machine Co.	S	No	No	0	5	5	0
Kansas City Power & Light Co.	M	No	Yes	30	0	30	0
MAPCO Transportation Co.	L	No	No	30	0	30	0
Nova Tech Co.	S	No	Yes	0	5	5	0
Pro-Mark Company	S	No	Yes	0	5	5	0
Ramer & Associates	S	No	Yes	0	5	5	0
Union Electric Co.	M	No	Yes	15	0	15	0
DOE Pittsburgh Energy Tech Center		*No*	*No*	0	0	0	108
Williams Pipe Line Co.	M	No	Yes	15	0	15	0
Williams Technology, Inc.	M	No	No	0	15	15	0
TOTAL:				**165**	**40**	**205**	**158**

[1] Foreign companies with U.S. based manufacturing and R/D operations are considered foreign.
[2] Membership fees plus augmented "core" research funds.

Table 10. Industrial Support (Summary)

	Year 1	Year 2	Year 3	Year 4
Direct Cash: Core Program (Fees)	180,000	165,000		
Non-Core Program: (Sponsored Projects)	90,000	158,000		
Value of Company Personnel in Collaborative Work[1]	30,000	40,000		
Value of Donated Equipment	0	0		
Total	300,000	363,000		
Number of Member Companies	12	13		

(1) Do not count Industrial Advisory Board Meetings.

TABLE 11: STATE/IUCRC FUNCTIONAL BUDGET: YEAR TWO
September 1, 1992 - August 31, 1993

	SOURCES OF SUPPORT				
	STATE	INDUSTRY[1]	NSF	UNIVERSITY[2]	OTHER[3]
"Core" Research Salaries[4], Supplies and Services/Other[5]	131,284	150,000	150,000	160,019	65,880
Non "Core" Research					
Total Research	131,284	150,000	150,000	160,019	65,880
Equipment[6]	8,716	5,000		71,000	
Facilities				15,000	
Industrial Collaboration and Technology Transfer[7]	60,000	40,000			
Management[8]		10,000	50,000	20,000	
Indirect Cost				200,000	42,120
GRAND TOTAL	200,000	205,000	200,000	446,019	108,000

[1] Industrial Membership fees plus industry augmented "core" funds.
[2] Cash and Kind.
[3] Federal Agencies, Foundations, gifts, etc.
[4] Include fringe benefits.
[5] Travel, consultant, publications.
[6] No more than 10% of total "core" funds.
[7] No more than 30% of total "core" funds of the State and Industry. To support costs for workshops, training courses, experimental test.
[8] Center Directors time in management, administrative costs, travel, etc.

TABLE 12: STATE/IUCRC FUNCTIONAL BUDGET: YEAR THREE
September 1993 - August 1994

	SOURCES OF SUPPORT				
	STATE	INDUSTRY[1]	NSF	UNIVERSITY[2]	OTHER[3]
"Core" Research Salaries[4], Supplies and Services/Other[5]	170,000	165,000	194,500	138,983	33,550
Non "Core" Research					
Total Research	170,000	165,000	194,500		33,550
Equipment[6]		5,000	5,500	*	
Facilities					
Industrial Collaboration and Technology Transfer[7]	80,000	60,000			
Management[8]		20,000	50,000	25,000	
Indirect Cost				354,308	21,450
GRAND TOTAL	250,000	250,000	250,000	518,291	55,000

[1] Industrial Membership fees plus industry augmented "core" funds.
[2] Cash and Kind.
[3] Federal Agencies, Foundations, gifts, etc.
[4] Include fringe benefits.
[5] Travel, consultant, publications.
[6] No more than 10% of total "core" funds.
[7] No more than 30% of total "core" funds of the State and Industry. To support costs for workshops, training sources, experimental test.
[8] Center Directors time in management, administrative costs, travel, etc.
* Anticipated contribution by College of Engineering not included (Previous year received $71,000)

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY

ORGANIZATION: The Curators of the University of Missouri	PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Henry Liu	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds Granted By NSF (If Different)
1. H. Liu		1	1	$ 19,080	$
2. T. Marrero		1	1	13,800	
3. P. Davis			2	19,074	
4. C. Lenau			2	11,040	
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
7. (4) TOTAL SENIOR PERSONNEL (1 - 6)		2	6	62,994	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES .5 FTE	6			20,000	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.) technician	7			15,800	
3. (6) GRADUATE STUDENTS 3 Ph.Ds, .5FTE, 12 mo.; 3 MS, .5FTE, 12 mo.				70,299	
4. ( ) UNDERGRADUATE STUDENTS 20 hrs/week for 32 weeks, $7/hr				4,480	
5. ( ) SECRETARIAL - CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A + B)				173,573	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) 25% A1-4, B1-2; tuition for B3 (12,452)				37,151	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C) Tuition: 18 hrs/student @ 115.30/hr)				210,724	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $1,000.) PC for laboratory data acquisition (with software) -- needed for additional pipeline test loops.					
TOTAL PERMANENT EQUIPMENT				5,500	
E. TRAVEL 1. DOMESTIC: Present papers at national conferences (4 person-trips)				5,000	
2. FOREIGN: Attend international conference (2 person-trips)				5,000	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $					
2. TRAVEL					
3. SUBSISTENCE					
4. OTHER					
( ) TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES: pipe, valves, other fittings, coal, steel plates, plexiglass, etc.				12,776	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				3,000	
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER Center Evaluation (to UMC Small Business Center)				8,000	
TOTAL OTHER DIRECT COSTS				23,776	
H. TOTAL DIRECT COSTS (A THROUGH G)				250,000	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS					
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				250,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPM 252 AND 253)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 250,000	$

PI / PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
		INDIRECT COST RATE VERIFICATION		
INST. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date Of Rate Sheet	Initials - DGC

NSF Form 1030 (8/90) Supersedes All Previous Editions

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPM 233)

Capsule Pipeline Research Center Core Program
State Portion Budget
Year Three (9/1/93-8/31/94)

A. Senior Personnel	
1. H. Liu (1 ss month, 1 ay month)	19,080
2. T. Marrero (1 ss month, 1 ay month)	13,800
3. S. Nair (2 ss months)	11,040
Total Senior Personnel	**43,920**
B. Other Personnel	
1. Technician (9 months)	15,800
2. Senior Secretary (100% FTE) (Technology Transfer)	15,342
3. Graduate Research Assistants 2 Ph.D. and 3 M.S. (.5 FTE for 12 months)	57,987
4. Part-time Personnel	3,442
Total Other Personnel	**92,571**
C. Fringe Benefits	
1. 25% of A, B1, B2	18,766
2. Tuition for B2	10,377
Total Fringe Benefits	**29,143**
Total A, B, C	**165,634**
D. Travel	5,000
E. Research at UMR (under Dr. Wilson)	65,000
F. Equipment	0
G. Printing, phone, copying, etc.	3,000
H. Consultant	4,366
I. Materials and Supplies	7,000
Total Direct Costs	**250,000**

Capsule Pipeline Research Center Core Program
Industry Portion Budget
Year Three (9/1/93-8/31/94)

A. Senior Personnel	
1. H. Liu (1 ss month, 1 ay month)	19,080
2. T. Marrero (1 ss month, 1 ay month)	13,800
3. B. Gunnink (2 ss months)	11,640
4. Y. Lin (2 ss months)	10,392
5. R. Luecke (2 ss months)	13,920
6. Research Associate (12 cy months)	35,000
7. B. Burkett (12 cy months) (@.37 FTE)	16,632
Total Senior Personnel	**120,464**
B. Other Personnel	
1. Senior Secretary (12 cy months)	19,116
2. Graduate Research Assistants 2 Ph.D., 2 M.S., .5 FTE for 12 mo.	46,866
3. Part-time personnel (hourly)	10,000
Total Other Personnel	**75,982**
TOTAL PERSONNEL (A+B)	**196,446**
C. Fringe Benefits	
1. 25% of A1-A6, B1	30,737
2. 8% of A7	1,331
3. Tuition for B3	8,302
Total Fringe Benefits	**40,370**
Total A, B, C	**236,816**
D. Equipment	0
E. Travel Visit power plants, companies, and travel to conferences	8,000
F. Coal and Slurry Technology Association Fee	2,000
G. Materials/Supplies	3,184
Total Direct Costs	**250,000**

Cost Sharing Budget
9/1/93 - 8/31/94

A. <u>Personnel</u>	
1. H. Liu	
2 ay months	$ 19,680
2. T. Marrero	
2 ay months	14,400
3. P. Davis	
2 ay months	19,074
4. C. Lenau	
2 ay months	11,040
5. B. Gunnink	
2 ay months	11,640
6. Y. Lin	
2 ay months	10,392
7. R. Luecke	
2 ay months	13,920
8. S. Nair	
2 ay months	11,040
9. Postdoctoral Fellow	
.5 FTE	20,000
Total Personnel	$131,186
B. <u>Fringe Benefits</u>	
25% of A1-9	$ 32,797
Total Direct Costs	**$163,983**
Indirect Costs (39% MTDC):	
MU Cost Sharing (39% of 163,983)	**$ 63,953**
NSF, Industry, MDED portions (39% of 744,500)	**$290,355**
Total Cost Sharing	**$518,291**

Capsule Pipeline Research Center Evaluator's Report

by Frank Seibert
Director, Small Business Development Center
University of Missouri-Columbia

The Capsule Pipeline Research Center at the University of Missouri-Columbia is in its second year of operation, following a very busy and very productive first year. Three Advisory Board Meetings have been conducted since the inception of the Center, and these meetings were attended by the full CLP Consortium Members, Small Business Participants, Representatives from the NSF, a representative of State of Missouri's Department of Economic Development, and the Faculty, Students and Staff of the Coal Log Pipeline Center. Dr. Henry Liu and I have attended State/ICURC meetings in Washington D.C. sponsored by the NSF for the past two years. The NSF conducted a Site Review on October 7,8 & 9, 1992 and sent their collective findings to Dr. Henry Liu. Progress on all research projects has been realized and will be updated at the next Advisory Board Meeting on May 18, 1993. Numerous communications between the NSF, CLP Consortium Members and Dr. Henry Liu have taken place on an array of issues and topics relative to the Center's research programs. Without exception, Dr. Liu has responded to every concern highlighted in these communications.

The extent of satisfaction and commitment among the Consortium Members is evidenced in the nature of the communications between the Center Director and the Consortium Members. Several of the IAB members have questioned the way in which research projects are prioritized and have expressed this to the Center Director. Different points of view of the stakeholders have been openly and thoroughly discussed. The Center Director communicates in writing whenever significant differences of opinion occur. The survey results from the past two meetings support the contention that the members are becoming increasingly pleased with the progress of the Center. The results of the most recent survey reflect the following; 100 % of the respondents rated *"Considerably Satisfied"* to the **Technical Quality** of the Center(an increase of 12.5% over last year), 42.9% rated *"Completely Satisfied"* and 57.1% rated *"Considerably Satisfied"* to **Communications between Consortium Staff and your Company** (this represents an increase of more than 22% over last year's responses for the two levels of satisfaction), 100% of the respondents rated *"Considerably Satisfied"* to **Center Administrative Practices** (only 33.3% last rated the Center this high last year, and 66.7% rated only *"Somewhat Satisfied"*), 14.3% of the respondents rated *"Completely Satisfied"* and 57.1% rated *"Considerably Satisfied"* to **Responsiveness of the research to industry needs** (this represents a slight(15.9%) improvement over last year for the two levels of satisfaction)), 28.6% of the respondents rated *"Completely Satisfied"* and 57.1% rated *"Considerably Satisfied"* to **Innovative Quality of Research**(an improvement of 30.2% over last year for the two categories), and 28.6% of the respondents rated *"Completely Satisfied"* and 42.9% rated *"Considerably Satisfied"* to **Project Selection Process**(an improvement of 27.1% over last year for the same two categories). The results of the surveys are very positive indicators of the progress the Center has made in improving relations with the Consortium Members.

The Center Director has carefully and tactfully responded to the concerns of the members. Following discussions with NSF and Consortium Members, future IAB meetings will be open meetings, but voting privileges will be reserved to IAB Members. The roles of the Center Members have been developed and articulated during the past two meetings. Only one company withdrew from the Center since the start of operations, and that was the ARCO company. They cited their reason for leaving the Consortium because of financial problems within the company. Two new members have joined the Center during the last year: NOVA Tech Inc., Lenexa, Kansas(they specialize in computer control of pipeline Systems) and Pro-Mark Process Systems, St Louis, Missouri(they are an equipment company). Several additional electrical utilities are being sought as new members, including Tennessee Valley Authority (TVA), Northern States Power Company, and Southern Company Services. The Electric Power Research Institute(EPRI) is helping the Center by encouraging utility companies to join the CLP Consortium through its Tailored Coordination(TC) Program.

Technology transfer issues have attracted considerable attention at the CLP Research Center, and have produced the following; involvement of several companies in CLP research, numerous technical presentations on the CLP at national and international conferences, the completion of a video production about the center's activities and potential for economic development, two newsletters to date, numerous publications, company seminars/visits, preparation for the first field testing site, technical presentations to all Consortium members, and the presentation of a seminar on "solids transportation". Technology transfer is a high priority item on the Center's agenda, as evidenced in the future plans for the center, outlined in this annual report.

The Center began operations with members from State Government, the NSF, Industry Representatives, and the University of Missouri(Columbia and Rolla Campuses). The nature of the Center's activities mandates that different scientific and academic disciplines join together to identify and solve problems/issues. Departments from UMC involved are; Civil Engineering, Mechanical Engineering, Chemical Engineering, and the School of Law. UMR's Department of Mining Engineering is also intimately involved in coal log research and related activities. Technical assistance is also being provided by private consultants. Furthermore, the College of Business and Public Administration will become involved with the Center by supporting Marketing Research through a Faculty member and an undergraduate or graduate student. Dr. Liu has involved the Faculty and Consortium Members in developing a strategic plan for the center, complete with milestones. A plan for attracting new members and a plan for increasing Center funding have also been developed. Getting a commitment from Williams Pipe Line Company to provide a site(existing pipeline) for field testing is a major achievement, as the outcome of this research depends on the achievable results of the center, not just research and publications.

The Center continues to operate in a smooth and efficient manner, due in large part to the effective leadership of its Director, the strong support from the Associate Director, the College of Engineering Administration, the Campus Administration, the industry and government sponsors, and the dedication of Faculty, Staff and Students.

Appendix 1: Individual Project Descriptions

(Note: Beginning the next page, a description is provided for each individual project operating under the Center during the second year (9/1/92-8/31/93). The expenditure listed for each project includes only salaries, wages and fringe benefits of the personnel working on the project, including the P.I., research associates (if any), post doctors (if any), and students. Other expenditures such as equipment and materials purchased, travel expenses and so on for each project are not included because they are centrally managed and difficult to break down. The listed expenditures are approximately 70% of the total expenditure of each projects.)

Project Title: **Compaction of Binderless Coal Logs**

Principal Investigator: Brett Gunnink, Assistant Professor of Civil Engineering

Duration: 9/1/92 - 8/31/93

2nd-Year Expenditure: $43,545

Research Associates: None
(0 person-years)

Post-Doctoral Fellow: None
(0 person-years)

Graduate Research Assistants: Z. Liang, J. Kanunar, F. Chen
(1.00 person-years)

Other students who worked on project: R. Camp
(0.0625 person-years)

Purpose of Research:

To explore and optimize a compaction technique for making binderless coal logs.

Need for Research:

Means for making economical and durable coal logs must be found before coal log pipelines can be used commercially. Compaction appears to be a promising way to fabricate coal logs that should be explored.

Research Progress:

Work during the second year focused on improving the water adsorption characteristics of binderless coal logs. We are capable of making logs with sufficient mechanical strength. However, if adsorption of water is excessive there is an excessive loss of strength. We have discovered that if logs are formed at a moisture content equal to the equilibrium moisture content for the coal, water adsorption is minimal, and there is little loss of strength. However, for the powder river basin coal we are studying, that equilibrium moisture content is high and logs formed at that moisture content have insufficient mechanical strength. The equilibrium moisture content of the coal can be lowered when dried under appropriate conditions. This is well recognized and is the basis for the hot water drying operations that are currently being commercialized. We have discovered that if the appropriate moisture, temperature and pressure conditions are created during the formation of a coal log, the resultant coal log's equilibrium moisture content is also lowered. As a result, these logs adsorb little water and retain their mechanical strength. We will refer to logs formed in this manner as hot water dried coal logs or HWD logs. Further details of the process for making HWD coal logs will not be reported at this time due to patent disclosure considerations. Therefore, the remainder of this report will include results on the strength, adsorption properties and degradation performance of HWD coal logs.

Table 1 contrasts the strength and adsorption properties for HWD logs and conventional logs. The conventional logs in table 1 had an initial water content (% of dry mass) of 15% and were compacted at 90 °C with a maximum compressive stress of 20,000 psi. Post-adsorption data are for logs that were exposed to 500 psi water for 24 hours. The HWD coal logs had much higher pre-adsorption strength than the conventional logs. What is more important, the HWD logs also had much higher post-adsorption strength than conventional logs. Exposing HWD logs to high pressure water resulted in an insignificant loss of compressive strength, whereas, post-adsorption compressive strength in conventional logs is approximately 25% of pre-adsorption values. Tensile strength is reduced to 52% of the pre-adsorption value for HWD logs, whereas, it is reduced to 38% of the pre-adsorption value for conventional logs. The post-adsorption strength of HWD logs is 8.4 times the strength of conventional logs in compression, and 3.7 times the strength of conventional logs in tension.

From the data in Table 1 it can be shown that conventional coal logs adsorb 2.5 times as much water as HWD coal logs. Conventional coal logs also swell volumetrically when exposed to water. The net result of water adsorption and swelling is a small decrease in the specific gravity of the conventional logs. In contrast, HWD logs swell very little. Thus, the adsorption of water in HWD logs causes the specific gravity of the logs to increase.

Table 1 - Comparison of post and pre-adsorption properties of conventional and HWD coal logs.

	Conventional Pre-adsorption	Conventional Post-adsorption	HWD Pre-adsorption	HWD Post-adsorption
Compressive Strength (psi)	991	267	2386	2254
Tensile Strength (psi)	69	26	186	97
Specific Gravity	1.28	1.27	1.26	1.31
Water Content (% total mass)	13.0	24.2	16.0	20.5
Water Content (% dry mass)	15.0	32.0	19.0	25.8

Table 2 summarizes the results of degradation testing of HWD coal logs. The first four logs in this table (HT-10, 11, 12, and 14) were exposed to 500 psi water for 24 hours before being circulated in the 2 inch diameter test pipeline. All of these logs met the CPRC durability criteria by circulating for 350 cycles with less than 3% weight loss. However, the CPRC durability criteria require exposure to 500 psi water to 7 days. Consequently, the last two logs in Table 2 (HT-17, and UNO) were exposed to 500 psi water for 7 days. One of these logs, HT-17 did not meet durability criteria. For all the logs, except HT-UNO, the degradation test was terminated after the logs broke into two pieces. The logs failed by a clean brittle fracture, with the two pieces intact. For the other log, HT-UNO, the test was terminated after 2000 revolutions and the log remained in one piece. All logs were circulated at the lift-off velocity of 9 ft/s.

Table 2 - Summary of degradation testing of HWD coal logs.

Log ID	Circulation Time (m)	Number of Revolutions	Travel Distance (miles)	Weight Loss (%)
HT-10	180	1200	18.4	3.6
HT-11	70	467	7.2	3.4
HT-12	140	932	14.3	3.5
HT-14	155	1033	15.9	4.0
HT-17	30	200	3.1	3.4
HT-UNO	300	2000	30.7	9.9

The HWD logs are probably durable enough for commercial pipelines as is. However, we remain somewhat concerned about the circumferential cracking and the resultant brittle fracture failure in these logs. Therefore, we are exploring three ways eliminating this problem: (1) an investigation of the effect of making coal logs in a multi-part mold on the occurrence of circumferential cracking, (2) an investigation of the effect of fiber reinforcement on the occurrence and propagation of circumferential cracking, and (3) an investigation of the effect of a thin polymer coating on the propagation of circumferential cracking.

Significant Accomplishments:

The most significant accomplishment during the second year is the development of HWD coal logs. HWD logs are high strength water resistant logs. Work during this year focused on characterizing the strength and performance characteristics of HWD logs. The HWD logs have performed very well and we believe that their development constitutes a major breakthrough in coal log fabrication. The HWD logs meet log durability criteria adopted by the CPRC in May of 1992. All but one of the logs tested circulated for 350 cycles with no more than 3% weight loss. Details of the strength and performance characteristics of HWD logs are included in the research progress section of this report.

Future Plan:

The work plan for the next six months to a year will focus on expanded degradation testing of HWD coal logs and minimizing the occurrence and propagation of circumferential cracking in these logs. This will include:

1. expanded degradation testing of HWD coal logs by circulating logs in the test pipeline,
2. an investigation of the effect of making coal logs in a multi-part mold on the occurrence of circumferential cracking,
3. an investigation of the effect of fiber reinforcement on the occurrence and propagation of circumferential cracking, and
4. an investigation of the effect of a thin polymer coating on the propagation of circumferential cracking.

In addition, during the next year we will begin to investigate the fabrication of 8 inch diameter logs. To do this it will be necessary to closely interact with colleagues in involved in machine design.

Publications:

Gunnink, B.W. and Liang, Z., "Compaction of Binderless Coal for Coal Log Pipelines", accepted for publication in *Fuel Processing Technology*, Elsevier, Amsterdam.

