# CAPSULE PIPELINE RESEARCH CENTER

UNIVERSITY OF MISSOURI-COLUMBIA

**NSF State/Industry University Cooperative Research Center**

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**3-Year Progress Report**

Period Covered: September 1, 1993 - August 31, 1994

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April 1, 1994

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I certify to the best of my knowledge that:

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(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this application.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a offense (U.S.Code, Title 18, Section 1001).

| Name (Typed) | Signature | Date |
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| PI/PD Henry Liu | Henry Liu | 4/7/94 |
| Co-PI/PD Thomas R. Marrero | Thomas R. Marrero | April 7, 1994 |
| Co-PI/PD Brett Gunnink | [signature] | 4/7/94 |
| Co-PI/PD James Seaba | James P. Seaba | 4/7/94 |
| Co-PI/PD Shankha Banerji | [signature] | 4/7/94 |

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## ABSTRACT

The Capsule Pipeline Research Center is devoted to performing research in capsule pipelines so that this emerging technology can be developed for early use to transport solids including coal, grain, other agricultural products, solid wastes, etc.

The mission of the first four years (1991-95) is to focus on the coal log pipeline (CLP) technology for transporting coal. In the subsequent four years (1995-99), the Center will gradually transform its mission to cover other types of capsule pipelines, both hydraulic and pneumatic, for transporting other types of cargoes.

Areas of research covered by Core Program of the first three years include hydrodynamics of capsule flow, manufacturing of coal logs, automatic control of coal log pipeline, and legal research in coal pipelines. The Non-Core Program sponsored by the U.S. Department of Energy and the Electric Power Research Institute explored the economics and commercialization of CLP, and how to handle coal logs and treat CLP effluent at power plants. A total of 13 faculty members and 56 students from both the Columbia Campus and the Rolla Campus have participated in the research.

Important research findings and accomplishments during the first-three years include: success in making durable binderless coal logs by compaction, success in underwater extrusion of binderless coal logs, success in compacting and extruding coal logs with less than 3% hydrophobic binder at room temperature, 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, demonstrated the effectiveness of using polymer for drag reduction in CLP, demonstrated the influence of zeta potential on coal log fabrication, improved understanding of the water absorption properties of coal logs, better understanding of the mechanism of coal log abrasion (wear), completed a detailed economic evaluation of the CLP technology and compared coal transportation cost by CLP to that by rail, truck and slurry pipelines, and completion of several areas of legal research.

The Center also conducted important technology transfer activities including workshops, work sessions, company seminars, involvement of companies in CLP research, issuance of newsletters, completion of a video tape on CLP, and presentation of research findings at numerous national and international meetings.

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## TABLES

# 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. During the fourth year (starting 9/1/94), grain companies, solid waste shippers, 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. This is so because CLP is economical both for long-distance and relatively short-distance transportation of coal. The CLP technology has enormous economic value to the state, the region, and the nation.

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 and HCP in the U.S. will reduce coal and grain transportation costs, making U.S. coal and grain more economically competitive in the world market.

**B. Accomplishments and Plans**

Major accomplishments during the first 2 1/2 years include: success in developing a hot-water compaction process that makes durable binderless coal logs; initial success in underwater extrusion of binderless coal logs at room temperature; success in making durable coal logs at room temperature by using no more than 3% hydrophobic binder; demonstrated the effectiveness of making better logs by neutralizing the zeta potential; demonstrated a sharp reduction in energy loss (drag reduction) in CLP by using a polymer; clarified the coal log abrasion (wear) mechanism in pipe; designed a coal log compaction machine for fast production of coal logs; completed 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 and unsteady motions; improved the capsule injection and pump-bypass schemes; completed an economic study of coal log pipeline transportation of coal; completed an end-of-pipeline study; explored slurry transport of coal logs; and developed theories for coal log compaction and water absorption.

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

Technology transfer activities include: company seminars, workshops, work sessions, preparation of manual of practice of CLP, completion of a high-quality video tape on CLP and distribution of 50 copies of the tape, publication of newsletters (distributed over 1,500 copies), publication of a Center program brochure (distributed 2,000 copies), publication/presentation of papers at national and international conferences and journals, and receiving coverage from national media and the 1993 Encyclopedia Britannica.

The plan for the next 1 1/2 years is to complete all projects initiated in the last 2 1/2 years, and to start making and testing large (5.3-inch and 7.5 inch) coal logs based on knowledge gained from our current small-scale testing, testing large logs in a pipe loop and a commercial pipeline in Kansas, and selection of a promising site for commercial demonstration of CLP. The plan for the second 4 years (1995-1999) is to study capsule pipeline technology for transporting grain, solid wastes and other products.

## 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 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 between 100 and 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 the 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 the Center 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. Thus, the potential economic value of coal log pipelines to Missouri and neighboring states is enormous.

Furthermore, once the 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.