Liang, Z., (1993) "Compaction of Binderless Coal for Coal Log Pipelines", thesis presented to the University of Missouri-Columbia, at Columbia, Missouri, in partial fulfillment of the requirements for the degree of Master of Science.

Gunnink, B.W. and Liang, Z., (1992) "Compaction of Binderless Coal Logs for Coal Pipelines", *Proceedings 17th International Conference on Coal Utilization and Slurry Technologies*, Coal and Slurry Technology Association, 677-686.

Patents: None to date

Industry Involvement:

Industry involvement has included many discussions concerning coal log fabrication with consortium members at biennial meetings. Several consortium representatives provided the principal investigator with literature about hot water drying processes for coal. This literature was the seed from which the idea for HWD coal logs grew.

Project Title: Underwater Extrusion of Coal Log

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

Duration: 9/1/92 - 8/31/93

Second-Year-Expenditure: $12,672

Research Associates: None (0 person-year)

Post-Doctoral Fellow: None (0 person-year)

Graduate Research Assistant: Liqing Wang (0.375 person-year)

Other students who worked on project: Shannon Eckhoff (undergraduate, 0.1 person-year)

Purpose of Research:

To explore the feasibility of underwater extrusion of coal logs with minimum amount of binder or without binder.

Need for Research:

The fabrication of strong coal logs, so that they can withstand up to 2000 psi water pressure and long distance transportation in pipeline without breakage, with minimum energy and cost, is of vital importance to future commercial success of the coal log pipeline technology. Also, it may be advantageous if coal logs from a fabrication machine can be injected directly into a pressurized, water-filled pipeline, so that the coal logs are not exposed to atmospheric air after fabrication. The underwater extrusion process could reduce adverse effect on extrusion due to gravity, increase the strength of the coal logs, reduce the manufacturing time, and simplify the process of coal log injection.

Second-Year Work (9/1/92-8/31/93):

Using a small auger-type extruder (1.5 HP motor) and a fixture that can withstand high water pressure (designed for 2000 psi and tested at 1000), we did some underwater extrusion experiment. For low binder (2-3% of asphalt) coal log extrusion at low water pressure (<100 psi), underwater extrusion is just as good as extruding logs into the air. They have the same problem of absorbing excessive water. However, buoyancy effect enables longer logs to be extruded without support, and rapid cooling increased short term strength of extruded logs. Extruding coal logs into high-pressure water offers another potential advantage: higher pressure causes greater compaction which in turns produces better logs. However, so far we have not been able to verify this. Due to the limited power of our extruder, the higher exit pressure clogs the die. It is highly desirable to adjust the exit pressure in-process. Controlling water pressure in-process will be much easier than controlling the diameter or the length of the die to produce the intended pressure. We cannot extrude at higher water pressure because the current extruder will clog if the back pressure from the water chamber is higher than 100 psi.

An important discovery is that durable coal logs can be extruded without any binder. We added some water to originally dry coal material before extrusion. When extruded, the logs lost most of the water added, ending up with about the same moisture content as before water was added in the coal (26% of moisture). In contrast to logs made of pre-heated and dried coal, logs extruded this way can be considered "wet logs". This way of making logs has several advantages. First, it enables us to extrude binderless logs. Second, these logs maintain dimensional stability and integrity under high water pressure for a long time (tested under 500 psi for a week). Third, without pre-heating and drying of coal much saving can be accomplished. Fourth, the process seems not sensitive to particle size distribution, which is very important for mass production of coal logs. In extruding this type of wet logs, underwater extrusion has an obvious advantage. If the extruded wet logs are exposed to the air, and then put into pipeline for transportation, they are not as strong as extruded into the water directly. There are some problems that remain to be solved, before the logs extruded can be as durable as desired. One major difficulty is the elimination of flaky, helical-shaped, friction-produced surfaces inside the logs. This problem has been solved before by graphite electrode manufacturers by using a piston type extruder. We are not able to extrude under higher water pressure (>100 psi) because of the physical limitations of our extruder.

Plan for Next Year (9/1/93-8/31/94):

The research we plan to complete next year includes the following:

1. We are purchasing a large, piston type extruder for extrusion. The procurement is in process. This machine should solve at least two of our binderless-coal-log, underwater-extrusion problems. One is that we should be able to use higher and controllable water pressure to produce stronger logs. The second is the elimination of internal flaky surfaces, which greatly reduced the flexure strength of the wet logs. The internal shear of coal material during extrusion is beneficial. This can be obtained for piston extrusion using specially designed die.

2. Continue to find out the best combination of parameters, such as exit pressure and initial moisture content, for making binderless and durable coal logs.

3. We also want to experiment underwater extrusion of coal logs with small amount of binder. We should test the binder also as a reagent to change the coal into some degree of hydrophobic material. Otherwise, even with post-extrusion surface treatment (logs can be extruded into surface treatment chamber), the dry logs may still swell and lose their strength. For wet logs, binder and reagent may improve the impact strength. However, binder will not be used unless the binderless process could not produce strong enough logs.

4. We plan to develop first an approximate analytical model for the extrusion process, then gradually refine the model for different material and ambient conditions. Since the properties of coal differ so much for different mines, it is desirable to utilize our experience and knowledge to construct a model, that can predict coal log extrusion, and suggest die design improvements for high quality coal log manufacturing.

Publications:

Binderless Coal Log Extrusion, CPRC internal report (publication temporarily withheld due to proprietary information), March, 1993, 14 pages.

Patents:

Water-Assisted Binderless Extrusion of Coal Logs, preliminary invention disclosure filed with the University Office of Patents & Licensing, April 9, 1993.

Industry Involvement:

Visited two extrusion companies for surplus equipment for extrusion:

1. Mohr Corporation at Detroit, MI, on Feburary 10, 1993.
2. Great Lakes Research Corporation at Elizaberthton, TN, on March 3, 1993

Project Title: **Machine Design for Coal Log Fabrication**

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

Duration: 9/1/92 - 8/31/93

Second-Year-Expenditure: $7,054

Research Associates: None (0 person-year)

Post-Doctoral Fellow: None (0 person-year)

Graduate Research Assistant: Liqing Wang (0.125 person-year)

Other students who worked on project: Brent Leonard (undergraduate, 0.375 person-year)

Purpose of Research:

The main objective of this project is to conceptually design a machine for coal log fabrication at commercial mass production rate. Coal log surface treatment equipment and other accessaries are also included in the design.

Need for Research:

The machine design can suggest desirable improvements for laboratory coal log fabrication process, provide a basis for better estimation of the fabrication rate, and the cost of coal log fabrication in commercial operation.

Second-Year Work (9/1/92-8/31/93):

Based on the experience we gained from an initial design, and comments from our industrial consultants, we have revised the conceptual design of the coal log fabrication machine for mass production. The revised designs are based on compaction and extrusion processes, respectively.

Major changes on the compaction machine are the consideration of easy access for maintenance, stack-up capsule storage instead of moving all capsules on a chain, several stages of compaction in order to use different type of compacting actuators to speed up the operation, and improvement on the splitable mold design.

A new type of machine design is based on the extrusion process. Since it has been shown that binderless and underwater extrusion is a promising direction for manufacturing durable logs, we want to explore the potential of a mass production machine based on this process. The design is primitive, but it can serve as a base for soliciting comments and for further discussion.

A splitable mold has been designed for laboratory use. Improved splitable mold can be used on mass production, compaction machine.

Plan for Next Year (9/1/93-8/31/94):

We plan to have the following research and development activities in the coming year:

1. Develop an analytical model for the extrusion of coal logs and run tests to verify the model. Then, use the model to design an optimum extruder for making coal logs.

2. Continue to improve the conceptual designs for compaction, and extrusion machines. As the durable log manufacturing processes are better established, the machine design will also gradually take shape.

3. Test various partial processes, and subsystem designs. This includes, for example, improvement on splitable mold and its cap design, and improvement of extruder die design based on analytical model of the extrusion process.

4. Build a scale model of the designed commercial log compaction machine for testing and demonstration.

Publications:

Coal Log Compaction Machine Design and Cost Estimation, CPRC Internal Report. Not published due to the proprietary nature of this work, September 1992.

Patents: None.

Industry Involvement:

Consultation and discussion with: James Rammer & Associates, Pro-Mark Process Systems, The Bonnot Company, and T. J. Gundlach Machine Company. A meeting was held at the Holiday Inn Executive Center, Columbia, MO, on the evening of October 7, 1992, to discuss coal log compaction machine design with several industry members involved in the Center.

Project Title: Impermeable Coal-Log Casings

Principal Investigator: Dr. Richard H. Luecke, Professor of Chemical Engineering

Duration: 9/1/92-8/31/93

2nd-Year Expenditure: $27,788

Research Associates: None (0 person-year)

Post Doctoral Fellow: None (0 person-year)

Graduate Research Assistant: Dan Carney (0.25 person-year)

Other Student who Worked on Project: James Eichelberger (0.20 person-year)

Purpose of Research: To prevent water infiltration into dry coal logs by encasing it with material that is impermeable to water.

Need for the Research:

Coal logs that were used to demonstrate feasibility in the 8 inch test pipeline were extruded with 15-25% asphalt binder. Economic evaluations show that the maximum allowable amount of binder is about 3%. This is equivalent to a layer of asphalt about 3 mm thick on the outside of a 20 inch diameter coal log.

Over the past two years, compaction techniques have been developed to manufacture coal logs with high strength without using binder. However, if made from dried coal, these coal logs are very sensitive to water. Water enters and expands the coal particles in the dried coal log destroying its strength. To be feasible candidates for commercial use in the coal log pipeline, it is essential to keep water away from the dried coal particles.

Other coal log manufacturing methods are also under investigation (and are described elsewhere in this report) using coal that contains an equilibrium amount of water. Generally higher strengths can be reached using the dried coal but logs made with high water contents have shown strength that is more than sufficient to pass the "pipeline endurance test". There are, however, two principal problems with the high water content logs:

1. The high water content, binderless logs are not as strong as the dry logs;

2. These logs have significantly higher densities than the dried coal logs. The increased density means that significantly higher velocities are required for pumping so that more energy is required to transport the logs.

3. The increased moisture reduces the heating value per unit weight of the delivered coal log.

Thus a coal log manufacturing method is available that does not require binder and does not require keeping water out of the finished log. Nonetheless because of the pumping-energy economics, research has continued to try to find a suitable method to prevent water from reaching coal particles in coal logs. And in any case it would be useful to have a coating to increase abrasion resistance of the coal log.

Research Progress:

Various methods of coating coal logs with impermeable materials were evaluated. So far, only the use of a thick (2-4 mm) external coating of wax on a coal log has remained impermeable to water during exposure at 500 psi for 24-48 hours. A log (44.5 mm diameter x 50 mm long) was coated with wax by repeated dipping (similar to candlemaking) creating an exterior coating about 4 mm thick. After this log resisted water penetration at high pressures, it was circulated in the accelerated-wear test pipeline where it was found that a slow loss of the coating occurred. The coating was still intact after 4 hours of circulation but after another 2-1/2 hours small patches of coal could be seen where the wax had worn through. These results are relatively recent and testing and evaluation of this approach is continuing.

In our initial experiments for protection from water infiltration, dry pulverized coal was precoated with asphalt before compaction. It was planned to use this composite as a casing for binderless coal logs. Various dispersion techniques were tried but using even up to 25% asphalt was not successful in completely sealing water out of the coal. Not only did treated samples gain moisture but also direct measurements of the permeability of small disks showed that 20-30% asphalt pre-mixed with the coal did not render it impervious to water. Although higher asphalt concentrations improved water impermeability, even at concentration levels up to 30%, water permeability was much higher than could be tolerated. These results suggested that direct coating of the exterior surface of the formed and finished dry coal logs with pure asphalt may be a better way to seal moisture out of the log.

Surface coating of chips (wafers) and small logs (44.5 mm diameter x 50 mm long) with pure asphalt made them impervious to water at atmospheric pressure. However at high pressures (500 psi), water infiltration occurred during tests for prolonged periods (up to 48 hours). Even relatively thick coverings of asphalt (up to 4 mm) permitted water to saturate dried coal logs (or coal log chips) when subjected to 500 psi water for 24-48 hours. Small holes were found in the coatings after the tests that were not detectable before. Failure of the asphalt coatings was deemed to be the result of cold viscous flow of the non-Newtonian asphalt.

A series of tests were then conducted to impregnate the outer layers of the logs with waxes which harden at room temperature. Impregnation was accomplished by subjecting the finished log first to vacuum and then to pressure while under the surface of molten wax. Although hard, smooth, shiny logs with 4 to 12% wax were produced, all failed in high pressure (500 psi) water immersion tests. The 4 to 12% wax in small logs would translate to much lower fractions in large log since only the outer layers would be wax treated. For example, if there were 10% wax in the outer 1 inch layer of a 20 inch diameter log, the overall percentage of wax would be 2%.

It is of interest to note that during the evacuation the air was expelled from these logs through a few isolated surface flaws, such as tiny pores or non-visible cracks, rather than uniformly over the surface. Undoubtedly the entrapped air was reaching the surface of the log through an internal network of channels and flaws. It would be expected however that the molten wax would fill these passageways during the subsequent pressurized period. Nonetheless water reached and ruined log interiors rapidly (10 minutes to 1 hour) even in logs submerged in molten wax for 4 hours at 40 psig following the evacuation process. We currently postulate the presence of small hydrophilic centers that resist wax coating on and in the log. These then may provide entrance points for high pressure water.

As a sidelight to the coating experiments, we have developed procedures for consistent production of logs without observable surface flaws. Basically the procedures involve programming the rate of pressure changes to conform to the slower change rates of temperature. It is important also to maintain a good quality surface on the die in which the log is formed.

Significant Accomplishments:

Only the external wax coatings obtained by repeated dipping were capable of resisting high pressure water infiltration. This coating became worn after several hours of accelerated-wear pipeline test so that the coal surface was ultimately exposed allowing water infiltration.

In the course of this work, other procedures were found which will be important to the ultimate success of the coal capsule pipeline. These include a graduated pressure-temperature procedure for the production of high quality logs and methods to evaluate temperature distribution in coal logs during the heating cycles.

Proposed Future Work:

There still is a need for a coating on the logs to resist water infiltration and to help maintain the integrity of the outer layers of the water resistant logs.

1. We plan to continue the search for techniques and conditions to water seal coal logs using external coatings. We will test harder waxes since cold flow of wax may be a factor in failures during endurance tests.

2 The immersion impregnation techniques developed with wax will be extended to asphalt. Although asphalt as an exterior surface coating was not effective, it is possible that the more intimate contact between the asphalt and coal with the impregnation method may provide greater resistance to cold flow. In any event, asphalt is a low-priced, readily available water-resistant material that is very effective in "wetting" coal and must be explored as a possible candidate.

3. We also will evaluate other materials as surface coatings. These may include polymers, flocculating agents and other materials.

Publications:

None.

Patents:

None (But, as with publications, one may develop if the research proves successful.)

Industry Involvement:

Waxes and asphalt have been provided by: National Wax Company (Skokie, IL), and Shell Company, Illinois.

Project Title: Surface Treatments of Coal Logs

Principal Investigator: Thomas R. Marrero, Associate Professor of Chemical Engineering and Associate Director of Capsule Pipeline Research Center

Duration: 9/01/92-8/31/93

2nd-Year Expenditure: $77,315

Research Associates: William J. Burkett (0.33 person-year)

Post-Doctoral Fellows: None (0 person-year)

Graduate Research Assistants: S-H. Chen (0.5 person-year)
R.J. Smith (0.5 person-year)
S-H. Sun (0.5 person-year)
M. Kersting (0.1 person-year)

Undergraduate Assistants: J. Bennett (0.25 person-year)
A. Rockabrand (0.25 person-year)
R.J. Smith (0.25 person-year)

Purpose for the Research: To investigate the surface treatment of coal logs to minimize water absorption and maintain log tensile strength; treatment methods to include: coal slurry impregnation, heat and chemical additives.

Need for the Research:

Coal characteristics (rank, particle size, moisture content, binder) and compaction process conditions (temperature, pressure, etc.) need to be better understood for coal log fabrication. Surface-treated coal logs could possibly produce economical and satisfactory coal logs. The technical feasibility for surface treatment of coal logs needs to be evaluated.

Research Progress (Second Year Work, 9/01/92-8/31/93):

Initial experiments were conducted to determine the important factors of slurry impregnation. These factors include coal particle size in the log, coal particle size in the slurry, slurry concentration, and time and pressure of impregnation. The experiments were conducted with small 30 g coal logs (1.25-inch diameter). To efficiently impregnate the coal logs, the average void size of the untreated logs needs to be determined. The work performed next dealt with correlating particle size to average void size and permeability. As expected, smaller particles decreased permeability and void fraction. Permeability experiments were conducted on compacted disks (6 g, 1.25-inch diameter) made from a specific particle size range of coal. Test results indicate that slurry impregnated into the disk reduced its permeability by a factor of more than 30, see Figure 1. (R.J. Smith).

The heat treatment of coal log surfaces was studied by means of both microwave and radiant heat sources. Subbituminous coal was used. The initial tests using microwaves were inconclusive. A radiant heater was constructed that would allow the immersion of coal logs inside a cylinder inerted with nitrogen. Heater surface temperatures were up to 1000°C and the logs were immersed for intervals of less than 30 seconds. It is known that coal will flow when heated as long as decomposition does not occur. These initial trials failed to make an impermeable log surface when they were statically immersed in water for 24 hours at 3.5 MPa (500 psi). Additional tests need to be done to understand the unsteady state thermal transfer characteristics of a coal log and how to produce thicker films when by heat treatment. (S-H. Sun).

The effects of particle size, binder concentration and compaction pressure on coal log water absorption, permeability and strength were experimentally studied. For a given coal and binder, the intensity of each independent variable was considered at three levels. At each condition about 6 replicates were made. As expected, higher compaction pressures produced better logs and increased amounts of binder improved the coals' water absorptivity. Using maximum packing density particle size distribution in logs decreases water absorption and permeability. Strength increases to a maximum and then decreases as the asphalt concentration increases. These effects are presented in Figures 2 and 3; Figure 2 indicates strength before immersion, and Figure 3 after immersion in water at 3.5 MPa (500 psi). Both conditions resulted in maximum tensile strengths with an asphalt content of about 20 weight percent. (S-H. Chen).

A preliminary model for permeability is being developed according to Darcy's law and empirical factors. (N. Dural).

Significant Accomplishments:

Preliminary tests have started to investigate means to reduce coal log water uptake by heat treatment of surfaces, slurry impregnation, and binder additions. Slurry impregnation reduced permeability rates. The effects of asphalt on tensile strength indicate a peak strength at about 20 weight percent asphalt.

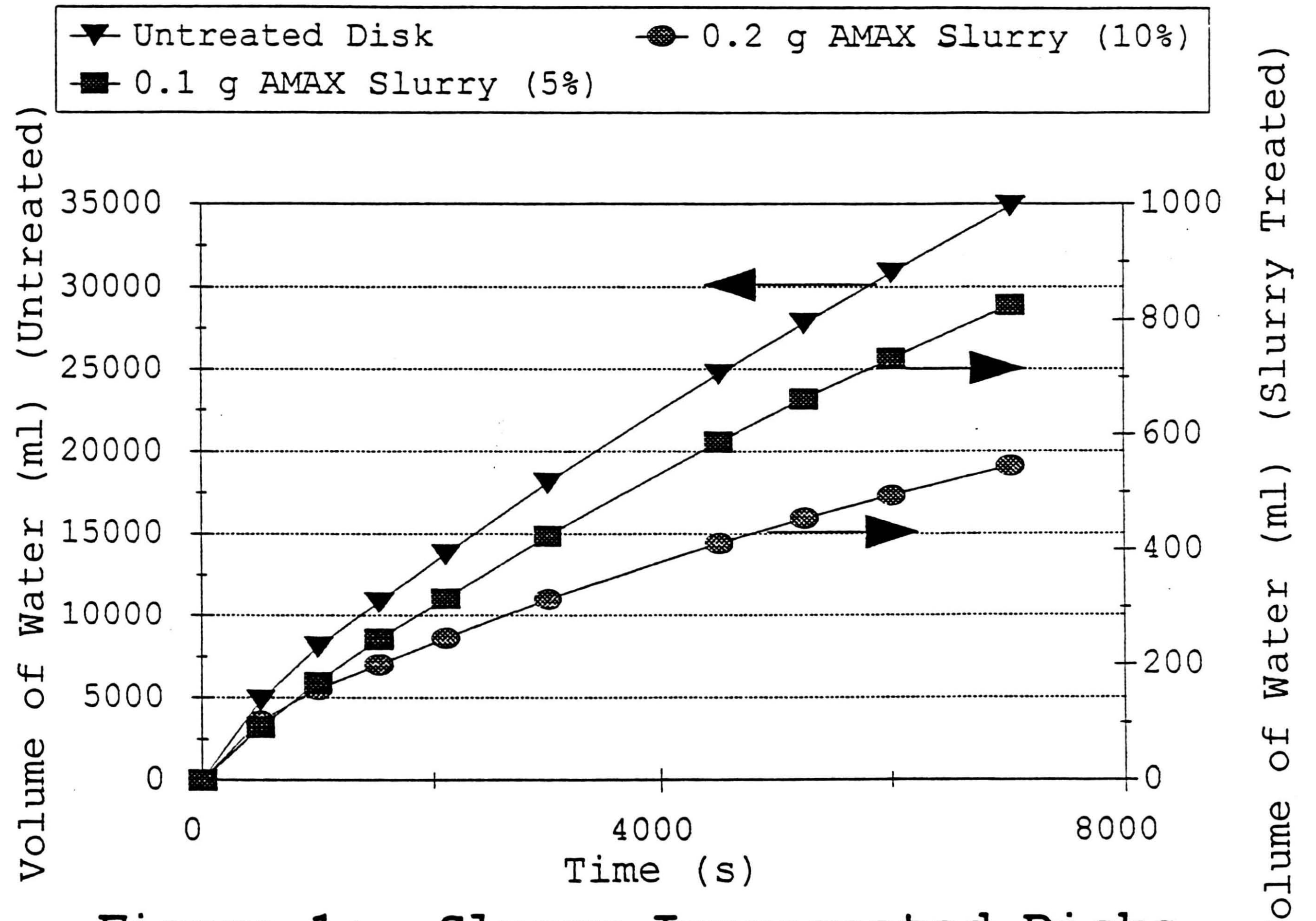


Figure 1: Slurry Impregnated Disks

Figure 2. Splitting tensile strength of a coal log with particles of the maximum packing density before water immersion test (24 hours at 3.5 MPa (500 psi).

Compaction Pressure (MPa)	Binder Percentage			
	5%	10%	20%	30%
37	0.12	0.18	0.42	0.37
74	0.20	0.33	0.51	0.30
148	0.27	0.34	0.52	0.29

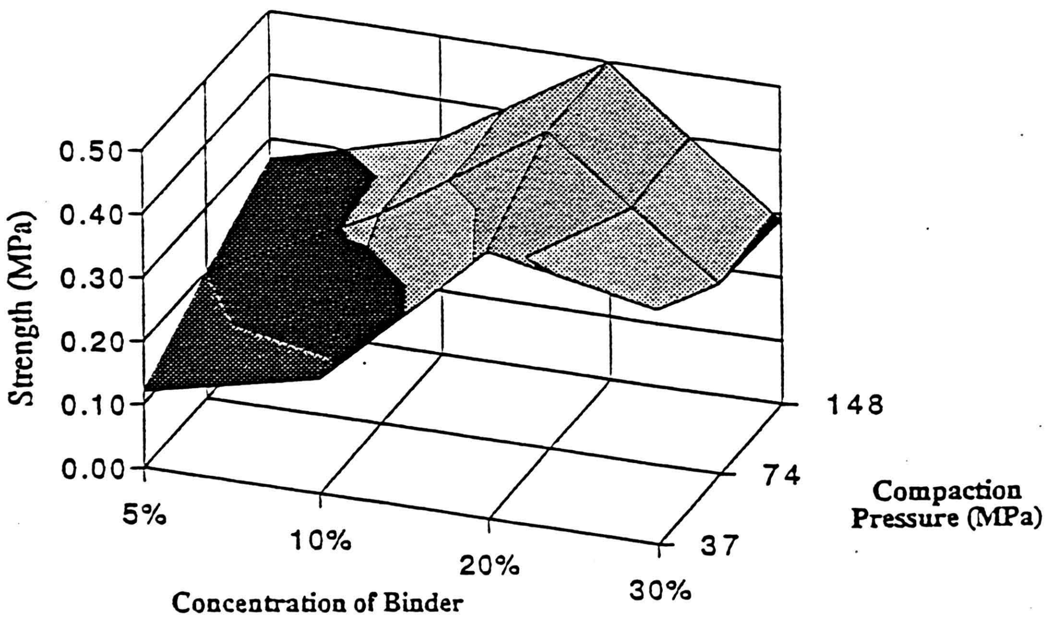
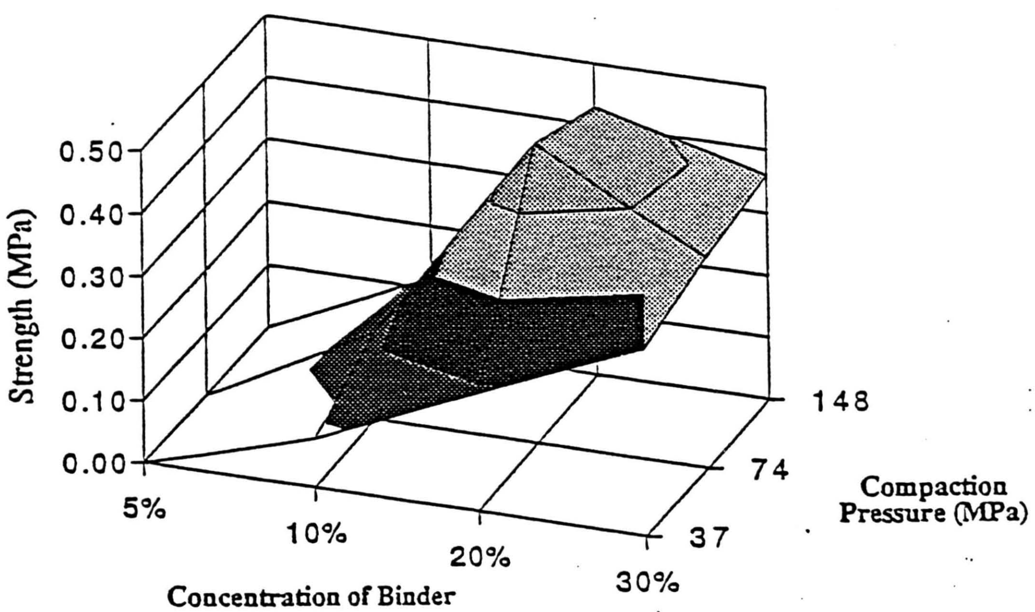


Figure 3. Splitting tensile strength of a coal log with the maximum packing density after water immersion test (24 hours at 3.5 MPa (500 psi).

Compaction Pressure (MPa)	Binder Percentage			
	5%	10%	20%	30%
37	0.00	0.08	0.19	0.30
74	0.00	0.14	0.48	0.34
148	0.00	0.12	0.43	0.36



Future Plans:

Surface treatment tests will be continued using slurries and heat. A mathematical model to predict water absorption will be developed. A review of adhesion theory will be made to evaluate the effects of surface charge, acid-base interactions, and any other factors that may influence the agglomeration of coal particles.

Publications:

Berg, D.M., 1993, "Hot Extrusion of Coal Logs," M.S. Thesis (Draft).

Chen, S-H., 1993, "Effects of Particle Size, Binder Concentration and Compaction Pressure on Coal Log Properties," M.S. Thesis (Draft).

Liu, H. and T.R. Marrero, 1992, "Coal Log Pipeline: Basic Concept and State of Development," poster paper presented at Ninth Annual International Pittsburgh Coal Conference, Pittsburgh, PA, October.

Marrero, T.R., 1992, "Coal Log Pipeline Concept and Technology," Recent Topics and Future Use of Capsule Transportation Technology (The Japan Society of Multiphase Flow, Tokyo).

Marrero, T.R., W.J. Burkett, D.M. Berg and K. Nika, 1992, "Coal Log Fabrication by Extrusion," presented at the International Conference on Bulk Materials Handling and Transportation: Symposium on Freight Pipelines, Wollongong, Australia.

Marrero, T.R. and J.W. Wilson, 1993, "Coal Log Fuel Handling and Treatment at Power Plants," CPRC Report No. 93-2, sponsored by the Electric Power Research Institute, Palo Alto, CA.

Marrero, T.R., 1993, "Coal Log Pipeline Transportation Technology", (in the session: A New Area of Chemical Engineering Research) to be presented at the American Society of Engineering Educators Annual Conference, University of Illinois, June.

Wilson, J.W. and T.R. Marrero, 1993, "Coal Log Pipeline Concept and Performance Characteristics," submitted (in April) for publication to J.S. African Institute of Mining and Metallurgy.

Patents (Disclosures): None

Industry Involvement:

I visited a few companies and discussed coal-log related research during the following trips:

DATE	COMPANY	PLACE	TOPIC
8-25-92	Macrotech	Paris, TN	Extrusion
10-01-92	Coulter	St. Louis, MO	Particle Size Equipment
10-29-92	Materials Research Center	Rolla, MO	Polymer Coatings
11-17-92	Harbison-Walker	Vandalia, Mo	Mixer
3-03-93	Great Lakes Research	Elizabethton, TN	Extruder (Ram Type)

Project Title: Hydrodynamics of CLP

Principal Investigator: Henry Liu, Professor of Civil Engineering

Duration: 9/01/92-8/31/93

2nd-Year Expenditure: $67,845

Research Associates: James Richards (0.6 person-year)

Post-Doctoral Fellows: None (0 person-year)

Graduate Research Assistants: C.C. Cheng (0.5 person-year)
X. Huang (0.25 person-year)

Other Students who worked on project: Mike Holder (0.3 person-year)

Purpose for the Research:

To investigate important features of the hydrodynamics of CLP previously unexplored, or insufficiently explored. This year's focus is on testing the behavior of short logs in pipeline and trying to understand the various causes of coal log wear in pipe so that it can be minimized and controlled.

Need for the Research:

Short logs (aspect ratio less than 2) are needed for two reasons: they reduce lift-off velocity, and they are less likely to break in pipe. However, insufficient data exist to predict the hydrodynamic behaviors of short logs. A need exists to collect such data. Also, coal log wear in pipe needs to be studied in order to find effective ways to control wear.

Research Progress (Second Year Work, 9/01/92-8/31/93):

Tests conducted in the 2-inch pipe showed that short logs cause more headloss and wear than long logs at the same velocity. Therefore, they should not be used except as a last resort. The different causes of coal log wear in pipe include: (a) impact wear -- due to impact of coal logs on pipe walls and rough joints, and impact between neighboring logs in a train, (b) abrasion wear -- surface abrasion (scratches) due to log surface contact with pipe wall and rough joints or large coal particles lodged between coal logs and pipe (broken-log abrasion), (c) erosion wear -- due to liquid or slurry impingement on coal log and (d) abrasion caused by water hammer (pressure surges and flow reversal). A test loop has been built to study (observe) various wear modes. Some limited wear tests were also conducted in the 8-inch test loop. Work in this area is in progress. More details of this work is given in the 4th 1992 Quarterly Report published in January 1993 and sent to all sponsors.

Plan for Next Year (9/1/93-8/31/94):

In addition to completing the coal log wear research, two other areas of hydrodynamics will be initiated: (1) jam prevention study -- investigating various ways of coal log jamming in pipe, and how to prevent such jamming; and (2) testing drag-reducing agents in CLP -- assessing their effectiveness in reducing energy loss in CLP, and finding out how rapid do they degrade in CLP. Both are important hydraulic areas of CLP hitherto unexplored.

Publications:

Liu, H. and Marrero, T.R., "Coal Log Pipeline: Basic Concept and State of Development," poster paper presented at Ninth Annual International Pittsburgh Coal Conference, Pittsburgh, PA, October, 1992.

Liu, H. and Richards, J.L., "Hydraulics of a Stationary Capsule in Pipe," Journal of Hydraulic Engineering, American Society of Civil Engineers, accepted for publication in April 1993.

Liu, H., "Hydraulic Behaviors of Coal Log Flow in Pipe," invited paper for a book on freight pipelines published by Elsevier Science Publisher, submitted in May 1993.

Richards, J.L., Behavior of Coal Log Trains in Hydraulic Transport through Pipe, M.S. Thesis, Department of Civil Engineering, University of Missouri-Columbia, August 1992, 105 pages.

Patents (Disclosures): None

Industry Involvement: None

Project Title:	**Slurry Effects on Hydrodynamics of CLP**
Principal Investigator:	James Seaba, Assistant Professor of Mech. & Aero. Engineering
Duration:	9/1/92-8/31/93
Second-Year Expenditure:	$17,943
Graduate Research Assistant:	Gang Xu (0.5 person/yr)
Visiting Scholar:	Mr. Yu Lin (0.5 person/yr)

Purpose of Proposed Research:

To study the feasibility of using coal slurry in place of water as the transporting medium in the CLP.

Need for Research:

The replacement of water with coal-water slurry increases the density of the carrier fluid and decreases the velocity required to transport the coal log. The lift-off velocity of the coal log during transport can be reduced by up to 62% using coal slurry, assuming the present lift-off equation is valid using coal slurry. Benefits of using coal slurry as the transporting medium for coal log transport are: water consumption is reduced 50% by weight, mass flow of coal per unit volume pipe is increased, and possible reduction of wear of the coal log due to lower transportation velocities. Current research in the manufacturing of coal logs indicates a trend toward high density, high compressive strength logs, for resistance against abrasion. Transporting high density logs (specific gravity = 1.3) makes the coal slurry investigation an important aspect of capsule pipeline transport.

Slurry effects on coal log transport is an exploratory investigation to access the effects of density and rheology on capsule pipeline transportation. It will also study the coal-particle/coal-log interaction relative to degradation and transportation. These aspects of capsule transportation have not been explored previously, and may expand the capsule pipeline technology to other areas of solid bulk transportation.

Research Progress:

This project can be divided into three main areas; coal slurry rheology, coal-log/coal-slurry hydrodynamics, and experimental design. The rheology of the coal slurry has many factors which influence this study, i.e., particle size distribution (PSD), temperature of fluid, concentration, particle shape, coal surface properties, etc. To be as consistent as possible a "real" slurry is used in this study. The slurry is provided by the Black Mesa Pipeline of Williams Technologies. The slurry is analyzed to determine its PSD, concentration, specific weight, and rheological properties. The rheological properties are used to model the flow by substituting the Newtonian fluid corresponding to water with the rheological model associated with the coal slurry. Currently, a Brookfield viscometer is used for the rheology measurements, but it has been determined that it cannot accurately determine the yield stress of the coal-water slurry. A more suitable instrument has been identified and efforts for the acquisition of a new viscometer are underway.

Coal-log/coal-slurry hydrodynamics has been studied to model the slurry. A Bingham plastic model has been used to model the coal slurry determined by rheological measurements. The coal slurry modeling (no coal log) procedure uses a modified form of the Darcy-Weisbach formula which includes the yield stress and apparent viscosity from rheology of the coal slurry. The modeling procedure has been determined and will be used when the test facility is operational.

A test facility has been designed and built as shown in Figure 2. Several design considerations have been employed in the test facility. Coal particle degradation is a primary concern in the testing of coal slurry. The slurry pump is the primary source of particle breakdown due to the impingement of coal particles on the impeller surface. The slurry pump used in this study does not use impellers, but smooth rotating discs to pump the fluid. The boundary layer produced by the rotating discs pump the fluid. Therefore, the coal particle interaction with a solid surface, such as an impeller, is minimized, thereby reducing coal particle degradation.

Another important design consideration is loading and unloading coal logs without changing the system flow rate. This is accomplished by an open loop system where the coal logs are loaded in the head tank as shown in Figure 2. The coal logs are released by a trigger forming a coal-log train. The train moves through the test section where the data is acquired, and then are deposited in the coal log collection tank. The collection tank can be separated from the system by a valve and the logs removed. This procedure keeps the operating conditions constant for multiple runs.

The experimental parameters of bulk fluid velocity, coal log velocity, and pressure drop due to the addition of the coal logs are determined by previous techniques with the exception of the pressure measurement system. The measurement of the small pressure difference created by the addition of the coal log (~1.0" H_2O) in a relatively high pressure system (~120" H_2O) is difficult. The present system uses two differential pressure transducers to measure the pressure change caused by the coal log train within ±0.04" H_2O. This is a significant improvement compared to the previous method.

A new data acquisition system was setup which takes seven different inputs of data on a microsecond time scale and is triggered automatically from a sensor on the pipeline. The data acquisition system analyzes and graphs the data in a desired format.

Preliminary results are being analyzed from the test facility. Current tests are being run with aluminum-Plexiglas logs and water to compare to an existing data base. The preliminary results show similar trends as performed by previous investigators, however, not enough data has been collected to make any conclusions. Future work will consist of running the system with the coal slurry.

Significant Accomplishments:

The completion of the test facility has been the greatest accomplishment. The facility will expand the capabilities of CPRC to transport logs in any fluid medium, and provide precise data relative to the hydrodynamics of coal log transport. The data acquisition system is totally automated with analysis and graphical representation immediately after test.

Future Plan:

The coal slurry effects on coal-log transport is **not** the present direction the CPRC will take for the commercialization of the coal-log pipeline. Therefore, this project will be discontinued by August, 1993. However, CPRC did provide the seed monies to obtain preliminary results of coal slurry effects which will be presented in the near future. Proposals have been submitted to other funding agencies to investigate this concept. The new test facility will also check previous work pertaining to the hydrodynamics of coal log transportation in water, and future work relating to coal log degradation.

Publications:

Seaba, J.P., and Xu, G. "Slurry Suspension of Coal Logs -- An Exploratory Study," 18th International Technical Conference on Coal Utilization & Fuel Systems. 1993

Industry Involvement:

Williams Technologies Inc. has supplied 500 gallons of coal slurry from its Black Mesa pipeline for this experiment and provided inputs for the experimental design of the system. Mr. Joe Anderson was in charge of the coal slurry acquisition, Mr. Lowell Hinkins was the supervisor of operations at the Black Mesa pipeline, and discussions with Mr. Jack Tennant provided helpful insights which was used in the design of our coal-slurry/coal-log test facility.

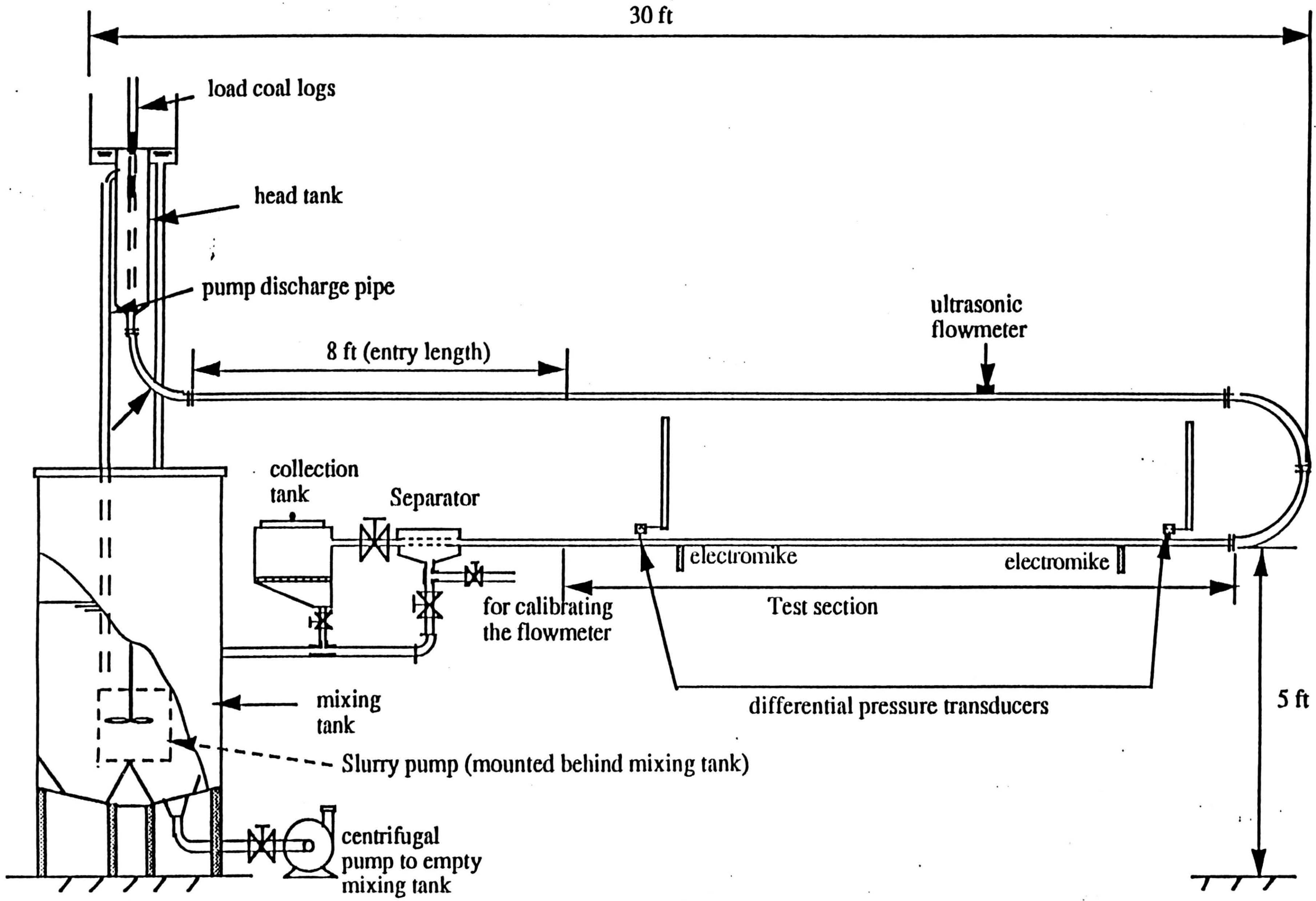


Figure 2. Coal Log and Slurry Test Facility

Project Title: Unsteady Flow in Coal Log Pipeline

Principal Investigator: Charles Lenau, Professor of Civil Engineering

Duration: 9/1/92 - 8/31/93

2nd-Year Expenditure: $34,859

Research Associates: None

Post-Doctoral Fellow: None

Graduate Research Assistants:

Majed M. El-Bayya (0.5 person-year)

Rattanathip (Anna) Phimjaichon (0.5 person-year)

Other Students who Worked on Project:

Jianping Wu (0.25 person-year)

Purpose of Research:

(1) To develop a methodology for analyzing unsteady flow and hydraulic transients generated by the operation of coal log pipelines. (2) To study the hydraulic transients associated with the operation of a pump bypass system and an injection system.