The development of the capsule pipeline technology for transporting grain and other agricultural products, solid wastes and so forth during the second four years of the Center will have even a greater positive impact on the state's economy. For instance, Missouri is located in the nation's grain belt. Not only must Missouri's grain be shipped to its markets, large quantities of grain produced in neighboring states also pass through Missouri to reach their destinations. For years, transportation of grain has been a serious problem for farmers. Midwestern farmers have been longing for grain pipelines to serve their needs--see newsclippings on grain pipelines included in Appendix 2. The development of the HCP technology for transporting grain will greatly benefit farmers in the grain belt, especially in Missouri if the State becomes the nation's leader in grain pipeline technology.

Missouri and other states have increasing problems with solid waste transport--both municipal waste and hazardous waste. Based on a study conducted by the Stanford Research Institute (Ref.1)*, capsule pipeline is the most promising way for transporting municipal solid waste from waste processing plants to incinerators or power plants for combustion. Large cities in Missouri, such as St. Louis and Kansas City, will especially benefit from such pipelines. Furthermore, due to the development of such a new pipeline technology in

* References are listed in Appendix 3.

Missouri, it is reasonable to expect that a solid waste pipeline industry will be created in Missouri, to serve not only Missouri but other states. That will again generate jobs in the State, and contribute to the State's economic well-being.

Missouri and many other states also have an acute problem with transportation of hazardous wastes, especially nuclear wastes. Due to fear of spilling hazardous wastes during transportation by surface modes such as rail, truck and barge, many communities do not allow hazardous wastes be transported across their boundaries. The use of underground pipelines to transport such wastes will greatly reduce the chance of spill, thereby making transportation of hazardous wastes more acceptable to the public. Again, Missouri will benefit greatly because considerable amount of both high radio-active and low radio-active wastes are generated in the State. Also, any new industry developed in Missouri in this area will create jobs and economic opportunity for the State.

Finally, although most of the economic benefits to Missouri and the nation produced by the Center's R&D program are long-term in nature, there are also some immediate or short-term benefits. For instance, the Center has submitted a proposal to the U.S. Department of Energy to construct a full-scale coal log pipeline facility in Thomas Hill, Missouri--see Appendix 2. The cost of this facility is estimated to exceed ten million dollars. This pipeline in Thomas Hill will generate jobs and boost local economy both during and after construction. Because Thomas Hill's economy was hurt recently by the discontinuance of coal mining in that area, the pipeline project will be welcomed by the local residents and the State government. Likewise, the City of Columbia will gain some jobs and visitors each year as the Center's business expands. Due to the participation of a large number of faculty and students in the Center's research, huge educational benefits also result to the University and the State. These benefits are growing as the Center's activities and budget expand.

The strategy used by the Center to develop the State's economy is to get more and more Missouri companies involved in the Center's activities. This can be seen from the growing number of Missouri companies participating in the Center's program--see Table 4 on page 21. These companies, plus selected companies from out-of-state, will form the backbone of the nation's freight pipeline industry in the 21st Century. To insure that such an industry will be generated in the future, the Center will, during its second four years of operation, carry out a plan to incorporate a Capsule Pipeline Company (CPC) entirely owned by private industries--see section entitled "COMMERCIALIZATION PLAN." The most likely location of this new company will be in Missouri. Most recently, the Associated Industries of Missouri has contacted and offered to help the Center. It has given free advertisement to the Center in its official publication--see article in Appendix 2. The State sponsor of the Center--the Missouri Department of Economic Development--will also help the Center in reaching more companies and organizations in Missouri interested in the Center's work.

# RESEARCH PROGRAM

## A. Plan

The Center's research program is planned to accomplish the stated goal which, for the first four years, is to complete the development of the CLP (Coal Log Pipeline) technology for commercial use. To attain this goal in four years, and with the Center being the only institute in the nation engaged in CLP and HCP (Hydraulic Capsule Pipeline) 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. Even greater interdisciplinary involvement is required for the second four years of the Center's research in HCP and PCP (Pneumatic Capsule Pipeline) for transporting grain, solid wastes, and other freight.

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, the Sponsors, 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. As an example of the careful planning, a document entitled "Coal Log Pipeline Research & Development: Planning for the Next 20 Months (1/1/94-8/31/95)" is included in Appendix 5.

## B. Research Thrusts (1st 4 Years)

### B.1. Core Program:

The research under the Center's Core Program for the first 4 years can be classified into seven broad areas **(thrusts)** as follows:

#### 1. Hydrodynamics of CLP

The hydrodynamics of CLP must be clearly understood before one can design an appropriate CLP system and expect to operate it without difficulties. Prior to the establishment of the Center, many areas of the hydrodynamics of CLP were 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 (wear) of coal logs in pipeline, capsule jamming, capsule pumping and injection, effect of drag-reducing additive on the pressure drop of CLP and HCP, and so forth. Research conducted by the Center in the last 2 1/2 years was focused in these areas. It has greatly enhanced the knowledge and state-of-the-art in these previously poorly understood subjects. This research is led by Dr. Henry Liu, Professor of Civil Engineering, who is an expert in hydrodynamics. Two other faculty members involved in this research are Dr. Charles W. Lenau, Professor of Civil Engineering, and Dr. James Seaba, Assistant Professor of Mechanical & Aerospace Engineering.