Need for Research:

Operation of coal log pipelines requires periodic closing and opening of valves which generates pressure and discharge transients in the system. Successful operation of a pipeline requires that the size of these transients be controlled. Much can be learned about these transients without actually considering the interaction of the water and the coal logs. However, it is highly desirable to have a good mathematical model for coal log and water interaction to check designs before the actual coal log pipeline is built.

Research Progress

(1) Unsteady Flow of Coal Logs

El-Bayya designed and built an apparatus for studying hydraulic transients in coal log pipeline. As anticipated a number of problems have surfaced that delayed the testing of our mathematical model [(El-Bayya, 91) and (Lenau and El-Bayya, 92)]. For the experimental apparatus the model predicts that the coal log and water interaction has very little impact upon the maximum and minimum pressures unless the main control valve can be closed in less than 0.1 sec.[1] At the present time the valve requires approximately 0.2 sec to close. A second problem that has been encountered is the formation of bubbles in the water during the negative pressure

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[1]This time is specific to the experimental apparatus and will be different for other systems.

cycle after valve closure. One pressure transducer has been damaged due to (apparently) bubble collapse in the proximity of the transducer. We plan to minimize these problems by replacing the control valve with a valve that can be closed more quickly and by using a different type of pressure transducer

On the positive side, preliminary experimentation indicates that coal logs can tolerate large pressure surges without damage to the logs.

(2) Pump Bypass and injector Systems

Rattanathip (Anna) Phimjaichon completed her M. S. thesis in August (Phimjaichon, 92). She studied the hydraulic transients generated by the valve switching in a pump bypass system. For this analysis the coal log and water interaction was neglected.

Phimjaichon studied the case of a very high head bypass system which permitted approximately 60 miles between bypass stations. The driver pump was centrifugal and the steady state bulk velocity was 8 fps. The storage lines were 1000 ft long so that the bypass cycle time was approximately 125 sec. The time required to open/close valves, T, was varied between 1 and 7 sec.

Phimjaichon's study showed that pressure increases due to valve switch-over is not a very large percentage of steady state pump head. Her study also showed that the bypass system generated positive pressure waves that move upstream of the system. These waves had a peak pressure about 50% of the pressure developed on the discharge side of the driver pump. Thus, these pressure waves would be a problem if the wall thickness of the pipeline were progressively stepped down between bypass stations to take advantage of the decreasing steady state pressure. Otherwise, there appears to be no threat of pipe or pump damage.

Phimjaichon's study showed that cyclic flow reversals in the storage pipes are present during valve switch-over. These flow reversals can be minimized by increasing the rate of valve closure/opening when the valve is almost fully open and decreasing the rate of valve closure/opening when the valve is almost closed. The pressure waves that move upstream of the bypass (see previous paragraph) are associated with flow reversal of the same magnitude as the steady state discharge. The period of flow reversal is approximately equal to the valve switching time T. It is anticipated that this flow reversal may complicate the operation of the bypass system because the coal logs may drop to the pipe bottom or reverse in direction if the period of flow reversal is too long. Hence, from the perspective of minimizing the effects of flow reversal, a rapid valve switching time is desirable.

Jianping Wu has been studying the unsteady flow associated with an injector system without considering the water and coal log interaction. Difficulties with the proposed operation of the injector system were discovered. One problem was that during valve switch-over the very high pressure portion of the injector system was connected to the low pressure portion. This cross connection caused severe flow reversals in the loading pipes. The cross connection problem was eliminated by completing one set of valve adjustments before starting other valve adjustments so that the high and low pressure portions of the injection system are never cross-connected.

Significant Accomplishments:

Phimjaichon's work on the pump bypass system that pressure increases due to valve switch-over is not a very large percentage of steady state pump head. Her study also showed that the bypass system generated positive pressure waves that move upstream (and downstream) of the system. Hence, the wall thickness of the pipeline should be uniform and not progressively stepped down between bypass stations to take advantage of the decreasing steady-state pressure.

Future Plan:

(1) Unsteady Flow of Coal Logs

During the next six months Majed El-Bayya should be able to take defensible data with his apparatus and data acquisition system. With this data he should be able to evaluate our mathematical model for capsule and water interaction and recommend modification of the model if needed.

(2) Pump Bypass and injector Systems

During the next six months Jianping Wu should be able to complete a valve operating strategy for the injector without considering the water and coal log interaction, to modify the computer code to include the coal log water interaction and to test the operating strategy with the modified code.

Publications:

Majed El-Bayya and I submitted a paper "Unsteady Flow in Hydraulic Capsule Pipeline" to the Engineering Mechanics Division of the American Society of Civil Engineering . This paper is under review at this time.

Patents: none

Industry Involvement: none

References:

El-Bayya, M., 1991, "Transient Flow in Hydraulic Capsule Pipeline," M. S. Thesis, Department of Civil Engineering, University of Missouri-Columbia.

Lenau, C. W. and El-Bayya M. M., 1992, "Treatment of Unsteady Flow through Capsule Pipelines: Capsule-Water Interaction," International Conference on Bulk Materials Handling and Transportation; Symposium on Freight Pipelines (Wollongong, Australia), Vol. 1, preprints of papers, The Institution of Engineers, Australia.

Phimjaichon, R., 1992, "Prediction of Waterhammer in HCP Pump Bypass System," M. S. Thesis, Department of Civil Engineering, University of Missouri-Columbia.

Project Title : **Automatic Control of Coal Log Pipeline System**

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

Duration : 9/1/92 - 8/31/93

Second-Year Expenditure : $36,991

Research Associates : None (0 person-year)

Post-Doctoral Fellows : None (0 person-year)

Graduate Research Assistants : J. Wu, C. Y. Shieh and D-X Sun (0.75 person-year)

Other students who worked on the project : None (0 person-year)

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.

Need for the Research :

The coal log pipeline system concepts are novel as compared to existing commercial pipeline systems. The complexity of such novel systems places greater demands on sensing, control hardware, and control strategy design for such systems as compared to existing commercial pipeline systems. Fundamental studies of the system dynamics and component interactions are needed to comprehend their dynamic characteristics and system scale properties. In addition to these requirements for effective and rugged controller design, control implementation and display involves several issues. These include mechanical hardware design, valve and sensor design requirements, their reliability, and distributed control architecture design. Incorporation of safety features into the control design is also of considerable importance.

Research Progress :

Computer Controlled Test Bed System

Significant progress was made during the period on the development and functioning of the small-scale experimental demonstration system that is planned to be used as a test bed for future studies and for the development of a large-scale prototype coal log pipeline system. While the details of the system were reported in the previous annual report, a brief description is included here along with the enhancements incorporated during Year 2 : the total length of the system is approximately 130 ft. and it uses 1.25-inch diameter, transparent PVC pipes. It consists of the mechanical subsystems, sensors, interface hardware, and a control workstation with associated software. The mechanical subsystems consist of the injection subsystem, the booster pump subsystem, and the ejection subsystem. The injection subsystem has four-locks each of which is fed by a conveyor belt, sixteen valves, a main pump, and an auxiliary pump. The electric motor-driven conveyor belts are operated at the same velocity as the flow. This injection configuration allows for rapid filling of the four branches using the auxiliary pump while simultaneously establishing a steady stream of coal logs in the main pipe. The sixteen valves are also used by the main pump with coordination being provided by the control station described below. The main pump provides the energy required to pump the coal logs to the booster station. A pump bypass subsystem which simulates the booster station consists of a regular centrifugal pump, two coal log bypass lines, and eight valves. The ejection system consists of a conveyor belt which transports the coal logs out of the reservoir for storage. The mechanical design of the Y joints in the system is primarily based on geometrical considerations where the angle of approach to the Y junctions of the legs, 2α, can be calculated from the relation $\alpha = \sin^{-1}[2(1-k)/ka]$ where a is the aspect ratio and k is the diameter ratio. The design of the diverter involves flow considerations, actuation subsystem design, and, importantly, reliability. The diverter gate is designed to impede fluid flow minimally to avoid pressure surges while restricting capsule flow to the selected direction. The gate, which is made of a nylon type material, allows for rapid switching of directions without causing damage to the components. An 486 CPU-based IBM compatible has been selected as the main control computer. Such an arrangement consolidates the control at one station and could possibly include system status display functions. The primary interface is a Metrabyte PIO-96 card which is a high density parallel digital I/O card with TTL/DTL compatible lines. The control code is developed in a modular fashion, using C language. The controller has several modes of operation including system startup, diagnostics, individual device operation, and options for single/multiple coal log train transport, continuous operation and orderly system shut down. Safety software monitoring the system operation has been incorporated only to some extent currently, but the code will issue appropriate warnings and trigger system shutdown if necessary.

During Year 2, the Y-joints redesigns were completed and tested successfully, and new magneto-inductive sensors replaced the optical ones that were being used. The control strategy now senses only the leading and trailing logs as opposed to a 'counting' type approach adopted earlier. The air entrapment problem at the intake has been solved by designing diffusers for all the four intake branches. The new design eliminates both the capsule jamming problem as well as the leakage problem both of which have been plaguing the demo system for the past several months. The system is capable of injecting four trains of capsules automatically under the control of the computer with the manual part being only in the loading of the capsules onto the four conveyers. The operation of the three pumps, sixteen valves as well as the diverter and train separator are controlled based on the data input from fifteen magneto-inductive proximity sensors located throughout the system. The leading and trailing capsules in each train have small metallic rings at the front end which trigger the sensors indicating the arrival or departure of a train at a particular sensor location. A typical computer control cycle is as follows : the log trains are transferred to the four inlet launching tubes (locks) from the conveyor belts by using the auxiliary pump and the appropriate valves. This is done sequentially by monitoring the sensors at the inlet of the locks. Once the logs are in the locks, the computer then switches valves and turns the main pumps on, pumping the log train out by monitoring the sensors at the outlet of the launching tubes. Once all the four trains are pumped out, the computer switches its attention to the by-pass section and monitors the sensor at the upstream end of the diverter valve. After the passing of each train, the computer switches the diverter to the opposite position to fill up the opposite bypass line. The program automatically shuts down the system by switching the pumps off and then the valves, after the last log train passes into the ejection subsystem. The control software was also upgraded considerably with user friendly modules for individual device operation and check, as well as trouble shooting.

The control design has been successfully tested with a fast cycle time of approximately 90 seconds. The system which is completely automatic in operation is currently rugged and reliable after several design modifications were incorporated in the development process. For instance, the Y joints at the inlet and bypass sections often caused jamming of the capsules in the past. The reasons for this were a combination of air entrainment through joint leak spots, as well as the joint geometry itself. A mechanical redesign of the joints was undertaken which modified the geometry and eliminated leakage by fabricating the Y-joint from a single piece of plexiglass. The air entrapment problem at the intake has been solved by designing diffusers for all the four intake branches and by running the system with water for a few minutes prior to injecting the capsules. Careful mechanical design of the subsystems has, by far, been found to be the most important factor for such complex systems as far as control is concerned.

<u>Dynamic Modeling of a Coal Log Pipeline System</u>

A realistic scenario with a large scale system is being simulated using the method of characteristics. The system includes the injection subsystem as well as the pump bypass system. The study methodically incorporates the pumps and valves to develop a complete model for a capsule pipeline system including injection subsystem, the booster pump subsystem, and the ejection subsystem The pressure surges in the system at the injection and pump bypass subsystems are being investigated initially using the fluid-only case with the log train to be incorporated next. The parameters and dimensions for the simulation study are listed in Table 1. This study is carried out by J. Wu, under the joint supervision of Drs. Lenau and Nair.

Table 1. Parameters and dimensions used in the large-scale prototype system simulation

Injection subsystem (Multilock type)	Pipe diameter	1.0 ft
	Length, each lock (4 total)	1,000 ft
	Head, main pump (positive disp. type)	2,000 psi
	Head, auxiliary pump (centrifugal type)	7.6 psi
	Head, reservoir	8.0 ft
Booster station (Pump bypass type)	Pipe diameter	1.0 ft
	Length, storage pipe (2 total)	1,000 ft
	Length, water pipe	1,000 ft
	Head, booster pump (positive disp. type)	2,000 psi
Capsule	Diameter ratio, k	0.9
	Aspect ratio, a	2.0
	Specific gravity, S	1.2

Significant Accomplishments :

The successful redesign of the mechanical subsystems of the test bed system contributed to automatic operations for long periods. To date, the computer controlled test bed system has operated very well without any problems for more than hundred times consecutively. This was considered a major accomplishment since the mechanical elements including 3 pumps, 24 valves, and 15 sensors, have to be coordinated and controlled in a reliable manner automatically by the control software. Important directions for the development of the large-scale prototype system have been obtained from the demo system. These include mechanical design, sensor design, and control hardware and software architectures. The small scale system continues to serve as a test-bed for a host of relevant studies including high speed operation, which are essential before the research and development enters the large-scale phase.

Future Plan :

Computer Controlled Test-Bed System

The small-scale demonstration unit is to be used as a test bed to investigate high-speed operation issues, especially flow reversal due to valve switching and water hammer effects. It can also be used to measure pressure and velocities for various types of capsule flow conditions. Decentralized control of the small-scale unit using two additional independent processors is being pursued so that the control computer could function in a 'master' mode performing supervisory functions such as decision making, overall monitoring, safety, and display of system status. Such Supervisory Control and Data Acquisition System (SCADA) software is being evaluated currently with advice from industry. The independent processors being investigated include RTUs and PLCs, with one for operating the injection subsystem and one for the pump bypass system. The possibility of eliminating the manual loading operation when the capsules are transferred to the conveyor belts will also be investigated. The design and operational experience gained from this unit is being used to formalize the design issues for the large-scale prototype system. In addition to several ongoing theoretical studies related to the reliable operation of such systems, some of the control related ones include : design of a train separator for the small scale unit as well as for an eight-inch pipeline also currently operational at MU; design of hardware and strategies for the control of the spacing between capsules in a train as well as the spacing between the trains. This would involve, for instance, different density/shape design for the leading capsule etc.; design of an intelligent pig for such pipeline systems - considering the fact that sophisticated electronic technology is available in compact form and low cost, such pigs could conceivably perform a much larger range of operations that would be needed for coal log pipelines, as compared to the conventional ones; and reliable mechanical designs for the subsystems and components; and safety features. A 'design for control' approach, with significant emphasis placed on the mechanical design of the subsystems, we believe, would considerably minimize the control overheads i.e., complexity of the control strategy and the control hardware, making the overall system rugged and reliable.

Dynamic Modeling Issues

The study of the dynamic issues mentioned in the previous section will continue concurrently so that enough experience is obtained for bringing the technology closer to commercial use.

Development of a Large Scale Prototype Coal Log Pipeline

The issues pertaining to the development of a large-scale prototype system will be investigated, based on the experience gained from the extremely successful mechanical and control design of the computer controlled system. The possibility of automating the existing 8-inch pipeline at MU will first be investigated. Work is currently also underway on possibly using a ten mile long pipeline operated by Williams Pipeline Company for testing the coal log pipeline concepts at the large-scale level.

Development of the Manuals for the Small Scale System

Both hardware and software manuals for the small scale automated unit are being developed concurrently. Currently, an operations manual detailing the computer control of the unit is complete.

Publications :

Nair, S. S. and Wu, J. P, April 1993, "Theoretical and Experimental Considerations for Coal Log Pipeline Control Systems - Preliminary Studies," *18th International Technical Conference on Coal Utilization and Fuel Systems*, Clearwater, Florida (accepted for publication.)

Industry Involvement :

The controls group is involved with Novatech Inc, Kansas City, Missouri, which is a small business partner with the Capsule Pipeline Research Center. The company is engaged in computer interfacing, protocol development and hardware and software implementation issues with several industries, primarily oil and natural gas pipelines. The products they use include Remote Terminal Units, Programmable Logic Controllers (PLCs) and several types of sensors on the hardware side, and communications protocols, and programs related to SCADA operations on the software side. They develop their own hardware and software in addition to using commercially available ones. The involvement of Novatech with CPRC is thus mutually beneficial and very relevant to both the parties. The controls group has had several discussions with the president of Novatech, Aubrey Zey. All members of the group including the senior electronics technician Richard Oberto visited the company also and discussed extensively about the computer interfacing and monitoring issues.

Novatech compiled a report critiquing the small scale demonstration unit at CPRC . Since the company is mainly involved in microprocessor interfacing and software development, their comments were limited to those areas, and not to control strategies or issues. One of their main contribution has been to help make the small scale demonstration unit at CPRC conform to industry standards. Also, they are providing advice on the use of SCADA software for the project. The expertise gained from the collaboration will be important for the next stage of the project which involves the development of hardware and software modules for a large-scale prototype coal log pipeline system, which is being initiated currently.

Project Title: LEGAL RESEARCH IN COAL LOG PIPELINE

Principal Investigator: Peter N. Davis, Isidor Loeb Professor of Law

Duration: 9/1/92 - 8/31/93

First-Year Expenditure: $21,841

Research Associates: None (0 person-year)

Post-Doctoral Fellow: None (0 person-year)

Graduate Research Assistants: Nicole Cress (3L) (0.2 person-year)
Pat Sullivan (2L) (0.2 person-year)

Purpose of Research:

To explore legal issues involved in commercialization of CLP, including eminent domain of coal pipeline rights-of-way, water rights acquisition, right to cross railroads, conversion of existing oil gas pipelines, pipeline waste disposal, and environmental assessment.

Need for Research:

The legal regimes in various states are the principal factors influencing a coal pipeline's feasibility and economic viability. State court decisions and statutes determine most of the rights and powers of coal pipelines. In addition, federal law is important in acquiring rights-of-way across western public lands and across major rivers, assessing environmental impacts, and complying with water quality regulations.

During the decade since legal issues related to coal slurry pipelines (particularly right-of-way eminent domain and water rights acquisition) were researched and published, the state case law has evolved and several relevant state statutes have been amended. This research will bring our understanding of those coal pipeline legal issues up to date. Three relevant areas have not been the subject of prior published legal research, crossing railroads, the E.T.S.I. litigation consent decrees, and pipeline conversions. The railroads' legal obstruction to the E.T.S.I. coal slurry pipeline mandates research into the first two topics. Conversion of an unused oil & gas pipeline for a demonstration coal log pipeline raises an easement reversion issue (based on change of use specified in the easement deed).

Legal research of this character generates information about the legal framework within which a prospective coal pipeline will operate, but does not attempt to resolve any site-specific legal issues; it seeks to identify legal ambiguities and to suggest probable resolutions, but not to definitively resolve them.

Research Progress (9/1/92 - 8/31/93):

Research performed. During the fall and winter semesters 1992-93 (Sept. '92 - May '93), several legal investigations were begun, many of which were completed. They are:

Eminent domain topics:
(1) government eminent domain over government land -- completed
(2) public utility acquisition of rights-of-way over government land -- in progress.

Pipelines crossing railroads topics:
(1) pipeline/railroad crossing statutes -- completed.
(2) pipeline/railroad crossing cases -- completed.
(3) Pacific Railroad Act pipeline/railroad crossing cases -- completed.

Water rights topics:
(1) analysis of interstate equitable apportionment cases -- preliminary analysis completed.*

Water pollution topics:
(1) "point source" cases under the federal Clean Water Act -- completed.
(2) rights of riparians below the discharge point -- in progress.*

Pipeline conversion topics:
(1) obtaining texts of typical oil & gas pipeline easement forms -- completed.
(2) obtaining texts of *Williams Pipe Line* easements in Boone County MO -- completed.
(3) analysis of *Phillips Natural Gas* decision -- completed.

ETSI v. RR conspiracy litigation topics:
(1) general description of litigation -- completed.
(2) obtaining texts of case decisions -- in progress.
(3) obtaining texts of consent decrees -- in progress.

Remedial legislation topics:
(1) identification of hearings of past federal coal pipeline eminent domain bills -- completed.

Sources for Research. We are using two major sources for our legal research, (1) the collection of law reports, statutes, legal treatises and other secondary legal materials, and many federal government documents in the Law Library of the University of Missouri-Columbia, and (2) the *WestLaw* and *Lexis* computerized legal database services to which our law library subscribes. Together these give us access to the entirety of law reports and statutes in the United States from the colonial period to date.

Tentative Findings (9/1/92 - 8/31/93):

Last year our most significant findings involved coal pipeline eminent domain authority and interstate water export regulation. We determined that coal pipelines have right-of way eminent authority in 22 states and water rights eminent domain authority in 1 states and prohibit such authority in 2 states. We also determined that 13 states regulate interstate exports of water.

This year we added incrementally to our legal analysis. Our most significant findings involved pipelines crossing railroads and pipeline conversion issues. We determined that coal pipelines have statutory authority to cross railroads without the latter's consent in 10 states, and that case decisions suggest that pipelines should be able to do so in all states under usual common law rules. We obtained the texts of typical oil & gas pipeline easements to determine whether conversion to coal pipeline use would cause reversion of the easement. Some easement restrict use to oil & gas pipelines, other allow any pipeline use. The former would revert, the latter would not.

Future Plan (9/1/93 - 8/31/94):

The legal issues research for summer 1993 and the next project year will be analysis of (1) procedure for pipelines to acquire rights-of-way across lands owned by the federal and state governments, (2) constraints on water rights transfers under eastern diversion permit statutes and western prior appropriation permit statutes, (3) extent of regulation of brackish water diversions in eastern and western states, (4) state interstate water export permit statutes, (5) ETSI/railroad conspiracy litigation and settlement decrees, and (6) history of proposed federal coal pipeline eminent domain bills.

In addition to this research, I plan to write a major law review article during summer 1993 which will cover the research results to date. The topics covered will be much the same as in the publications discussed below, but in a more extensive manner.

This will leave for the final project year analysis of (1) residual water pollution issues which go beyond my major non-project water pollution law research, (2) residual issues on general interstate river allocation beyond my prior non-project research, (3) all pipeline construction environmental assessment issues, and (4) all remaining remedial legislation issues.

For this work, two part-time summer research assistants will be hired. I expect one or both to be able to continue their part-time work during the academic year 1993-94. Nicole Cress will graduate in May 1993 and will leave the project at that time. I do not know whether Pat Sullivan will be able to continue on the project, since he will be Editor-in-Chief of the MISSOURI LAW REVIEW for the year beginning May 1993.

Publications and Lectures (9/1/92 - 8/31/93):

During fall semester 1991, I prepared a 5000-word paper, *Legal Aspects of Future Coal Pipelines in the United States*, which I presented at the 4th International Conference on Bulk Materials Storage, Handling, and Transportation, held in Wollongong NSW, Australia, on July 6-8, 1992 (co-sponsored by Institution of Engineers, Australia, and International Freight Pipeline Society). This paper was published in June 1992 in the Proceedings of the conference, at pp. 221-25 (*see* full citation, below). The paper analysed the right-of-way and water rights eminent domain statutes in 25 states, and the western interstate water export permit statutes. Also, it described the various water rights doctrines affecting coal pipeline diversions. In my oral presentation, I discussed the eminent domain statutes in all 50 states.

On April 29, 1993, I presented a later version of the same paper with updated research, entitled *Legal Aspects of Coal Pipelines in the United States -- Preliminary Findings*, at 18th International Technical Conference on Coal Utilization & Fuel Systems held at Clearwater FL (sponsored by Coal & Slurry Technology Ass'n). This 12-page paper (with 3 maps) was prepared with the assistance of my research assistants, Nicole Cress and Pat Sullivan. It will be published in the Proceedings of the conference. This paper covered all the topics in my first paper, including the eminent domain statutes in all 50 states. Additionally it analysed the statutes and court decisions on pipelines crossing railroads, and on easement reversion issues upon when converting oil & gas pipelines to coal pipeline use.

Patents (Disclosure) (9/1/92 - 8/31/93):

None.

Industry Involvement (9/1/92 - 8/31/93):

As part of our pipeline conversion issues research, I had a phone conversation with a lawyer in the general counsel's office of Williams Pipe Line Company in Tulsa OK on the company's experience with easement reversion problems upon oil & gas pipeline conversion to fiber optic cable conduit use.

References:

(1) P.N. Davis, *Legal Aspects of Future Coal Pipelines in the United States*, in 1 Proceedings of 4th International Conference on Bulk Materials and Freight Pipelines 1992, at 221-25 (Institution of Eng'rs, Australia, Rpt. No. 92/7, June 1992).

(2) P.N. Davis, N. Cress & J.P. Sullivan, *Legal Aspects of Coal Pipelines in the United States -- Preliminary Findings*, submitted to and accepted by 18th International Technical Conference on Coal Utilization & Fuel Systems held at Clearwater FL, Apr. 29, 1993.

Project Title: Coal Log Fabrication Using Hydrophobic Binders

PI: Dr. John W. Wilson, Chairman, Professor
Duration: 9/1/92-8/31/93
2nd-Year Expenditure: $59,000
Post-Doctoral Fellow: Dr. Yungchin Ding, 1st year
Graduate Research Assistant: Bing Zhao, 1st Year

Purpose of Research:

Study various binders with hydrophobic properties that can be used for coal log manufacturing and to improve the robustness and water resistance of coal logs during their long distance pipeline transportation.

Need for Research;

In the coal log fabrication process, the use of a binder can play an important role in affecting the properties of coal logs for pipeline transportation, end-of-pipeline storage and handling requirements at the coal-burning utility plants. It is important to select a good binder that has a strong binding capability and hydrophobic characteristic that consolidates the coal particles into strong coal logs, and at the same time, provide better water resistance and fast water evaporation rates after the pipeline journey.

Research Progress (2nd-year work)

A. Selection of binders for coal log fabrication

A literature search for binders that can be used for coal log fabrication was conducted during the past year. After a careful review of this literature, the criteria chosen to select the most appropriate hydrophobic binders that could be used to manufacture coal logs, are as follows:

1. Availability and quantity of reserves to make the binder.
2. Strong binding capability on coal particles, i.e., alleviate water absorption effect.
3. Good hydrophobic characteristics.
4. Low cost.
5. Non-hazardous materials that will not cause environmental problems during the manufacturing process, transportation and combustion of the coal logs.
6. Ease of preparation of binder for coal log fabrication.
7. Pulverization characteriatic

In accordance with the criteria mentioned above, several hydrophobic binders were selected for coal log fabrication tests, they were, PC-150 and SS-1H emulsified asphalts, emulsified coal tar, and Shur bond 12010 (heavy paraffinic distillate). These selected emulsified binders have the advantage of ease of preparation (mixing process before fabrication) over non-emulsified binders. They can evenly distribute/coat the coal particles during the mixing operation in ambient conditions. This particular characteristic is considered to be one of the most critical factors for producing good strong logs.

B. Coal log fabrication

Small 1 3/4" coal logs were made using a compaction method using uniaxial pressures of between 4,000 and 10,000 psi. These small logs were used to test the binding capability of selected emulsified binders, as well as the influence of applying pressure and percentage of binder on the durability, water absorption and resistance, and the pulverizing characteristics of the coal logs.

In order to simulate the abrasive effect of the pipeline on the degradation of coal logs, slaking and durability (tumbling) tests were carried out using a lab scale ball mill. The slaking and durability index of a log can be obtained by running the coal log in a water-filled ball mill (tumbler) at a pre-determined rpm and time period. The weight remained of the tested coal log divided by the original weight of tested log is defined as the slaking and durability index.

C. Coal log fabrication using Gilsonite as a binding agent

Gilsonite was first proposed and used as a binding agent for coal log fabrication by MacroTech Inc. Gilsonite contains 99.9% bitumen and has a melting point that varies from 295°F to 390°F. Several tests have been conducted to manufacture coal logs using Gilsonite as a binder.

To prepare Gilsonite for use as a binder, the material must be melted by raising the temperature above its melting point, and then diluting it with petroleum solvents such as mineral spirit or naphtha. Gilsonite binders made in this way (2-5% by weight of feed coal) were mixed with coal particles in a blender. Because of the poor mixing characteristics of all Gilsonite binders, the coal logs fabricated at a pressure of 10,000 psi had fairly low strength and poor slaking and durability characteristics.

After a careful review of the test procedures and results, it was found that incomplete mixing of the Gilsonite binder with the coal particles was the key factor related to the strength of coal logs formed. Because of the high melting point of Gilsonite, the Gilsonite binder solidified as soon as the temperature of the binder dropped below its melting point. Therefore, the binder could not be distributed over the entire coal sample, and thus resulted in producing low strength coal logs.

D. Influence of applying uniaxial pressure in coal log fabrication

To examine the effect of pressure on coal log fabrication, several 1 3/4" coal logs were made using 2% PC-150 emulsified asphalt with the applied uniaxial pressure increased from 4,000 psi to 10,000 psi. As soon as the coal logs were made, they were emersed in water for one hour for water absorption tests. The test results showed that the degree of water absorbed by coal logs decreased from 10.1% to less than 1% as the applied uniaxial pressure increased from 4,000 psi to 7,000 psi and above.

Following the water absorption test, water absorbed coal logs were put into the ball mill for slaking and durability tests. After 10 minutes running time at 70 rpm, the slaking and durability index of the coal logs under test decreased as the applied uniaxial pressure increased from 4,000 psi to 10,000 psi.

E. Influence of percentage of binder on coal log fabrication

The percentage of binder used for coal log fabrication seems to be directly related to the durability of the coal logs, that is, the greater the percentage of binder used, the stronger the log. To evaluate this, 1 3/4" coal logs were made from various percentages of PC-150 binder (1.5% to 4.0%) at a pressure of 8,000 psi. After leaving these logs at ambient temperature for 24 hrs, they were emersed in water for another 24 hrs before conducting the slaking and durability test. The test results showed that the slaking and durability index of tested coal logs increased from 36.3% to 85.7% as the emulsified asphalt percentage increased from 1.5% to 4.0%.

F. Pulverizing characteristics of fabricated coal logs

The pulverizing characteristics of a coal log is also considered to be an important factor that affects the coal log handling and combustion requirements at utility plants. Two coal logs made by pressures of 7,000 and 8,000 psi were used for conducting the pulverizing test by using a lab. scale hammer mill. In order to evaluate the influence of temperature on coal log pulverization, both coal logs were heated to 100°C in a furnace before pulverization. From the particle size analysis results, it was found that more than 60% of the pulverized coal particles passed through a 100 mesh test sieve which was much higher than the original coal sample (40% passed 100 mesh) used for coal log fabrication. This suggests that the binder used had no influence on the pulverizing characteristic of the coal log, even at high temperature conditions.

Significant Accomplishment:

Several hydrophobic emulsion binders have been selected and tested for coal log fabrication. The binders selected all have very good mixing properties, i.e., they evenly distribute/coat coal particles during the mixing process. According to the slaking and durability test results, these binders also show strong binding capabilities. For the end-of-pipeline pulverizing consideration, the emulsion binders show no effects on the pulverization of coal logs. The water absorption test results suggest that the adsorbed water by the coal log can be reduced to less than 1% if the applied uniaxial pressure for making coal logs is higher than 7,000 psi.

Future Plans:

1. Continue tests with emulsified binders using the uniaxial compaction method. Several strength-enhancement additives will be tested along with the emulsified binders. The optimum operating parameters for making strong and durable coal logs will be studied from both a practical and economical view point.

2. Tests using the extrusion method are also planned for coal log fabrication using emulsified binders.

3. The influence of the emulsified binders on the end-of-the-pipeline coal log storage and handling systems will also be investigated. These investigations will be carried out later and will include water absorption/resistance tests, pulverizing tests and combustion tests.

4. The manufacture of larger coal logs (nominally 8" in diameter) are also planned to be carried out after the tests with the small size logs show repetitive and successful results.

Publications:

1. Wilson, J.W. and Y. Ding, "A Technical and Economic Assessment of Coal Log Pipeline Technology at Electric Power Generating Plants," Proceeding, 18th International Technical Conference on Coal Utilization and fuel Systems, Coal and Slurry Technology Association, April 1993.

2. Wilson, J.W. and Y. Ding, " The Influence of Coal Type on Coal Log Pipeline Transportation," Proceeding, Geological Society of America North-Central Meeting 1993, March 1993.

3. Marrero, T.R. and J.W. Wilson, Coal Log Fuel Handling and Treatment at Power Plants, A Report for Electric Power Research Institute Inc., Contract Number: RP-1895-34.

4. Wilson, J.W., and T.R. Marrero, "Coal Log Pipeline Concept and Performance Characteristics", Journal, South African Institute of Mining and Metallurgy, later 1993.

Industrial Involvement:

The emulsified binders currently selected and tested for coal log fabrication were provided by several companies. The names of the companies and the personnel contacted are listed as follows:

1. ELF Asphalt Company- Asphalt emulsions, Mr. Marvin Exline (Indiana Research Center).

2. Reilly Industries- Coal tar emulsions, Mr. Bill Roader.

3. Sherex Company- Shur Bond 12010 (Heavy Paraffinic Distillate).

4. Cargill Company- Alkyd Resin, Mr. Jim Fanslow (Minneapolis Research Center).

Marketing and P.R. Activities:

1. Presentation to Northern States Power, MN, Feb. 1993.

2. U.M.R. Press Release, current progress of hydrophobic binder studies and coal log fabrication process, Feb. 1993

3. National Coal Association Coal News, research progress of current coal log fabrication work at U.M.R. as part of CLP research project, March 15, 1993, No. 5133.

4. U.M.C. Radio interview Dr. John W. Wilson, binders and progress to date, March 29, 1993.

5. Presentation to Industrial Members serving on the Development Board of Department of Mining Engineering, U.M.R., April 15, 1993.

Appendix 2: Attachment

(Coal Log Pipeline is mentioned on the next page)

Trains star in transport as pipelines wait in wings

By DOUG HARPER
Journal of Commerce

Although coal has always been one of the most plentiful and inexpensive energy sources in the United States, the high price of transporting it from the mine to the boiler has historically worked to its disadvantage.

The cost of extracting coal from a mine in Wyoming, for example, is less than $5 a ton. But by the time that same ton of Wyoming coal is delivered to a power plant in Missouri, the cost has risen to $20 a ton with the 400 percent increase in price entirely attributable to transportation.

Railroads have always played the major role in the domestic transportation of coal, carrying roughly 60 percent of all coal produced in this country.

"Two out of every three tons of coal shipped from the mine is carried by rail," noted Joseph E. Lema, vice president of transportation with the Washington-based National Coal Association.

He said that translates to approximately 615 million tons of coal annually being moved by rail. Of this total, about 150 millions tons interconnects with barges moving on inland waterways.

"Modern dedicated unit trains today account for 75 percent to 80 percent of total coal tonnage moved by rail. These are trains powered by five to seven locomotives that have anywhere from 100 to 120 cars, each of which can carry 100 tons of coal," Grasser said.

Although 1992 tonnage figures are not available, carload figures for last year indicate a 2.5 percent decrease from 1991.

Figures misleading

Thomas C. White, manager of external communications with the Washington- based Association of American Railroads, emphasized, however, these figures are somewhat misleading in that the tonnages are limited to Class I railroads.

He pointed out that total tonnages from non-Class I lines such as Western Rail Properties, a subsidiary of Chicago and North Western Transportation Co., total an additional tonnage of approximately 75 million tons of coal a year.

Trucks also play a small but important role in the movement of coal from mines, particularly in the eastern half of the United States, where distances from the mine to the user is usually not as great as in the West.

> *'Two out of every three tons of coal shipped from the mine is carried by rail.'*
>
> JOSEPH E. LEMA,
> National Coal Association

According to data compiled by Reebie Associates, a transportation management consulting firm headquartered in Greenwich, Conn., coal carried by truck in 1990 — the most recent year available — totaled 105.4 million tons; or about 10.75 percent of the total of 980.5 million tons transported that year.

The NCA's Lema stressed that, nationwide, the use of trucks to transport coal from mines to nearby utility plants is still relatively limited.

"In most instances, trucks are used to carry coal less than 50 miles from the mine to the power plant, although in recent years, shipment of coal by trucks a distance of 100 miles and more have taken place," noted Lema.

He said the greatest growth in the use of trucks is as part of intermodal systems.

"Increasingly, trucks are being used to transport coal from the mine to a rail or barge connection or to a coal preparation plant," Lema said.

He pointed out that the greatest factor mitigating against more widespread use of trucks for transporting coal has been the relatively high price of that mode.

On the average, barge transportation adds 10 to 15 mils a ton-mile to the cost of coal; rail transportation adds 15 to 30 mils a ton-mile, and truck transportation adds approximately 90 to 100 mils a ton-mile.

Pipeline plan

For decades, visionaries have maintained that an underground pipeline filled with a continuous stream of coal would be the most economical method of moving the commodity from a financial and an environmental point of view.

And a Department of Energy study conducted several years ago concluded that slurry pipelines could deliver coal for an average cost of $12 to $20 a ton less than coal shipped by rail.

Supporters of coal slurry pipelines cite the favorable experience of the Black Mesa Pipeline, the only significant slurry pipeline currently operating in the United States.

The 273-mile pipeline — in continuous operation since 1970 — transports coal slurry from Peabody Coal Co.'s Black Mesa Mine, near Kayenta, Ariz., to a power generating station at Laughlin, Nev.

In its 22 years of operation, the Black Mesa Pipeline, which has carried nearly 80 million tons of coal, has had less than half-a-dozen leaks that have resulted in the loss of fewer than 10,000 tons of coal. Slurry pipeline advocates claim that a comparable quantity of coal carried by railcars would have resulted in the environmental scattering of at least 300,000 tons of coal and coal dust from "blowout."

But despite the persuasive logic of the pro-pipeline lobby, their goal of a nationwide network of coal slurry pipelines seems as elusive as ever.

Eminent domain lacking

Legislation to grant federal eminent domain over land for coal pipelines was proposed in nearly every session of Congress between 1974 and 1989.

But in the face of opposition from a powerful coalition of railroads and farm groups, the legislation either languished in committee or was easily defeated on the few occasions when it progressed to a vote on the floor.

Historically, opponents of coal slurry pipelines have raised the specter of excessive water usage to help defeat pipeline legislation.

But that objection has been partially defused by current coal-water fuel (CWF) technology that permits the percentage of water in slurry to be reduced from 50 percent of the total to 30 percent.

And because of the delicacy of

PLEASE SEE TRAINS, 9A

(Continued from last page)

Trains star in transport as pipelines wait in wings

TRAINS, FROM 1A

... the issue of water usage, recent bills excluded water from the eminent domain procedure and delegated terms for use of pipeline water to the affected states.

Susan B. Carver, NCA assistant vice president for congressional affairs, said that while the organization continues to support legislation that would permit the construction of coal pipelines, the attitude of the incoming Clinton administration toward the technology is largely unknown.

"They certainly are big on creating new infrastructure, but how far that will go when it comes to new pipeline construction is another question," she said.

Stuart D. Serkin, executive director of the Coal and Slurry Technology Association in Washington, D.C., predicted that the Clinton administration will favor the development of natural gas resources instead of either coal or oil.

"I think the coal industry under the Clinton administration is going to have a bit of a tough time. One thing we will pursue with them is going to be clean coal technology, but it's going to take a lot of work," he said.

Among the most promising of the new pipeline technologies is the coal log pipeline (CLP), the creation of Dr. Henry Liu, a professor of civil engineering at the University of Missouri-Columbia.

Dr. Liu, who serves as director of the newly formed Capsule Pipeline Research Center, has been awarded a grant of $925,000 by the National Science Foundation to develop CLP technology.

He claims that by compressing coal into "logs" and transporting them through underground pipelines, significant economies can be realized in the transportation of coal.

According to Dr. Liu, CLPs can move coal at less than half the cost of rail or slurry pipelines. In addition, he said CLPs can move between 200 percent and 300 percent more coal than a slurry pipeline using only one-fifth of the water.

Note: This article appeared in the Miami Herald and many other papers. The original article was published by the Journal of Commerce, New York City, January 20, 1993.

pollution of the oceans and seacoasts, in an imbalance between the conventional liner and tramps and the bulk, unit load, container, and roll-on, roll-off ships. New international regulations are required, including those on pollution. This imbalance was particularly noticeable at the beginning of the 1970s, with an overcapacity of container ships, particularly on the North Atlantic routes, where container capacity exceeded cargo availability by some 50 percent. This led to withdrawal of some of the consortia from the trade. Equally, the ports of the world competing for the container trade were constructing the necessary facilities far in excess of requirements. At the same time, the industry faced rising costs in both ship construction and operation. To help meet these higher operating costs, automatic controls are being applied at every stage of a journey, and the randomness of operation is being eliminated at the same time as the ratio of manpower to vessel size is being reduced.

Over-capacity problems

The passenger trade faced a more serious and longer-lasting problem. Competition from the airline industry, particularly on the longer sea voyages, had drastically reduced demand for passenger accommodations. On the North Atlantic routes, in 1970, scheduled and chartered airline flights carried 2,202,000 passengers between North America and Europe, while ships carried only 249,000. To meet this challenge, which was growing with the advent of the jumbo jet, the passenger shipping companies were turning to car ferries and cruises. Their future appears to lie in the leisure and holiday field.

Meanwhile, many of the older problems of the shipping industry remain. Despite the large measure of international agreement and cooperation achieved in the shipping industry, competition among merchant fleets persists. Current problems and developments have driven several major lines to merge nationally or to cooperate through consortia at the international level.

The shipping industry is unique in that it has an economic and strategic as well as a commercial importance, and its operations are rarely free from political or strategic interference by governments. For internal political reasons, some states consider shipping services as a state monopoly. In practice, however, this is difficult to achieve because a state's jurisdiction does not extend beyond its recognized territorial waters. Nevertheless, various practices are observed from time to time to protect the domestic shipping industry and to discriminate against other flags. Higher port dues may be charged to foreign ships, or national flag ships may be favoured. In bilateral trade agreements it is sometimes stipulated that a fixed proportion of the cargoes must be carried in ships of the national flag. A common method of assisting the domestic shipping industry is to reserve coastal shipping to ships of the national flag (cabotage), a policy that greatly assisted the expansion of the British mercantile marine until the policy was abandoned with the repeal of the Navigation Acts in 1849, except for the coastal trades, which were not brought into line until 1854. Several other nations, notably the United States, still follow this practice and strictly reserve their coastal trade for their own vessels. Assistance in the form of tax exemptions, preferential credit terms, direct subsidy of shipbuilding, or operating costs is often given to protect national fleets.

State concerns

Although operating costs are much the same for ships of all flags, the rates of taxation vary, and after World War II heavy taxes, combined with a sharp rise in shipbuilding prices, caused the registration of more and more shipping companies under flags of convenience. Some 40 million gross tons, over one-fifth of world tonnage, were so registered in the early 1970s.