Major accomplishments in the hydrodynamic research in the past 2 1/2 years include the following:

**(a) Theory for Predicting HCP Flow Behavior:**
Based on the concept that there are four distinctly different regimes of HCP flow, equations have been derived for each regime to predict the hydrodynamic behavior of HCP flow. The theory can accurately predict the capsule pressure gradient, capsule velocity, capsule drag and lift, capsule incipient velocity and capsule lift-off velocity (Ref. 2 & 3). Future research in this area will focus on predicting capsule train behavior, and the behavior of capsules (or logs) in bends and slopes.

**(b) Coal Slurry Suspension and Transport of Coal Logs:**
A study was completed to test the effect of coal slurry suspension of coal logs. The study found that the pressure drop (headloss) of the two-phase flow of coal logs in slurry is almost identical to that of slurry flow alone. Other interesting features of this type of flow were also found (Ref. 4 & 5). The coal-log/slurry flow was found to have some special advantages such as it transports more coal and uses less water than either the coal slurry pipeline or the ordinary coal log pipeline. Furthermore, the slurry provides larger buoyancy than water to suspend coal logs, and this lowers the lift-off velocity and reduces contacts between the logs and the pipe. It is a technology that may play a role in future transportation of large-diameter, heavy coal logs over long distances. Dr. James Seaba was involved in this research.

The Center has been advised by its Industry Advisory Board not to continue this research under the Core Program. However, a proposal has been submitted by Dr. Seaba to the U.S. Department of Energy (Pittsburgh Energy Technology Center) to sponsor additional research in this area. If the proposal is successful, the research will be carried out as a non-Core Project.

**(c) Drag Reduction in Coal Log Flow:**
A study has been completed on the effect of a conventional drag-reducing polymer (polyethelene oxide) on the headloss (energy consumption) of HCP and CLP. It was found that at polymer weight concentration of 25 ppm (parts per million), the polymer can produce as much as 75% drag reduction which is equivalent to 400% (four times) reduction in the pressure gradient or energy consumption (Ref. 6). This fact, never realized before for capsule pipelines, has great implications to future operation of CLP and HCP systems. It makes long-distance transportation of coal logs and capsules far more economical than realized before. The rate of degradation of polymer in capsule flow was found to be similar to those encountered in ordinary liquid flow. Such degradation can be minimized by injecting polymers downstream of each pumping station, as practiced in ordinary pipelines, such as the Trans-Alaska Pipeline.

**(d) Coal Log Damage and Jamming in Pipe:**
Research has been conducted to study different ways that coal logs are damaged in pipelines, and different ways that coal logs may jam in a pipe. The research, as yet incomplete at this time, has already led to a good understanding of the different wear and jam mechanisms and causes, and effective strategies to control damage (wear) and to prevent jamming (Ref. 7).

**2. Unsteady and Transient Flow in CLP**

The operation of CLP requires periodic closing and opening of valves, and startup and shutdown of pumps. Such unsteady operations generate 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. As a result of this research, a technique (including equations and computer programs) has been developed that can analyze the behavior of coal logs and the pressure waves in a coal log pipeline under various operational conditions such as capsule injection, pump startup, shutdown, and valve switching at both the intake and at pump bypasses (booster stations) (Ref. 8 & 9). The accuracy of the theory has been validated by experiments (Ref.10). The technique and analyses enables us to improve and optimize CLP system design and operations. Dr. Charles Lenau, Professor of Civil Engineering and an expert in hydraulic transients, has been heading this research. Future research in this area includes further improvement of the accuracy of the theory by improving the way headloss and contact friction are predicted, and application of the theory to investigate various scenarios of pump startup and shutdown.

**3. Coal Log Manufacturing**

Several promising ways to fabricate good coal logs have been investigated. These include binderless underwater extrusion, hot-water compaction of binderless, high-strength coal logs, and making hydrophobic coal logs. Six faculty members (Butler, Gunnink, Lin, Luecke, Marrero, Wilson), one post-doctoral fellow (Ding), one research associate (Burkett) and more than ten students worked in this area during the last 2 1/2 years.

This area has been given the greatest emphasis due to its practical importance and insufficient previous knowledge and know-how in making good, economical coal logs. As a result of this intensive effort, Gunnink's group in Civil Engineering has succeeded in developing a hot-water drying process to produce binderless logs that maintain strength in high-pressure water and that have passed an abrasion resistance test (Ref.11 & 12). Lin's group in Mechanical Engineering was able to extrude binderless logs that retain strength in high-pressure water (Ref.13 & 14). Marrero/Burkett's group in Chemical Engineering has succeeded in extruding good logs using a large ram-extruder installed in 1993 (Ref.15). And, Wilson/Ding's group (UMR Mining Engineering) has succeeded in making water-resistant, durable coal logs at low (less than 80°C) temperature with no more than 3% emulsified asphalt or Orimulsion--a low-cost substitute for emulsified asphalt (Ref.16). A theory has also been proposed with equations derived to predict the behavior of compaction of coal logs in a cylindrical mold (Ref.17). The plan for the next 1 1/2 years is to make large (5.3-inch and

7.5-inch) logs and test them in 6" and 8" diameter pipelines, to check the validity of the proposed theory on mold compaction, and to investigate the effect of vacuum to facilitate coal log manufacturing.

### 4. Coal Log Surface Treatment

The high-strength coal 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 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 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, gain weight, lose strength, and break up in pipe. Success in surface treatment research will not only result in a lighter log, it will also be possible to transport logs through pipe while keeping the logs dry. Such sealed dry logs would have high heating values, consume less water for transport, and eliminate the need for dewatering coal logs at power plants. This describes why surface treatment was studied.

Three methods of surface treatment were investigated: using coal/water slurry to seal the surface pores of dry logs (Ref.18), impregnating coal log surface with an impermeable material such as wax or asphalt (Ref.19), and heat treatment of coal log surface (Ref.20). Both the heat treatment and coal/water slurry treatment studies did not result in a practical method to treat dry logs. Some degree of success was experienced by using molten asphalt and coal/asphalt slurry to impregnate the logs (Ref.18 & 19).

This study was first directed by Dr. Marrero and later by Dr. Luecke (both in Chemical Engineering), with the help of four graduate students and three undergraduates. Due to industry member's questioning of the practicality of this research, and the fact that initial application of CLP can proceed without using dry logs, this research will be terminated in summer 1994, when the two M.S. students working on this research will have completed their thesis and degree requirements. The knowledge created from this research will be of value to future researchers who wish to pursue further research in this area.

### 5. Coal Log Machine Design

Conventional briquetting and extrusion machines cannot make coal logs fast enough for commercial CLP transportation of coal. It is important that a special machine be designed to make good logs at a fast rate so that the number of machines required to supply a single pipeline can be reduced to a minimum. Dr. Yuyi Lin, Assistant Professor of Mechanical and Aerospace Engineering, with the help of two students, has been working in this area for 1 1/2 years. The machine design has been focused on a special compaction machine. An improved design has been completed (Ref.21). Crucial components of the design are being tested in the laboratory. Note that meaningful machine design depends on a good understanding of the coal log manufacturing process. Therefore, the machine design work must follow, not precede, coal log manufacturing studies. Whenever there is a new manufacturing process developed or a breakthrough, the machine design must be altered. This explains why the machine design work did not start until 1 1/2 years ago.

The plan for the next 1 1/2 years 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 1 1/2 years.

## 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 special 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. Some 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 have been working closely together in their research. Dr. Satish Nair, Assistant Professor of Mechanical and Aerospace Engineering (MAE), is the leader of the automatic control research area. Dr. Nair is also the director of the Automatic Control Lab of the MAE Department.

Major accomplishments in this area of research during the last 2 1/2 years include the completion of two reports on automatic control of CLP (Ref.22 & 23), and the construction of a computer-controlled, automated CLP system in the laboratory which has proven to work very well.

Future work in this area will focus on developing a coal-log-train separator to facilitate the control of CLP pump bypass, assessing sensor need for CLP operation, and the design of a control system for a full-scale commercial CLP system.

## 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 2 1/2 years (Ref. 24), 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 1 1/2 years 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. Dr. Davis will also prepare a few model legislations, such as a model state law for eminent domain on coal pipelines, for use in states which do not have such laws, such as Missouri.

**B.2. Non-Core Program**

**1. 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 et al. in 1993 (Ref. 25), 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 in many situations. Based on this finding, the coal log manufacturing research was adjusted to making logs with less than 3% binder, or better yet without any binder--the binderless process. Also, a low-cost binding (Orimulsion) was identified as a substitute for asphalt emulsion.

The completion of the 1993 economic report does not mark the end of the need for further economic study. As the technology of CLP is rapidly advancing, revision of the report is needed on a frequent basis. Also, new problems were discovered, such as how to best determine future rail tariff increase. A study will also be conducted to compare the UMC cost model (based on a methodology used by the Office of Technology Assessment, U.S. Congress) to pipeline industry and EPRI (Electric Power Research Institute) models. These issues are being studied by Robert Zuniga as parts of his M.S. thesis, under the direction of Dr. Jim Noble of the Industrial Engineering Department. This study was first supported by a grant from the DOE Energy Related Invention Program until July 1992. Now it is supported by a grant from DOE Pittsburgh Energy Technology Center, considered as a Non-Core project.