Despite problems, the shipping industry has always proved itself resilient and, particularly in the middle and late 20th century, ready to adopt new technological aids to efficiency. Thus, it can be expected to meet the challenge of competition and changes in economic conditions. Its adaptation may be less through the increase of vessel sizes and the resultant economies of scale than through even greater specialization, rationalization of existing structures of operation, and innovations through new types of vessels and services offered to the market. (E.A.J.D.)

Freight pipelines

Most nations have an extensive network of pipelines for transporting water, wastewater (sewage), oil, natural gas, and many other products. Because pipelines are usually underground and out of sight, their contribution to freight transport and their importance to the economy of modern nations are often unrecognized by the general public. Yet, virtually all the water transported from treatment plants to individual households, all the natural gas from wellheads to individual users, and practically all the long-distance transportation of oil over land goes by pipeline.

Pipeline has been the preferred mode of transportation for liquid and gas over competing modes such as truck and rail for several reasons: it is less damaging to the environment, less susceptible to theft, and more economical, safe, convenient, and reliable than other modes. Although transporting solids by pipeline is more difficult and more costly than transporting liquid and gas by pipeline, in many situations pipelines have been chosen to transport solids ranging from coal and other minerals over long distances or to transport grain, rocks, cement, concrete, solid wastes, pulp, machine parts, books, and hundreds of other products over short distances. The list of solid cargoes transported by pipelines has been expanding steadily.

HISTORY

For thousands of years, pipelines have been constructed in various parts of the world to convey water for drinking and irrigation. This includes ancient use in China of pipe made of hollow bamboo and the use of aqueducts by the Romans and Persians. The Chinese even used bamboo pipe to transmit natural gas to light their capital, Peking, as early as 400 BC.

Ancient use in China

A significant improvement of pipeline technology took place in the 18th century, when cast-iron pipes were used commercially. Another major milestone was the advent in the 19th century of steel pipe, which greatly increased the strength of pipes of all sizes. The development of high-strength steel pipes made it possible to transport natural gas and oil over long distances. Initially, all steel pipes had to be threaded together. This was difficult to do for large pipes, and they were apt to leak under high pressure. The application of welding to join pipes in the 1920s made it possible to construct leakproof, high-pressure, large-diameter pipelines. Today, most high-pressure piping consists of steel pipe with welded joints.

Major innovations since 1950 include the introduction of ductile iron and large-diameter concrete pressure pipes for water, use of polyvinyl chloride (PVC) pipe for sewers; use of "pigs" to clean the interior of pipelines and to perform other duties; "batching" of different petroleum products in a common pipeline; application of cathodic protection to reduce corrosion and extend pipeline life; the use of space-age technologies such as computers to control pipelines and microwave stations and satellites to communicate between headquarters and the field; and new technologies and extensive measures to prevent and detect pipeline leaks. Furthermore, many new devices have been invented or produced to facilitate pipeline construction. These include large side booms to lay pipes, machines to drill under rivers and roads for crossing, machines to bend large pipes in the field, and X rays to detect welding flaws.

TYPES

Pipelines can be categorized in different ways. In what follows, pipelines will be categorized according to the commodity transported and the type of fluid flow.

Water and sewer lines. Pipelines are used universally to bring water from treatment plants to individual households or buildings. They form an underground network of pipe beneath cities and streets. Water pipelines are usually laid a few feet (one metre or more) underground, depending on the frost line of the location and the need for protection against accidental damage by digging or construction activities.

In modern water engineering, while copper tubing is commonly used for indoor plumbing, large-diameter outdoor high-pressure water mains (trunk lines) may use steel, ductile-iron, or concrete pressure pipes. Smaller-diameter lines (branch lines) may use steel, ductile-iron, or PVC pipes. When metal pipes are used to carry drinking water, the interior of the pipe often has a plastic or cement lining to prevent rusting, which may lead to a deterioration in water quality. The exteriors of metal pipes also are coated with an asphalt product and wrapped with special tape to reduce corrosion due to contact with certain soils. In addition, direct-current electrodes are often placed along steel pipelines in what is called cathodic protection.

Domestic sewage normally contains 98 percent water and 2 percent solids. The sewage transported by pipeline (sewers) is normally somewhat corrosive, but it is under low pressure. Depending on the pressure in the pipe and other conditions, sewer pipes are made of concrete, PVC, cast iron, or clay. PVC is especially popular for sizes less than 12 inches (30 centimetres) in diameter. Large-diameter storm sewers often use corrugated steel pipe.

Oil pipelines. There are two types of oil pipeline: crude oil pipeline and product pipeline. While the former carries crude oil to refineries, the latter transports refined products such as gasoline, kerosene, jet fuel, and heating oil from refineries to the market. Different grades of crude oil or different refined products are usually transported through the same pipeline in different batches. Mixing between batches is small and can be controlled. This is accomplished either by using large batches (long columns of the same oil or product) or by placing an inflated rubber sphere or ball between batches to separate them. Crude oil and some petroleum products moving through pipelines often contain a small amount of additives to reduce internal corrosion of pipe and decrease energy loss (drag reduction). The most commonly used drag-reducing additives are polymers such as polyethylene oxides. Oil pipelines almost exclusively use steel pipe without lining but with an external coating and cathodic protection to minimize external corrosion. They are welded together and bent to shape in the field.

"Batching"

Some of the oil pipelines constructed in the United States include the "Big Inch" and "Little Big Inch" pipelines built during World War II to counter the threat of German submarine attacks on coastal tankers; a large product pipeline from Houston, Texas, to Linden, N.J., built by the Colonial Pipeline Company in the 1960s to counter the strike of the maritime union; and the Trans-Alaska Pipeline built to bring crude oil from the North Slope to Prudhoe Bay for meeting the challenge posed by the Arab oil embargo of 1973.

Offshore pipelines

Offshore (submarine) pipelines are needed for transporting oil and natural gas from offshore oil wells and gas wells to overland pipelines, which further transport the oil to a refinery or the gas to a processing plant. They are more expensive and difficult to build than overland pipelines. Offshore construction usually employs a barge on which pipe sections are welded together and connected to the end of the overland pipe. As more sections are welded to the pipe end, the barge moves toward the oil or gas field, and the completed portion of the pipe is continuously lowered into the sea behind the barge. Construction progresses until the barge has reached the field and the pipe is connected to the oil or gas well. In deep seas with large waves, ships instead of barges are used to lay the pipe. The most notable offshore oil pipeline is one linking the British North Sea oil fields to the Shetland Islands.

Gas pipelines. Practically all overland transportation of natural gas is by pipeline. To transport natural gas by other modes such as truck, train, or barge would be more dangerous and expensive. While gas collection and transmission lines are made of steel, most distribution lines (*i.e.*, smaller lines connecting from the main or transmission lines to customers) built in the United States since 1980 use flexible plastic pipes, which are easy to lay and do not corrode.

The United States operates the world's largest and most sophisticated natural gas pipeline network. Most other nations in the world also use natural gas and have natural gas pipelines.

Pipelines for transporting other fluids. Pipelines have been built to transport many other fluids (liquids and gases). For instance, liquid fertilizers are often transported long distances via pipelines. The mixture of oil and natural gas coming out of a well must be transported as two-phase flow by pipelines to processing facilities before the oil can be separated from the gas. Liquefied natural gas (LNG) transported by ships (tankers) also requires short pipelines to connect the ships to onshore storage tanks. Pipelines as long as 180 miles have been built in the United States to transport carbon dioxide to oil fields for injection into reservoirs to enhance oil recovery. Finally, on a smaller scale, most chemical, food, and pharmaceutical plants use pipe to transport various liquids and gases within the plants. When such fluids are corrosive or cannot tolerate impurities, the pipe must be of inert materials.

Slurry pipelines. Slurry is the mixture of solid particles and a liquid, usually water. The particles can range in size from greater than four inches in equivalent diameter to less than one-thousandth of an inch. When the solid particles in the liquid are small and finely ground, the mixture is called fine slurry, and when the particles are larger, it is called coarse slurry. Traditionally, the mining industry has employed pipelines to transport mine wastes and tailings in slurry form to disposal sites, using water as the fluid. Dredging also uses slurry pipeline. The sand, gravel, or soil dredged from a river is often pumped with water through a pipeline to a construction site for a distance of up to a few miles.

In general, when pipelines are used to transport coarse slurry, the slurry velocity must be relatively high in order to suspend the solids. Such slurry transport is very abrasive to the pipe and the pump, and the power consumed is high. Consequently, coarse-slurry pipelines are economical only over relatively short distances, normally not more than a few miles. An important application of coarse-slurry pipeline is "concrete pumping," in which concrete is pumped from a parked truck through a portable steel pipe attached to a side boom to reach rooftops and bridge decks. It is a method of conveying and laying concrete employed increasingly in construction.

Coal slurry

Long-distance transport of solids by slurry pipeline must use relatively fine slurry. Existing coal-slurry pipelines carry fine slurry consisting of about 50 percent coal and 50 percent water by weight. The solid is first pulverized and mixed with water to form a paste. The slurry then enters a mixing tank, which contains one or more large rotating wheels or propellers that keep the particles uniformly mixed. Next, the slurry enters the pipeline. Special plunger or piston pumps are used to pump the slurry over long distances. The United States pioneered the coal-slurry pipeline technology. The first long-distance coal-slurry pipeline was constructed in Ohio in 1957. The line was discontinued later when the competing railroad agreed to lower its freight rate. The pipeline was then mothballed for years and used as a leverage against rail rate increases. It was said to have prompted railroads to modernize and become more competitive, introducing the concept of the unit train, which employs about 100 cars to haul coal nonstop from mines to power plants.

The world's longest coal-slurry pipeline is the Black Mesa pipeline in the United States. Built in 1970, this 18-inch pipeline transports 4.8 million tons of coal per year from Black Mesa, Ariz., to southern Nevada, over a distance of 273 miles. This coal pipeline has been highly successful. Figure 57 shows a pumping station along this pipeline. Many other long-distance slurry pipelines exist in the world to transport coal and other minerals such as iron concentrate and copper ore.

Pneumatic pipelines. Pneumatic pipelines, also called pneumo transport, transport solid particles using air as the carrier medium. Because air is free and exists everywhere, and because it does not wet or react chemically with most solids, pneumo transport is preferred to hydro transport for most cargoes wherever the transportation distance is short. Owing to high energy consumption and abrasiveness to pipe and materials, pneumatic pipelines are usually adopted for distances not more than a few hundred feet or metres. Large-diameter pneumatic pipelines can be used economically for longer distances, sometimes more than a mile or a kilometre.

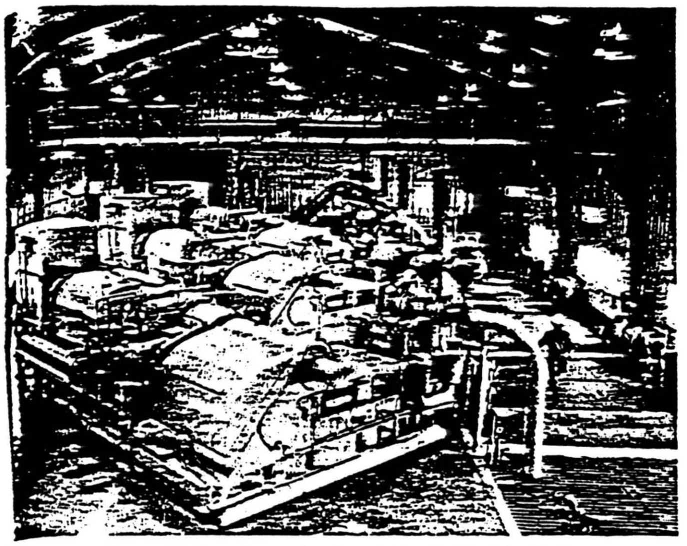

Figure 57: Pumping station (one of four) along the Black Mesa coal-slurry pipeline, running between Arizona and Nevada (see text).

Henry Liu

Pneumatic pipelines are employed extensively throughout the world in bulk materials handling, and hundreds of different cargoes have been transported successfully. Common applications include the loading of grain from silos or grain elevators to trucks or trains parked nearby, transport of refuse from collection stations to processing plants or from processing plants to disposal sites, transport of cement or sand to construction sites, and transport of coal from storage bins to boilers within a power plant.

There are two general types of pneumatic pipelines. The first employs suction lines, which create a suction or vacuum in the pipe by placing the compressor or blower near the downstream end of the pipe. The line operates like a vacuum cleaner. The second type is pressure lines, which have compressors or blowers located near the upstream end. This creates a pressure in the line that drives the air and the solids through the pipe. Pressure lines are used for longer distances and in places where solids concentrated at one location are transported to several separate locations using a single blower or compressor. In contrast, suction lines are more convenient for shorter distances and in places where solids from several locations are to be transported to a common destination by means of a common blower or compressor.

In addition to the pipe and blower, a pneumatic pipeline system also must have a tank or hopper connected near the pipeline inlet to feed solid particles into the pipeline and a tank near the pipeline outlet to separate the transported solids from the airstream. The exhaust air also must be filtered to prevent air pollution.

Combustible solids such as grain or coal transported pneumatically through pipe, if handled improperly, can cause fire or even explosion. This is due to the accumulation of electric charges on fine particles transported pneumatically. Prevention of such hazards can be accomplished by using metal rather than plastic pipes; by grounding the pipe, valves, and other fixtures that accumulate charges; by cleaning the interior of the pipe to rid it of dust; and by increasing the moisture of the air used for pneumatic transport.

Capsule pipelines. Capsule pipelines transport freight in capsules propelled by a fluid moving through a pipeline. When the fluid is air or another gas, the technology is called pneumatic capsule pipeline (PCP), and, when water or another liquid is used, it is termed hydraulic capsule pipeline (HCP). Owing to the low density of air, capsules in PCP cannot be suspended by air at ordinary speeds. Instead, the capsules are wheeled vehicles rolling through pipelines (see Figure 58). In contrast, because water is heavy, the capsules in HCP do not require wheels. They are both propelled and suspended by water under ordinary operational speeds. HCP systems are operated normally at a speed of 6 to 10 feet per second (1.8 to 3 metres per second), whereas the operational speed of PCP is normally much higher—20 to 50 feet per second. Owing to high frictional loss at high velocity, PCP consumes more energy in operation than HCP.

PCP has been in use since the 19th century for transporting mail, printed telegraph messages, machine parts, cash receipts, books, blood samples (in hospitals), and many other products. Since 1970, large wheeled PCP systems have been developed for transporting heavy cargo over relatively long distances. The largest PCP in the world is LILO-2 in the republic of Georgia, which has a diameter of 48 inches and a length of 11 miles. The system was built for transporting rock.

In contrast to the long history of PCP, the technology of HCP is still in its infant stage. HCP was first considered by the British military for transporting war matériel in East Asia during World War II. The concept received extensive investigation in Canada at the Alberta Research Council during 1958–75. Interest in this new technology soon spread to many other nations. In 1991, the United States established a Capsule Pipeline Research Center at the University of Missouri in Columbia, jointly funded by industry and government. Capsule pipeline research

A new type of HCP being developed is coal-log pipeline (CLP), which transports compressed coal logs. The system eliminates the use of capsules to enclose coal and the need for having a separate pipeline to return empty capsules. Compared with a coal-slurry pipeline of the same diameter, CLP can transport more coal using less water.

Capsule pipelines of large diameter (greater than seven feet) can be used to transport most of the cargoes normally carried by trucks or trains. In both Europe and the United States, large-diameter capsule pipelines (mostly PCPs) have been proposed for intercity freight transport in the 21st century. Proponents of such projects point out that such underground freight pipeline systems not only allow land surface to be used for other purposes but also reduce the number of trucks and trains needed, which in turn reduces air pollution, accidents, traffic jams, and damage to highway and rail infrastructures caused by the high traffic volume.

DESIGN AND OPERATION

Pipeline design includes a selection of the route traversed by the pipe, determination of the throughput (*i.e.*, the amount of fluid or solids transported) and the operational velocity, calculation of pressure gradient, selection of pumps and other equipment, determination of pipe thickness and material (*e.g.*, whether to use steel, concrete, cast iron, or PVC pipe), and an engineering economic analysis and a market analysis to determine the optimum system based on alternate designs. In each design, careful consideration must be given to safety, leak and damage prevention, government regulations, and environmental concerns.

Components. A pipeline is a system that consists of

Henry Liu

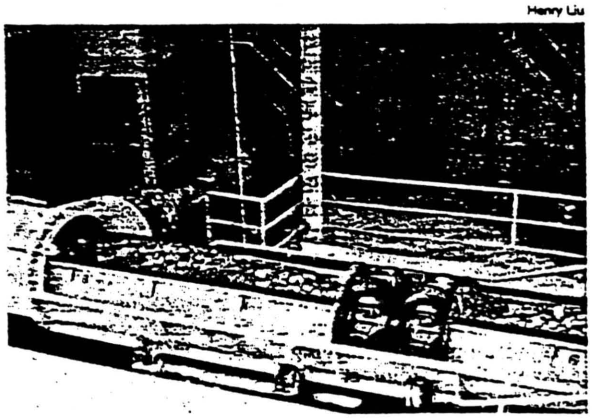

Figure 58: A pneumatic capsule pipeline shown at a handling station. The capsules feature a five-wheeled assembly and linkage at each end. This system transports crushed limestone to a cement plant.

pipes, fittings (valves and joints), pumps (compressors or blowers in the case of gas pipelines), booster stations (*i.e.*, intermediate pumping stations placed along the pipeline to house pumps or compressors), storage facilities connected to the pipe, intake and outlet structures, flowmeters and other sensors, automatic control equipment including computers, and a communication system that uses microwaves, cables, and satellites. Booster stations are needed only for long pipelines that require more than one pumping station. The distance between booster stations for large pipelines is on the order of 50 miles. Special pipelines that transport cryogenic fluids, such as liquefied natural gas and liquid carbon dioxide, must have refrigeration systems to keep the fluid in the pipe below critical temperatures.

Construction. Construction of pipelines involves route survey, ditching or trenching, transporting the pipes, fittings, and other materials to the site, stringing the pipes along the ditch, bending steel pipes in the field to suit local topography, applying coating and wrapping to steel pipes, joining pipes together either before or after they are lowered into the trench (this depends on the type of pipes used), checking for possible welding flaws or leakage at the joints, and then covering trenches by soil and restoration of the land to its original appearance. For long pipelines, construction is done in segments so that one segment of the pipeline is completed before construction proceeds to the next. This minimizes the time that any given place is disturbed by construction activities. Even for large pipelines, construction for any segment is usually completed within six months and often in much less time. Small pipelines can be constructed in days.

Completion of segments

When a pipeline must cross a river or creek, the pipe can be either attached a to a bridge, laid on the streambed underwater, or bored through the ground underneath the river. Modern boring machines allow convenient pipeline crossing of rivers and roads.

Operation. Modern long-distance pipelines are operated mainly automatically by a computer at the headquarters of the pipeline company. The computer monitors the pressure, flow rates, and other parameters at various locations along the pipe, performs many on-line computations, and sends commands to the field to control the operation of the valves and pumps. Manual intervention is frequently needed to modify the automatic operation, as when different batches of fuels are directed to different temporary storage tanks, or when the system must be shut down or restarted.

Safety. The safety of pipelines depends to a large extent on the materials transported. Pipelines that transport water or use water to transport coarse solids, such as hydraulic capsule pipelines, do not explode or pollute the environment in the event of pipe rupture or spill. They pose few safety or environmental hazards. Crude-oil pipelines, when ruptured, do not explode but may pollute waters and soil. Natural gas pipelines and product pipelines that contain highly volatile liquids such as gasoline may explode in a spill; they deserve the greatest safety considerations. Even in this case, however, it is generally accepted that the safest way to transport petroleum and natural gas is by pipeline. To use other modes such as truck or railroad to transport such fuel would be far more dangerous and costly.

Even though pipelines have the best safety record of all transportation modes, in the United States pipeline safety is still a major concern of the government and the public owing to occasional spills and accidents. As a result, a major emphasis of pipeline operations in the United States is safety. Many measures are taken to prevent and detect ruptures and leaks and to correct problems whenever they occur.

In the United States about half of all pipeline accidents are caused by a third party, as, for instance, a builder damaging a pipe while digging the foundation of a house. Consequently, pipeline companies make special efforts to educate the public about pipeline safety and inform cities and construction groups about the locations of underground pipelines in order to reduce third-party damage.

The second leading cause of pipeline failure is corrosion, which is an electrochemical process caused by the contact of metal pipe with wet soil (external corrosion) and with the fluid in the pipe if the fluid is corrosive or contains water with dissolved oxygen, carbon dioxide, or hydrogen sulfide (internal corrosion). Pipeline companies take many measures to prevent corrosion, such as covering underground pipelines with tape and using cathodic protection against external corrosion and adding special chemicals (corrosion inhibitants) to the fluid to prevent internal corrosion. Hydrazine (N_2H_4) and sodium sulfite (Na_2SO_3) are two chemicals commonly used to control internal corrosion of metal pipes that carry water. The chemicals reduce corrosion by reacting with and hence removing the dissolved oxygen in water.

Finally, detection of leaks is done by computer monitoring of abnormal flow rates and pressure and by flying aircraft along pipelines for visual inspection. Special "pigs" are also sent through pipelines to detect possible flaws of the pipeline walls and signs of corrosion. Highly corroded pipes are replaced before a leak develops. Often referred to as "smart pigs," these carry instruments that detect cracks and corrosion of pipeline interiors. (He.L.)

Urban mass transportation

Urban mass transportation is the movement of people within urban areas using group travel technologies such as buses and trains. The essential feature of mass transportation is that many people are carried in the same vehicle (*e.g.*, buses) or collection of attached vehicles (trains). This makes it possible to move people in the same travel corridor with greater efficiency, which can lead to lower costs to carry each person or—because the costs are shared by many people—the opportunity to spend more money to provide better service, or both.

Mass transit systems may be owned by private, profit-making companies or by governments or quasi-government agencies that may not operate for profit. Whether public or private, many mass transportation services are subsidized because they cannot cover all their costs from fares charged to their riders. Such subsidies assure the availability of mass transit, which contributes to making cities efficient and desirable places in which to live. The importance of mass transportation in supporting urban life differs among cities, depending largely on the role played by its chief competitor, the private automobile.

People travel to meet their needs for subsistence (to go to work, to acquire food and essential services), for personal development (to go to school and cultural facilities), and for entertainment (to participate in or watch sporting events, to visit friends). The need for travel is a derived need, because people rarely travel for the sake of travel itself; they travel to meet the primary needs of daily life. Mobility is an essential feature of urban life, for it defines the ability to participate in modern society.

Travelers make rational choices of the modes they use, each choosing the one that serves him or her best, although best may be viewed differently by each traveler. Transportation services in a city define the alternatives from which travelers must choose, the activities available to them, and the places to which they can go. The transportation available to an individual is the collective result of government policies, the overall demand for travel in the region, competition among different modes, and the resources available to each individual to buy services. Urban transportation services directly affect the character and quality of urban life, which can differ among individuals who have access to different kinds and amounts of transportation services.

EVOLUTION OF URBAN MASS TRANSPORTATION

Growth in the 19th century. The history of urban mass transportation is first a story of the evolution of technology, from walking, to riding animals, to riding in groups on vehicles pulled by animals, and eventually to cable cars, larger-capacity steam-powered trains, electric trains, and motor buses powered by internal-combustion engines. It is a story of gradually increasing speed, vehicle capacity, and range of travel that has shaped cities and structured the lives of those who live in them.

Minutes of the
University Policy Committee Meeting

Capsule Pipeline Research Center

Wednesday, March 17, 1993
10:00 am - 11:30 am

Present: Ms. Connie Armentrout, Office of Patents and Licensing; Dr. James W. Baldwin, Interim Dean, College of Engineering; Dr. Paul W. Braisted, Associate Dean, College of Engineering; Dr. Henry Liu, Director, Capsule Pipeline Research Center; Dr. Jay McGarraugh, Acting Chairman, Department of Civil Engineering; Dr. Thomas Marrero, Associate Director, Capsule Pipeline Research Center; Dr. Judson Sheridan, Vice Provost for Research; Dr. Donald Swoboda, Vice Provost for Extension; Dr. Dabir Viswanath, Chairman, Department of Chemical Engineering; Dr. Richard Warder, Chairman, Department of Mechanical and Aerospace Engineering; and Dr. John Wilson, Chairman, Department of Mining Engineering, UMR.

Dr. Sheridan opened the meeting with an introduction of all those present. He highlighted the funding background of the Capsule Pipeline Research Center as well as the positive relationships that exist between the Center, the various departments associated with the Center and the University of Missouri-Rolla.

He then introduced Dr. Henry Liu who proceeded to show a new videotape illustrating the coal log pipeline technology, the Center's research program, and funding sources. Dr. Liu stated that this video still needs minor revisions which are being done. The general consensus was that the videotape was excellent, and Dr. Sheridan suggested sharing it with the Chancellor. Dr. Warder offered the suggestion of having it shown during the half time shows at Big 8 Tournaments.

Dr. Liu distributed to each participant a copy of his draft response to the NSF Site Visit report, giving each person a few minutes to read it and make suggestions regarding the format and content. Ms. Armentrout suggested to add to the "marketing plan" that the CLP patent is listed in the University of Missouri System Technology Catalogue. This catalogue is sent to 1200 to 1800 companies each year by her office. Dr. Liu said that he would incorporate the suggestion in the response. Dr. Warder referred to an "uneveness" in Dr. Liu's response in terms of format and suggested that the format be made more uniform.

Dr. Sheridan discussed the subject of REU (Research Experience for Undergraduates) funding. He suggested that Dr. Liu submit a specific proposal requesting REU funding from NSF.

Utility companies were discussed, and Dr. Liu mentioned some difficulty with Kansas City Power and Light regarding their willingness to participate in a Tailored Coordinated (TC) program under EPRI (Electric Power Research Institute) auspices. Dr. Sheridan suggested to try enlisting the support of other companies. Dr. Marrero discussed current efforts by Mr. Bill Weber of EPRI to organize a TC project on coal log pipeline.

Dr. Liu read the suggestion from NSF regarding foreign licensing and said that he had "mixed feelings." He stated that it takes time and a lot of money, $15,000, to pursue a U.S. patent. The Center plans to submit a couple of invention disclosures this year, and he wondered who should pay for these.

Ms. Armentrout said that Dr. Liu should be able to get some help from the University in paying for these patents. She discussed NSF's suggestion to solicit international licensing. Since the CLP concept was published prior to the U.S. application filing, foreign patent protection is not possible. It will be possible to apply for U.S. and foreign patents on unpublished inventions that may be reported as a result of the project. It was emphasized by both Ms. Armentrout and Dr. Sheridan that one cannot obtain a foreign patent on the original CLP technology because the concept was published.

Funding for the Center was discussed. Dr. Sheridan mentioned that the Missouri House has allocated $200,000 for 1994 and that includes $25,000 for the 1993 matching funds. Mr. Jim Snyder of the UM System is trying to get the Senate to increase to $250,000 or at least between $200,000 and $250,000. Both Dr. Sheridan and Dr. Liu praised Mr. Snyder's efforts in helping the Center in the State Legislature.

Dr. Liu reported that the tasks of the Center are growing. One of these is to test a 20 mile pipe near Kansas City. However, Dr. Liu said that there is not enough funding in the current budget to do so. He indicated that another source of possible funding is the Technology Transfer Center at West Virginia which is calling for proposals. The capsule pipeline project is one of six technologies that had been suggested by the National Institute of Standard and Technology (NIST) for technology transfer. At present, ASME (American Society of Mechanical Engineers) is coordinating the submission of a proposal including MU's capsule pipeline.

Dr. Liu mentioned his gratitude for the Engineering Equipment Fund allocated by the College which will enable the Center to get some much needed new equipment. Dr. Liu also brought up the subject of space. He stated that there is an acute shortage of space for both teaching and research in the Hydraulics Lab. It affects not only research but also teaching, and even the forthcoming ABET accreditation. He asked for assistance from the College. Dr. Liu mentioned that the best solution is to make available the room next to the Hydraulics Lab (Room C-1243) for the Center, but this may require the

College to compensate Chemical Engineering for the loss of space. Dr. Viswanath agreed with the Dean's looking at the space requirements of all the departments. Dr. Baldwin mentioned that he would make a decision on this matter soon. Dr. Marrero mentioned that he felt faculty from different engineering departments were very supportive of the Center and that the Center has many good students working for it.

RIF and Faculty Release Time were discussed in terms of policy, increased faculty time for research, etc. Dr. Liu suggested that a uniform policy be established within Engineering, in which 50% of the salary release money will go to the department and 50% to the Center. Dr. Baldwin mentioned that this should be discussed within the College of Engineering.

At the close of the meeting, Dr. Liu reminded everyone of the Center's Industrial Advisory Board Meeting on May 18.

The meeting ended at 11:35 am.

NSF Capsule Pipeline Research Center

University Policy Committee

Purpose: The National Science Foundation (NSF) requires each State/Industry University Cooperative Research Center supported by NSF to have a "University Policy Committee" to formulate important University policies regarding the Center and to provide high-level university support and coordination.

Mode of Operation: The committee meets at least once a year to discuss various matters concerning the Center.

Committee Members (1993 Update)

Ms. Connie Armentrout, Coordinator, Patents & Licensing Office (882-2821)

Dr. James W. Baldwin, Interim Dean, College of Engineering (882-4378)

Dr. Paul W. Braisted, Associate Dean, College of Engineering (882-4486)

Dr. Kenneth D. Dean, Associate Dean, School of Law (882-6488)

Dr. Jay McGarraugh, Acting Chairman, Department of Civil Engineering (882-4688)

Dr. Judson D. Sheridan, Vice Provost for Research (Committee Chairman) (882-6311)

Dr. Donald W. Swoboda, Vice Provost for Extension (882-2394)

Dr. Dabir Viswanath, Chairman, Department of Chemical Engineering (882-4281)

Dr. Richard Warder, Jr., Chairman, Dept. of Mechanical & Aerospace Eng. (882-2785)

Dr. Don L. Warner, Dean, School of Mines and Metallurgy (UMR) (341-4153)

CLP/NSF Capsule Pipeline Center
Joint Advisory Board Meeting

Columbia, Missouri, October 8, 1992

ATTENDANCE LIST

INDUSTRY REPRESENTATIVES

Name/Title	Affiliation	Phone
Mr. Michael Barron, Vice President	T.J. Gundlach Machine Co.	618-233-7208
Mr. Henry Brolick, Vice President	Williams Technologies, Inc.	918-582-5811
Mr. Syd Fleming	DuPont Co.	302-695-4572
Mr. Alex Hapka	Kansas City Power & Light	816-556-2338
Mr. Ted Jaenke, President	Pro-Mark Systems	314-878-6450
Mr. James Ramer, President	Ramer & Associates	816-826-0100
Mr. Richard Smith, Supervising Engr.	Union Electric Co.	314-554-3529
Mr. John Stolwyk, Fuel Systems Analyst	Kansas City Power & Light	816-556-2338
Mr. Dave Thompson	Arch Mineral Corp.	314-994-2872
Mr. Leith Watkins, Engineering Mngr.	MAPCO Transportation	918-581-1814
Mr. William Vandersteel, General Mngr.	Tubexpress Associates	201-868-2000
Mr. Aubrey Zey, President	Nova Tech Corp.	913-451-1880

NSF REPRESENTATIVE

Name/Title	Affiliation	Phone
Mr. Win Aung, Program Director	NSF	202-786-9532

STATE REPRESENTATIVE

Name/Title	Affiliation	Phone
Mr. Tom Barry, Program Director	MO Dept. of Econ. Development	314-751-3906

EPRI REPRESENTATIVE

Name/Title	Affiliation	Phone
Mr. Bill Weber, Regional Manager	EPRI	205-868-5503

U.S. BUREAU OF MINES

Name/Title	Affiliation	Phone
Mr. Richard Wang	U.S. Bureau of Mines	412-892-4354

ATTENDANCE LIST (Continued)

U.S. DEPARTMENT OF ENERGY

Name/Title	Affiliation	Phone
Dr. Bill Peters	Pittsburgh Energy Technology Ctr.	412-675-5713

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Dr. Paul Braisted	UMC Engineering Deans' Office	314-882-4377
Mr. Bill Burkett	UMC Chemical Engineering	314-882-7196
Dr. Peter Davis	UMC Law School	314-882-2624
Dr. Brett Gunnink	UMC Civil Engineering	314-882-3299
Dr. Charles Lenau	UMC Civil Engineering	314-882-3070
Dr. Yuyi Lin	UMC Mechanical Engineering	314-882-7505
Dr. Henry Liu	UMC Civil Engineering	314-882-2779
Dr. Richard Luecke	UMC Chemical Engineering	314-882-3691
Dr. John McCormick	UMC Office of Research	314-882-9500
Dr. Thomas Marrero	UMC Chemical Engineering	314-882-3802
Dr. Satish Nair	UMC Mechanical Engineering	314-882-2964
Dr. James Seaba	UMC Mechanical Engineering	314-882-3605
Dr. Dabir Viswanath	UMC Chemical Engineering	314-882-4281
Dr. John Wilson	UMR Mining Engineering	314-341-4753

OTHER GUESTS

Dr. James Johnson	Civil Engineering Dept.; Howard University	202-806-6570
Dr. Daniel Joseph	Mechanical Engineering Dept.; University of Minnesota	

(5) Dr. Liu referred to the Strategic Plan for the first 4 years of the Center's existence. Extensive research and development are being conducted in order to develop CLP technology in four years' time. The approach being employed is a simultaneous investigation of all pertinent areas, such as: hydrodynamics, system design, automatic control, fabrication of coal logs, treatment of coal logs and effluent water, economics of coal log pipeline and legal issues. Discussion regarding deadlines for completion of such work ensued. Simultaneous research of all areas vs. sequential research of these areas along with the advantages and disadvantages inherent in each approach were also discussed at length. In conjunction with the Strategic Plan, Dr. Liu illustrated what is to be accomplished within what time frames via a diagram. In about a year from now, the Center plans to conduct a pilot plant test using an abandoned pipeline. The main purpose of the test is to assess the amount of degradation of coal logs transported over long distances in a commercial straight pipeline. He mentioned that the Williams Pipeline Company has offered to use an 8" pipeline (dual line) south of Kansas City for the test which will be considered. Liu plans to complete all research first using 2" logs after which he will change over to 8" logs.

(6) The second revision of the Economic Report is nearly completed. The draft report is being reviewed by the Williams Technologies, Inc. Some final revisions will be made to incorporate suggestions by the Williams Technologies. Another revision is planned in 1994 when the coal log technology is near completion. No revision will be made in 1993.

(7) The greatest priority at this time is coal log fabrication. More than half of the resources in manpower, money and time are invested here, according to Liu. In one year, hopefully, this will be completed; then, the priorities will shift.

(8) The strategy for developing durable and economic coal logs within a year is in place. This consists of accelerating research in coal log fabrication so that such logs can be developed by August, 1993. Liu feels the prospects of meeting this goal are good. The different approaches used to accomplish this goal include:

a. Producing durable and economical binderless logs by improving the compaction process. (Dr. Gunnink and his students are working on that.)

b. Producing durable and economical logs with less than 3% binder by compaction and extrusion. (Dr. Marrero, Mr. Burkett and their students are working on that.)

c. Treatment of coal log surface with sealant, heat or binder, or utilizing a rich surface layer. (Dr. Marrero, Dr. Luecke, Mr. Burkett and their students are working on that.)

d. Using underwater extrusion. (Dr. Lin and his students are working on that.)

e. Producing hydrophobic logs, which is a new research area, by collaborating with a company in Tennessee which uses a hydrophobic binder and very little binder in logs. Logs made of such binder do not break apart or weaken when immersed in water under pressure. (Dr. Wilson, Dr. Marrero and their students are working on that.)

CLP CONSORTIUM/NSF CAPSULE PIPELINE CENTER

Joint Advisory Board Meeting

October 8, 1992

(Minutes revised on November 3, 1992)

(1) Dr. John McCormick welcomed the participants on behalf of the Campus administration. He mentioned the importance of this Center to the Columbia campus, and thanked the sponsors.

(2) Dr. Paul Braisted welcomed the group on behalf of the College of Engineering and Dean Hines, who was out of town. He stated that he is pleased with the Center's accomplishments and is grateful to both the National Science Foundation, Missouri Department of Economic Development, Industry and other sponsors for their support which made the existence of the Center possible. Dr. Braisted cited the cooperation between University of Missouri - Rolla and University of Missouri - Columbia as being a very beneficial experience for both. He stated that he anticipates a long period of success.

(3) The morning session of the meeting was comprised of the technical presentations of all those individuals engaged in work on the capsule pipeline project (see attached agenda). Dr. Liu first gave a detailed (30-minute) report on the findings of a newly completed economic study. The final report was being reviewed by the Center's Principal Consultant: The Williams Technologies, Inc. As soon as the review is completed, the report will be finalized and sent to all sponsors. Dr. John Wilson also gave a rather detailed report of the newly completed end-of-pipeline study sponsored by EPRI (Electric Power Research Institute), and his research plan for the second year which is to concentrate on making coal logs that contain hydrophobic binder. Then, each faculty member working on the Center's projects gave a 15-minute presentation. For contents of each presentation, please refer to your copy of the quarterly report.

(4) The afternoon segment was devoted to business related issues. Dr. Liu opened the session by alluding to the progress made during the last three months. Many projects have been completed during that time, including: headloss model, assessment of pressure surges, a theoretical model for predicting unsteady flow of coal logs, update of economic analysis, CLP effluent study, making strong binderless coal logs by compaction, extruding coal logs with 4-5% binder, design of commercial size machine for coal log fabrication, preliminary assessment of legal issues on coal log pipelines, and computer-controlled, automatic coal log pipeline model.

(9) Dr. Liu indicated that several consultants who visited the Center were paid for their consulting work. They were Mr. Richard Steele of Steele & Sons, Mr. William Poundstone from Consolodated Coal, Mr. William Turker from Lakeland College and Mr. John Dooher from Adelphi University. He felt that these people's expertise greatly benefited the coal log fabrication research of the Center.

(10) Technical transfer activities for both the first year and the second year were discussed by Dr. Liu.

First-year technical transfer activities included:

- Involving companies in the Center's research.
- Preparing design/operations manual.
- Completing preliminary investigation of potential sites for field testing and demonstration - MAPCO, Williams Pipe Line Company, UMC University Power Plant.
- Company seminars/visits.
- Newsletter.
- Video (not done).
- Quarterly reports and annual reports.
- Publications and presentations.
- Short course on solids transport.

Second year technical transfer activities will include:

- Completion of the hydraulics portion of design/operations manual.
- Involvement of more companies.
- Detailed investigation of potential site for field testing.
- Completion of preliminary assessment of two sites for demo project and preparation of written report on each.
- Publication of two newsletters.
- Preparation of CLP video.
- Preparation of quarterly reports and annual reports.
- Publications and presentations.
- Presentation of a short course on CLP.
- Increased interaction with other related organizations.

Discussion of technical transfer and research continued - how NSF sees technical transfer, etc. The State accepts the guidelines NSF sets down for technical transfer as well as other aspects of the research.

(11) Support in terms of space, equipment funding, faculty release time contribution, utilities for pipeline and coal log labs, etc., was also discussed. This includes support from both the College of Engineering and Campus. Dr. Liu indicated that support was very good from all sources including the University. The College of Engineering and the Campus have made significant contributions to the Center -- see attachment.

Dr. Liu indicated the Financial Report for the Core Program for the first year is as follows:

National Science Foundation	=	$175,000
State	=	$175,000
Industry	=	$180,000
TOTAL:		$530,000

He stated that there was a small balance of $23,240 and, while this indicates that the Center is fiscally sound, this does not mean that it has sufficient funding. Many research expenditures had to be scaled back for fear of overspending.

At present, the Center has only one full-time technician and each professor working on the Center's research gets paid for only two months in Summer. No money is available to pay the third month of Summer nor during the academic year, i.e., when school is in session. These limits in spending have slowed down the Center's progress in research. Had the Center been better funded, it would have made even greater progress. Liu said that if funding improves during the second year, he wants to hire a second full-time technician, and pay each professor at least one more month. The Center also needs a full-time manager so that Dr. Liu and Dr. Marrero will have more time for research.

Dr. Liu also showed the Accountant's sheet of expenditures (see attachment). Technology transfer expenditures of the past year, as shown in an attached document, amount to approximately 22% of the Center's core budget. NSF guidelines require a minimum of 20% expenditure on technology transfer.

(12) It was decided that the next meeting would be held on Thursday, April 29, 1993.

(13) At the end of the meeting, the CLP Consortium members held a separate meeting with other sponsors, without the presence of any University or Center personnel. After the closed-door meeting, Mr. John Stolwyk, Chairman of the Industry Advisory Board, told Dr. Liu about what was discussed in the meeting, and gave Dr. Liu suggestions on coal log machine design and possible use of the Center's money for building a prototype machine, using outside contractors. Dr. Liu's position is stated as follows:

"The Center should continue to work on improving the design but not rush to build any model or prototype until the design is finalized. Otherwise, it would accomplish little but cost the Center a lot. The design cannot be finalized until our coal log production process is better defined. At present, we are still studying different processes such as extrusion and compaction. Even if compaction is the way to go, we still don't know at this point the optimum compaction temperature, pressure, holding time, coal particle size distribution, and how the log surface is to be sealed or made waterproof. All these parameters affect the design of the machine. They are currently being investigated. The Center needs a minimum of one more year to make progress in producing durable logs before the design can be finalized. The Center researchers will incorporate all the design improvements including those provided by our consultants.

As to the use of outside contractors to build the coal log fabrication machine, it can be done in the future when it is time to build such a machine, and when it is determined that the job can be done better outside. In such a case, a contract will be awarded by competitive bidding, as required by University regulations and state laws. Consortium members and Small Business Participants of the Center should not expect to get such a contract from the University because that would present a conflict-of-interest problem.

The Center encourages its industry participants to seek additional outside fundings for coal log related research, development and demonstration projects. However, this does not mean taking away needed funds intended for supporting the University's coal log project, funded through the University. It includes only funds awarded directly to industry, through proposals submitted by the industry members. The Center objects to diverting the Center's resources or using additional resources intended for the Center, for work conducted outside the University and beyond the control of the University."

CE/MAE 345
Pipeline Engineering
(W 93 Offering)

Reference No.: 27702

Credits: 3

Prerequisite: CE/MAE 251 Fluid Mechanics or Ch.E. 235 Princ. of Chemical Engineering

Time and Room: 10:15-11:30 T-R, E3508 Engineering

Course Description: Theoretical and practical aspects of pipeline engineering including design, construction, operation, planning, economics and safety of various types of pipelines.

Instructor: Dr. Henry Liu, Professor and Director, Capsule Pipeline Research Center, College of Engineering (Office: E2421 Engr. Bldg.; Phone: 882-2779).