**2. End-of-Pipeline Study**

At the power plant end of a CLP, how should coal logs be handled (i.e., dewatered, dried, crushed, stored and transported within the power plant), and how should the effluent water be treated before it is discharged into natural streams or reused at the power plant, are matters of strong interest to utility companies. 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 (Ref. 26), and key findings of this study were published and reported at several technical conferences (Ref.27-29). Dr. John Wilson and Dr. Thomas Marrero were co-directors of this project. Additional research to determine how to best treat the effluent water from coal log pipeline is needed. This will be done by two Environmental Engineering students who are currently supported by the Patricia Robert Harris Fellowship, U.S. Department of Education.

**C. Research Projects (1st 4 Years)**

Depending on the complexity of the tasks involved, each research thrust area described above 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 research assistant. Some projects may 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.

## Table 1. Center Projects During First 3 Years (1991-94)

| P.I. | Project Title | Purpose |
|---|---|---|
| Butler | Vacuum Effect on Coal Log Fabrication | To explore the effectiveness of using vacuum to enhance coal log fabrication. |
| 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. |
| Gunnink | Compaction of Binderless Coal Logs | To explore and optimize compaction technique for making binderless coal logs. |
| 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. |
| Lin | Machine Design for Coal Log Fabrication | To design coal log fabrication machines for commercial use. |
| Lin | Underwater Extrusion of Coal Logs | To explore the feasibility of underwater extrusion of coal logs. |
| 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, water absorption of coal logs, etc. |
| Liu/Seaba | Drag Reduction in CLP and HCP | To test the effectiveness of using various drag reducing additives to reduce energy consumption in CLP. |
| Liu/Gunnink | Zeta Potential Effect on Coal Log Fabrication | To test the effectiveness of altering zeta potential to strengthen coal logs. |
| Liu/Noble | Economics of CLP | To study the economics of CLP as compared to other modes of coal transportation. |
| Luecke/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. |
| Marrero | Extrusion of Coal Logs | To explore effective ways of making coal logs by extrusion. |

## Table 1. (Continued)

| | | |
|---|---|---|
| Marrero | Heating, Cooling & Drying of Coal Logs | To find ways to predict the heating, cooling and drying rates of coal logs. |
| Nair | Automatic Control of CLP | To study and design the automatic control systems needed for reliable operation of CLP systems. |
| Seaba | Slurry Transport of Coal Logs | To test coal log transport in a slurry medium in order to determine the feasibility and advantage of such a system. |
| Seaba | Coal Log Jam Prevention | To explore the various mechanisms of coal log jamming in pipe and how to prevent jamming. |
| Wilson/Marrero | End-of-Pipeline Study of CLP | To explore the handling of coal logs and treatment. |
| Wilson | Hydrophobic Coal Log Fabrication | To explore the use of special hydrophobic binders to make coal logs. |

**D. Rationale for Non-Core Program (1st 4 Years)**

The Non-Core research projects are closely tied to the Core program, and in certain cases, they coincide with the goal and tasks of the Core program. They provide additional support to 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, the State of Missouri Department of Economic Development and industry (the CLP Consortium), the Non-Core projects are short-term grants or contracts of lesser amounts than each Core contribution. Nonetheless, they are as valuable as Core program on a per-dollar basis.

Two Non-Core projects completed during the 2 1/2 years of 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 economics and commercialization of CLP, and an 8-month contract from the Electric Power Research Institute **(EPRI)** to study handling of coal logs and treatment of effluent at power plants--the so-called **"End-of-Pipeline Study."** They are listed in **Table 2.**

**Table 2. Non-Core Projects during First 3 Years (1991-94)**

| 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 | 8/10/93-8/9/96 | 218,000 |
| Patricia Robert Harris Fellowships | U.S. Department of Education | 1/1/84-12/31/89 | 210,000 |
| | | **Total:** | **$572,077** |

*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 (End-of-Pipeline Study) was to investigate the treatment of coal logs reaching a power plant from a pipeline, including dewatering, crushing, drying, grinding and storage. Also of interest to the project was 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.
A one-page summary on this project published by EPRI is attached to Appendix 2.

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.

A new non-core project funded by DOE Pittsburgh Energy Technology Center started in August 1993. This project provides additional money to study the same areas of the Core Program listed before, plus research in the economics of CLP. Also, in 1993 the Center was awarded by the U.S. Department of Education two 5-year fellowships called the **Patricia Robert Harris (PRH) Fellowships**. The fellowships were awarded to two Civil Engineering students, (Alison Hjelmfelt and Lauren Abbott, both majoring in environmental engineering). They will conduct research on different aspects of the treatment of CLP effluent at power plants. As shown in Table 2, the total funding from non-core projects received in the past 2 1/2 years is $572,077. Other proposals totaling more than one million dollars have also been submitted which may result in additional non-Core projects before the end of the 3rd year--see Table 3.