COURSE CONTENT

1. Incompressible flow of liquid and gas through pipe (1 week).
2. Compressible flow through pipe--adiabatic and isothermal (2 weeks).
3. Flow of natural gas through pipelines (2 weeks).
4. Pipe materials and fittings (1 week).
5. Pumps, compressors and other equipment (1 week).
6. Design of pipelines (2 weeks).
7. Corrosion protection (1 week).
8. Pipeline construction (1 week).
9. Pipeline economics (1 week).
10. Environmental and safety issues (1 week).
11. Pipeline right-of-way and permits (1 week).

CE/MAE 401 Special Topic in Pipeline
(Pipeline Transport of Slurries and Suspensions)
(W 93 Offering)

Prerequisite: Graduate Standing

Credits: 3

Course Description: Theoretical and practical aspects of two-phase flow of solid-liquid transported through pipe.

Time and Room: To be arranged

Other Information: Visiting professor Dr. George Round taught this course in W 93.

CONTENTS

Section 1 - Overview

1.0 Historical background - nomenclature
1.1 Hydraulic characteristics of slurries
1.2 Classification of slurry flow regimes - terminology
1.3 Critical velocities

Section 2 - Rheology and the physical properties of suspensions

2.0 Non Newtonian fluids - classification
2.1 Time independent and time dependent fluids
2.2 Rheology measurements
2.3 Factors affecting the rheology of slurries and suspensions
2.4 Dilute and dense phase mixtures
2.5 Rabinowitsch - Mooney relation

Section 3 - The motion of particles of fluids

3.0 The nature of fluid drag
3.1 Drag force on a sphere - Stokes' Law
3.2 Drag coefficient curves - the effect of boundaries
3.3 Generalized drag coefficient and shape factors
3.4 Generalized shape factor curves
3.5 Sedimentation of single particles and concentration effects
3.6 Average particle diameter

Section 4 - Flow of homogeneous and pseudohomogeneous mixtures

4.0 Transition velocities - correlations
4.1 Flows of time independent fluids in pipes - power law, ideal Bingham plastics, generalized Bingham plastics
4.2 Equations for pressure drop/flow relationships - derivation of equations
4.3 Design example

Section 5 - Flow of heterogeneous mixtures

5.0 Criteria for heterogeneity
5.1 Deposition velocity
5.2 Effects of particle size distribution and mean particle size
5.3 Durand correlation
5.4 Wasp carrier bed model - Hanks modification of the Wasp model
5.5 Wilson/Shook model
5.6 Design example

Section 6 - Mechanical and operating aspects

6.0 Choice of pumps and valves
6.1 Slurry preparation, mixing and dewatering
6.2 Pulsation and system control
6.3 Effect of controlled pulsations

Section 7 - Other aspects - corrosion, abrasion, economics

7.0 Feasibility
7.1 Equipment
7.2 pH effects and abrasion
7.3 Costs

Capsule Pipeline Research Center NEWS
COLLEGE OF ENGINEERING UNIVERSITY OF MISSOURI-COLUMBIA VOL. 2 NO. 1, SPRING 199

National Science Foundation praises research center

"Five departments on two campuses actively participate, including both faculty and students..."
— National Science Foundation CPRC review report

Following a thorough site visit of the Capsule Pipeline Research Center in October, a six-member National Science Foundation team issued its findings.

The report states "The quality of the research in this center is very high ... (we) feel that interdisciplinary participation in the center is excellent, better than we anticipated. Five departments on two campuses actively participate, including both faculty and students...(the) students we questioned seemed to recognize the value of this cross pollination, as did the investigators questioned separately."

During the review, the NSF team met with center personnel and the Industrial Advisory Board members to hear progress reports. The team also met with University and college administrators, State Representative and House Budget Chairman Chris Kelly, the assistant director of the State Department of Economic Development, John Johnson and various faculty and students.

In general, the post-review report issued by NSF indicates potential positive impacts of center research efforts on the local economy and an increase in our national competitiveness in a global economy were noted.

NSF recognized the future importance in increasing the number of graduates in fields supporting these technologies. Specifically, a need exists to increase the number of U.S. undergraduates interested in pursuing center-related studies at the graduate level.

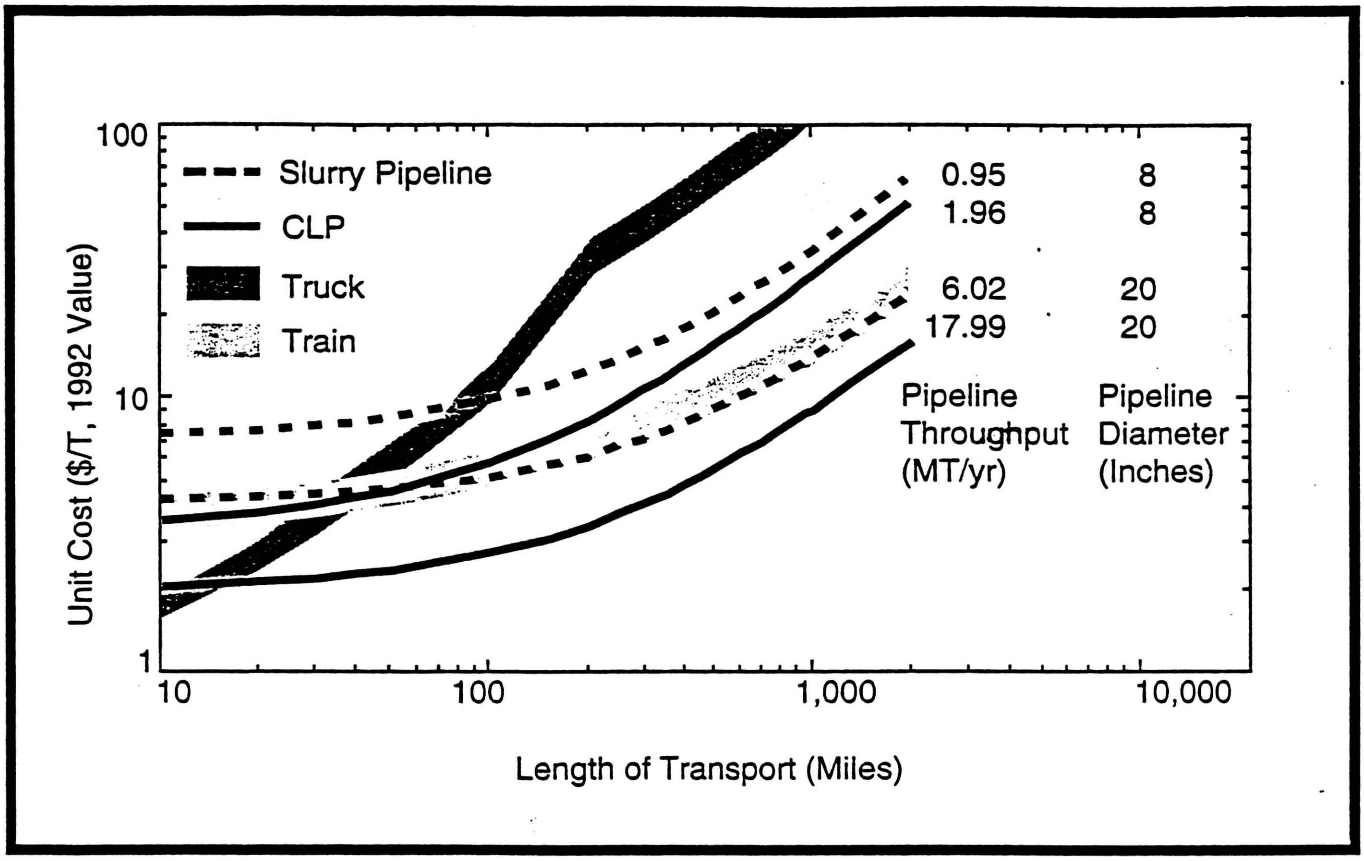
NSF also suggested that center conduct market research and seek international licenses and patents as an income source to further market the coal log pipeline concept. Currently, the center holds a U.S. Patent, "Coal Log Pipeline System and Method of Operation," with rights assigned to the Board of Curators of the University of Missouri.

Department of Energy provides grant support to CLP project

The Pittsburgh Energy Technology Center, U.S. Department of Energy (DOE), has given notice in the Federal Register of plans to provide grant assistance to the Coal Log Pipeline project. DOE comments that "the many potential advantages over truck and railroad transportation include: lower freight costs, less energy consumption, less pollution, decreased environmental problems, increased safety, and improved reliability."

Coal transportation is a major cost factor utilities face in determining feasible coal sources. The CLP will provide a means to significantly reduce this transportation cost and increase the coal use in the nation.

The three-year grant totals $208,000. It will supplement NSF-University-Industrial Consortium efforts of preparing the coal log pipeline system for commercial use. The DOE has previously provided grant assistance to CLP preliminary research efforts. The DOE's involvement in the CLP project is "to make the United States the World's leader in the capsule pipeline technology."



CLP economic and "end-of-pipeline" studies completed

A comprehensive study of the economics of coal log pipeline is complete. Results are in a two-volume report titled: *Economic Analysis of Coal Log Pipeline Transportation of Coal*, dated January 1993.

Thirty-two detailed scenarios depicting a wide variety of possible commercial applications are included in the report. Compared to other modes of coal transport (truck, rail and slurry pipeline), CLP transport is cost competitive in many situations. As expected, longer distances and larger throughputs of coal reduce the freight rate of the CLP in all cases.

The report reveals areas where significant cost savings can be achieved and where research should be directed or re-directed to further reduce anticipated operational and capital costs. By providing cost estimates for different aspects of a commercialized CLP, the report is a "blueprint" for future applications of coal log pipelines.

The report reveals where cost savings can be achieved and where research should be directed to reduce costs.

In 1992, the Electric Power Research Institute (EPRI) sponsored a research project at the University to determine the costs and the requirements of handling coal logs and treating CLP effluent water at power plants. This so-called "end-of-pipeline" study was completed in January. **Thomas Marrero**, CPRC associate director and **John Wilson**, chairman, University of Missouri-Rolla mining engineering, were co-principal investigators. Conservative estimates show end-of-pipeline system costs were below 50¢ per ton.

Laboratory tests and economic analyses were both included in the end-of-pipeline study. Coal logs were extruded using bituminous, sub-bituminous and lignite coal. The laboratory tests included coal characterization, coal log pulverization, and analyses of pipeline effluent water quality.

Center proposes using decommissioned pipeline

This pilot-plant study, planned for 1994, is a necessary step toward commercializing Coal log pipeline technology.

The center is planning to pursue a field test program and a commercial demonstration project as part of the CLP technology commercialization plan.

Using a decommissioned existing underground pipeline, the field test pilot-plant study is planned for 1994. Owned by the Williams Pipe Line Co., based in Tulsa, Okla., this 8-inch diameter dual line runs from Tulsa to Kansas City. Only about a 10-mile reach of the pipe near Kansas City is needed for the test. The plan calls for recirculating coal logs through the dual pipeline to test the strength of the logs in resisting wear through the pipe, the injection and pumping of the logs, and the control mechanism. This pilot-plant study is a necessary step toward commercializing CLP technology.

The center also is investigating potential sites offered by MAPCO (Mid-America Pipeline Company) for a full-scale demonstration project involving the construction of a less-than 50-mile long pipe for transporting coal logs from a coal mine to either a barge terminal or a power plant. Such a demonstration project can be pursued only after successful completion of the pilot plant study. The center's involvement in the demonstration project will be advisory in nature, providing needed expertise to plan and design the pipeline.

The project sponsor will be one or more private companies. They may submit a proposal to the U.S. Department of Energy to seek government assistance under the Clean Coal Technology Demonstration Program.

Breakthroughs in binderless coal logs

Significant research breakthroughs in coal log fabrication have been individually reported by professors **Brett Gunnink** and **Yuyi Lin**. Each professor has been directing research to produce a durable coal log that will absorb little water and retain strength under high-pressure immersion, while surviving a standard coal log wear test.

Gunnink, an assistant professor of civil engineering, has been pursuing binderless compaction for some time and has succesfully developed a special technique to make strong binderless logs. When immersed in pressurized water, these logs retain sufficient strength to pass an accelerated coal log degradation test.

Taking another direction, Lin, an assistant professor of mechanical & aerospace engineering, is studying binderless extrusion. His group has succeeded in extruding coal logs that do not expand significantly and retain much of their strength, even 500 psi of water pressure for more than six days. This is a major step forward from previous research that required a minimum of 4% binder.

Both professors are accelerating their research and refining their coal log fabrication techniques to meet or exceed current coal log wear criteria.

Canadian expert center's first visiting professor

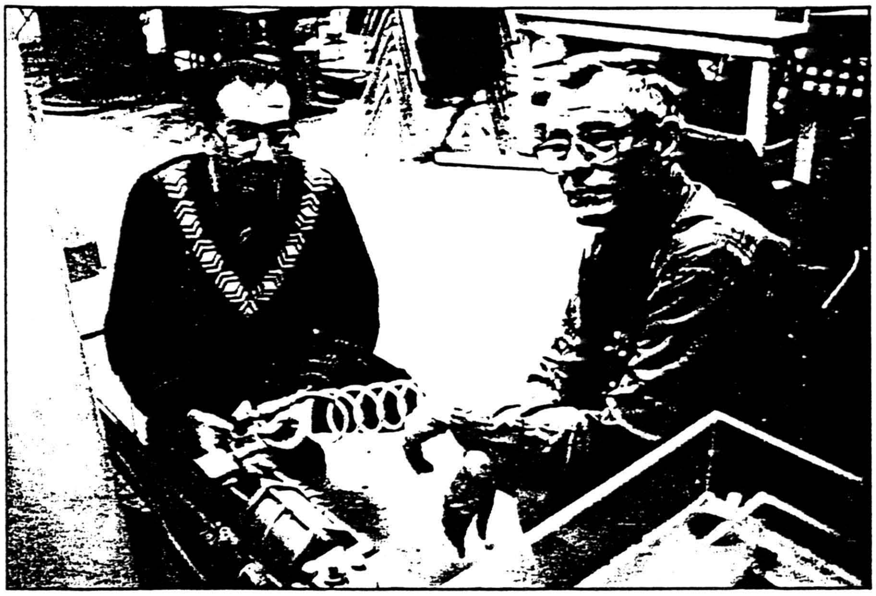
George F. Round, internationally renowned for work in pipeline transport of solids, is a visiting professor in the MU Department of Civil Engineering and the Capsule Pipeline Research Center until the end of May. His duties include instructing a graduate-level course titled Pipeline Flow of Slurries and Suspensions, giving seminars, and helping students with their pipeline-related research.

Round is professor of mechanical engineering at McMaster University in Canada. He has extensive international consulting experience and has published 75 papers and three books. Round also is involved in theater and has acted and directed award-winning productions. He is artistic director of Heritage Theater in Ontario, Canada.

Center director receives awards

In September 1992, the American Society of Civil Engineers (ASCE) awarded CPRC Director **Henry Liu** the Bechtel Pipeline Engineering Award in New York City. Also, the MU College of Engineering, presented the Burns & McDonnell Foundation Outstanding Research Award to Liu in March 1992.

Two new test loops completed



Two tests loops have been constructed for research aimed at the study of unsteady capsule flow and slurry effects on coal logs. **Charles Lenau,** *(top photo, right)* professor of civil engineering, with the help of doctoral candidate M. El-Bayya, *(top photo, left)* has developed a way to analyze unsteady flow generated by the operation of coal log pipelines. The experimental setup permits testing and refining of the theoretical model to predict unsteady capsule flow characteristics.

James Seaba, *(bottom photo, right)* assistant professor of mechanical & aerospace engineering, is searching for a way to use coal slurry as the transporting medium in coal log pipeline transportation. The pressure drop across a coal log train transported by water and various coal slurry mix ratios will be compared. The same test loop will be used to investigate the erosion of coal logs in a pipe, both by water and a water-coal mixture.

Expand your freight pipeline knowledge

The 1993 edition of the Encyclopaedia Britannica features a detailed discussion of freight pipelines authored by Center Director **Henry Liu.** The 3,000-word article discusses various types of pipelines including liquid pipelines, gas pipelines, slurry pipelines, pneumatic pipeline transportation of solids and capsule pipelines. The article treats the history, state-of-the-art, and current developments in pipelines. The environmental and safety benefits of pipelines as a freight transport mode also is discussed.

More information is made available on freight pipelines by Liu in the upcoming 1994 McGraw-Hill Yearbook of Science & Technology. This is the first time freight pipelines are included as a special topic in an encyclopedia.

Editorial

Environmental aspects of coal log pipelines

Air, water, and soil have gained a rightful prominence in today's discussions about technology and its impact on our lives and future well being. A major concern of many Americans is how to strike a balance between competing in a global economy while minimizing technology's impact on air, water and the ecosystem.

Coal log pipelines have strong environmental benefits. By using CLP to replace some of the coal transported by trucks and trains, there will be fewer heavy trucks on highways and streets and less frequent passing of freight trains through cities and rail crossings. This will result in fewer people killed each year (see accompanying graph), reduced air and noise pollution generated by trucks and trains, reduced use of imported oil, reduced traffic congestion on highways and streets, and reduced damage to highway and rail infrastructures.

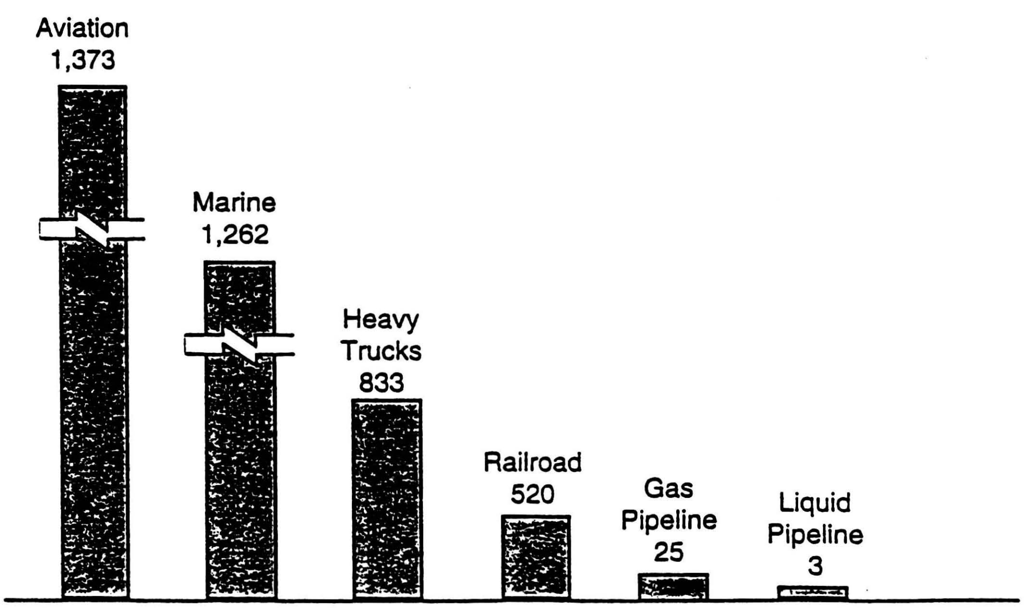
Some individuals worry about the water for CLP, and possible water pollution problems. The worry is unwarranted. The water used by a CLP is minimal. In any such pipeline, two-thirds of the total weight transported is coal; less than one-third is water. The water needed can come from either traditional sources such as surface or ground water, or desalinated brackish water in states such as Wyoming, Colorado, Utah and Montana where a water shortage exists. These states have large quantities of brackish water unfit for ordinary purposes such as drinking or irrigation. Sometimes, the brackish water even causes pollution to streams such as the Colorado River. With modern desalination technology, the cost for converting a ton of brackish water to fresh water is only about 65¢. This means it takes only about 20¢ to desalt enough brackish water to transport a ton of coal via CLP.

At the end of the pipeline, the utility will receive two products, coal and water. The water received from a CLP is usually much less than that required for operating a conventional coal-fired power plant. Therefore, all of the water transported by CLP will be used at the power plant; none will be wasted or discharged. The water must be treated before it can be used as make-up water for producing steam or other power plant purposes. This means CLP causes zero discharge and no pollution to air, water or soil.

Transportation Safety Comparison

Average yearly fatalities for selected modes of transportation in the United States.

Source: Statistical Abstract of the United States, Department of Commerce (1980-89 data)



Scholars go Down Under for international symposium

The 7th International Symposium on Freight Pipelines, a conference of the International Freight Pipeline Society, was held in Wollongong, Australia, July 6-8, 1992. The U.S. National Science Foundation supported a delegation of six U.S. university scholars, five of whom are associated with the CPRC.

Attendees from MU were: **Henry Liu, Thomas Marrero, Charles Lenau** and **Peter Davis.** From UMR, **John Wilson.** At the Australian symposium, papers related to freight pipeline transport were presented and published in the Preprints of Papers. Approximately 200 researchers attended from around the world.

Proposed test program needs industrial support

The center is launching a campaign to recruit more industry members to support the full-scale test program planned. At present, the center is supported by the CLP Consortium that consists of three electric utilities, three pipeline companies and two coal companies. Special patent privileges are provided to CLP Consortium members. Companies interested in joining should contact: **Thomas R. Marrero, CPRC associate director, (314) 882-3802.**

FOR INFORMATION about the Capsule Pipeline Research Center at MU, write or call Henry Liu, director, at the address below. *Capsule Pipeline Research Center News* is published twice a year by the CPRC. Please send address corrections or deletions to the same address.

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