**Table 3. Pending Proposals of CPRC (Non-Core Projects)**
**(as of 4/1/94)**

| P.I. | Title | Agency | Amount | Date Submitted |
|---|---|---|---|---|
| Gunnink | One-Million Pounds, Servo-Controlled Compression Testing Machine | NSF | $151,667 | 1/27/94 |
| Liu | Two-Phase Flow Through a Porous Coal Log | DOE/PETC | $199,683 | 11/30/93 |
| Liu | Permeability/Porosimeter for Studying Absorption in Coal Logs | DOE/Idaho | $120,000 | 12/3/93 |
| Liu | Pipeline Infrastructure Traineeship | NSF | $537,500 | 3/28/94 |
| Seaba | Slurry Effects on Hydrodynamics of Coal Log Pipeline | DOE/PETC | $139,998 | 11/24/93 |
| | **TOTAL** | | **$1,445,113** | |

## E. New Thrusts for Next 4 Years

As stated in the original proposal to NSF three years ago, the Center plans to broaden its mission in the next four years (1995-99), to cover not only CLP but also other types of capsule pipelines including both PCP (Pneumatic Capsule Pipeline) and HCP (Hydraulic Capsule Pipeline) for transporting grain, solid wastes and many other cargoes. The research thrusts for the next four years starting September 1, 1995 are briefly discussed as follows:

### 1. CLP (Coal Log Pipe) Work

Starting September 1, 1995, the main effort in the Center's CLP work is to assist industry in planning commercial projects of CLP, including site selection, engineering planning, design, and equipment selection. Such activities will be supported by non-Core contracts tied to each project.

Note that even after a new technology is commercialized, there is still a continued need for research to improve the technology and solve unexpected problems that occurred in the commercial use of the new technology. Therefore, during the second four years of the Center, approximately one-third of the Core Program resources will be devoted to additional research in CLP. It will be used to support least explored important areas such as coal log manufacturing and automatic control. The coal log research during this second four years must be more focused than in the first four years.

### 2. Manufacturing of Solid-Waste Logs

Two types of solid wastes will be studied: power-plant ashes (fly ash and bottom ash), and processed refuse.

It is believed that with the use of a small amount of binder such as Portland cement, power-plant ashes can be compacted or extruded into logs in much the same manner coal logs are manufactured. Such ash logs can be transported back to coal mines to fill the pits left from coal mining. This will serve the duel purpose of land restoration and solid-waste disposal. Depending on individual situations, the pipeline that transports ash logs can be either the same pipeline that transports the coal logs, or a separate parallel pipeline dedicated to transporting the ash logs, using the same right-of-way of and constructed together with the coal log pipeline. The research in this area will be focused on manufacturing of ash logs. Dr. Brett Gunnink, who is experienced in coal logs compaction, will direct this research.

As to processed refuse from large cities, the combustible part is often transported by trucks from the central processing plant to an incinerator or a power plant for burning. Instead of using trucks which create traffic and pollution problems, an underground pipeline to transport such refuse will be more desirable. In fact, a study conducted by the Stanford Research Institute (Ref. 1) concluded that the best way to transport such refuse is to compact it into slugs (logs) for pipeline transportation--the same concept as coal log pipeline. Research is needed to determine what is the best way to manufacture refuse logs, and whether binder is needed or not. Due to the existence of thermal plastic materials in such refuse, it is quite possible that by applying some heat, the refuse can be extruded or compacted into logs without having to use any binder. Dr. Shankha Banerji, Professor of Civil Engineering who teaches and conducts research in solid waste handling and treatment, will direct this research.

3. **Capsule Pipeline Transportation of Hazardous Wastes**

A general feasibility study is needed to determine how hazardous wastes, including radioactive wastes, can best be transported by capsule pipelines. The study should consider various alternatives such as using PCP (Pneumatic Capsule Pipeline), HCP (Hydraulic Capsule Pipeline) and HWLP (Hazardous Waste Log Pipeline). At present, highly radioactive wastes are sometimes made into glass logs. It will be of interest to investigate whether the glass logs can be transported in the same manner as coal logs in pipelines without breakage. This feasibility study can be followed by experimental tests of promising methods identified from the feasibility study. Dr. Thomas R. Marrero, Associate Professor of Chemical Engineering, will direct research in this area. He has prior experience in nuclear power plants when he was working for the General Electric Company.

4. **Grain Pipeline**

The economics of grain pipelines in the Grain Belt (i.e., the Midwest) has been demonstrated in a previous study (Ref. 30 & 31). However, research is needed to determine the best (most practical) way of preparing and handling grain capsules, especially in the area of capsule design. This research will be lead by Dr. David Currence, Associate Professor of Agricultural Engineering.

5. **PCP (Pneumatic Capsule Pipeline)**

PCP systems that use wheeled capsules for transporting heavy cargoes have been used in Japan (Ref. 32), and the former Soviet Union (Ref. 33). In the United States, the Tubexpress Systems, Inc. developed a PCP system but was unable to commercialize it. A revolutionized PCP system needs to be developed before the United States can become the world's leader in this technology. This requires research in advanced concepts such as using electromagnetic capsule pumps, an invention by Dr. Henry Liu and his colleagues at the University of Missouri (Ref. 34 & 35). Once such an advanced system has been developed, the United States will then be able to compete with the Japanese on PCP in both U.S. and international markets. Dr. Henry Liu, Professor of Civil Engineering, and Dr. Richard Wallace, Assistant Professor of Electric Engineering, will conduct joint research in this field.

## F. Publications and Intellectual Properties List

During the 2 1/2 years of operation of the Capsule Pipeline Research Center, numerous publications and theses resulted. They are listed in Appendix 4. Many inventions also occurred. However, due to limited budget for patent applications, only two patents have been pursued in the last 2 1/2 years, on inventions judged to have the greatest commercial potential. They are listed below:

(a) "Water-Assisted Binderless Extrusion of Coal Logs,"Yuyi Lin and Henry Liu, invention disclosure submitted in April 1994.

(b) "Compaction of Hot Water Dried Coal Agglomerates," Brett Gunnink, invention disclosure submitted in April 1994.

### Other Invention Disclosures Planned

(a) "Compaction Machine for Coal Log Manufacturing," by Yuyi Lin, Alley Butler, James Ramer and the Gunlach Machine Company.

(b) "Methods for Reducing Wall Friction in Compaction Mold," by Henry Liu, Thomas Marrero, Brett Gunnink, Bill Burkett, Richard Luecke, and Yuyi Lin.

(c) "Coal Log Fabrication Using Emulsified Hydrophobic Binders," by John Wilson and Y.C. Ding.

### Commercial License on CLP

A licensing agreement on U.S. Patent No. 4946317 ("Coal Log Pipeline System and Method of Operation") has been drafted by Connie Armentrout, Coordinator, Office of Patents and Licensing, University of Missouri. The draft has been sent for comment to the six companies that joined the CLP Consortium in 1990 and are still supporting the Center at a minimum of $15,000 per year. The license will be issued to these six companies in September 1994, after each has completed the payment of the 5-Year fees specified in the original contract.

# INDUSTRY COLLABORATION/TECHNOLOGY TRANSFER

## A. Industry Collaboration in Research and Other Activities

There are three types of companies supporting the Capsule Pipeline Research Center: those that provide financial support and/or equipment to the Center, those that provide in-kind contribution (service), and those that contribute both. The in-kind service is usually in the form of providing special service in research, development or technology transfer (R,D&T).

Several industry participants have been involved in the Center's R,D&T. For instance, the Williams Technologies, Inc. (WTI) helped the Center in 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. WTI also helped to develop the Center's R&D plans and provided advice on several technical areas, such as pump and valve requirements. 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 also ground coal for the Center, and participated in coal log machine design. Other companies participating in machine design include the Erie Press, the Pro-Mark Company, and the Ramer and Associates. Macrotech Inc. in Paris, Tennessee, was involved in extruding hydrophobic coal logs for Dr. Wilson's study; and Nova Tech, Inc., Kansas City, has been involved in Dr. Nair's research in automatic control systems.

An important activity by Pipeline companies involves the planning and site selection for testing coal logs in an existing commercial pipeline. First, the Williams Pipeline company offered to let the Center use a 5-mile reach of an abandoned pipeline south of Kansas City for coal log testing. The Company provided valuable data on this line and cooperated and assisted in a site visit. Unfortunately, the outcome of the investigation indicated that this pipeline was unsuitable for the test. Then, the Mid-America Pipeline Company (MAPCO) stepped in and offered to use a 4-mile pipe it has in Conway, Kansas for the test. Following a site visit, it was determined that this pipeline is suitable for the test. Preparation is underway to test coal logs in this pipe in the Summer of 1994. The MAPCO company will be closely involved in the test.

Furthermore, three work sessions were held in 1994 on three different topics involving different companies. Each work session was a one-day meeting (discussion and brain-storming) with one or more companies on a given subject of coal log pipeline. The first work session was on coal log pipeline economic analysis and hydraulics, participated by the Williams Pipe Line Company, and the Williams Technologies, Inc. The second work session was on coal log fabrication machine design, participated by the Gundlach Machine Company, the Erie Press, Inc. and the Ramer and Associates. The third was on automatic control of coal log pipeline, attended by the Nova Tech, Inc. All these work sessions proved to be very productive and beneficial to the Center's mission. Company participants also indicated that the work sessions were productive and useful. The minutes of a work session is attached to Appendix 2.

Note that prior to the establishment of the Center, there was little industry involvement in the R,D&T of CLP. The Center has fostered industry interest in this new technology, as demonstrated by growing industry involvement. The Center encourages industry involvement in its work, especially in areas that companies have interest and expertise. The Center's policy encourages direct contact between faculty researchers in specific areas and companies with expertise in such areas.

**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 the State) on the one hand, and our existing industry sponsors (CLP Consortium Members) on the other. While the government sponsors want the Center to grow and have more and more new members, the general feeling of our 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. Growth also allows bringing in companies with expertise in various areas to help advance the Center's research agenda. Yet, once the Center has reached the level of funding and help needed from companies to accomplish the Center's goal, we should no longer divert our energy and spend our time in fund raising or recruiting. We 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 2 1/2 years. The goal has been to recruit some additional members so that the Center's industry matching fund can reach or exceed $250,000. This will qualify the Center for the highest level of funding that can be matched by the State and NSF. Recruiting was also needed to replace companies which, for whatever reasons, had elected to drop out.

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 Columbia for an on-site visit and meeting. As a result of such efforts, several companies have joined since the formation of the Center in 1991. This includes Erie Press, Nova Tech, Pro-Mark Company, and Gundlach Machine Company. Most recently (March 1994), three additional companies have indicated they will join. They are Wilbros Butler Engineers, T.D. Williamson, Inc., and Burns & McDonnell. The first two are pipeline related companies in Tulsa. Burns & McDonnell is a large consulting firm in Kansas City.

Moreover, the Electric Power Research Institute (EPRI) is also helping the Center to recruit some utility companies to support the Center under a Tailored Collaboration (TC) Program--see letter in Appendix 2. As a result, two workshops were conducted

**Table 4. Industrial Participation (Year 3)**

| Company | Member Category | Years of Part. | Company Size: Sm Bus | Mid-Size | Fort 500 | Joint Research Project | 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 |
| **Burns & McDonnell*** | Principal | 3 | | X | | Yes | 30K |
| Erie Press | Sm. Bus. | | X | | | | |
| Gundlach Machine Co. | Sm. Bus. | 2,3 | X | | | Yes | 5K |
| 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 |
| T. D. Williamson | Sm. Bus. | 3 | X | | | Yes | 5K |
| **Union Electric Co.** | Member | 1,2,3 | | X | | No | 15K |
| Wilbros Butler Eng.* | Member | 3 | | X | | Yes | 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.
3. Asterisk indicates contract signing pending.
4. Names of the seven Missouri companies are boldfaced.

to encourage electric utilities; they were held in St. Louis (August 5, 1993), and Atlanta (December 12, 1993). More will be conducted in the future. As a result of these efforts, it is anticipated that at least one new utility company will join before September 1, 1994. The number of present industry participants of the Capsule Pipeline Research Center is 15--see Table 4. This represents a net increase of 5 members from the first year of the Center.

Recruit for new members must be stepped up during the next year for two reasons: (1) The Center's mission for the second four years will be broadened to cover not only CLP but also other types of capsule pipelines for transporting solid waste, grain, etc. This calls for broader supports for the Center. (2) Both NSF and the State agency supporting the Center want the Center to be self-sufficient (entirely supported by industry and government contracts) by the end of the next four years. This is reflected in the decreasing contribution to budgets by NSF and State for Years 5 through 8--see Budget Details on p. 42.

## 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 and not-yet-commercialized emergency technology, industry is yet unable to use any of the findings of this research (Table 5). However, all the companies involved in the Center's activities plan to use the CLP technology or benefit from it, once it is developed.

## D. Other Technology Transfer Activities

The Center's technology transfer activities of the last 2 1/2 years are summarized in Table 6, and industry-related visits are listed in Appendix 7. In addition to involving companies in research, the technology transfer activities include preparation of design and operation manuals, company seminars, workshops, work sessions, issuance of newsletters (sample included in Appendix 2), production of a video tape on coal log pipelines (50 copies distributed to sponsors and interested parties), and dissemination of information at national and international conferences. Furthermore, the Center exhibited at the Mining Congress in Nevada in October, 1992, and twice at the Annual Coal & Slurry Technology Conference in Clearwater, Florida. Also, during the last 2 1/2 years, the Center published and presented a number of papers as given in the attached Publication List in Appendix 4, and received favorable publicity in national press -- see newspaper article attached in Appendix 2. Finally, an article on freight pipelines written by Dr. Liu was published 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. The 1994 McGraw Yearbook of Technology also discussed capsule pipeline and coal log pipeline. All these accomplishments helped greatly in dissemination of information on coal log pipeline.

**Table 5: 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 andpolymer operations. | -Improved profit margin and quality performance<br>-Market share penetration |
| Texas Instrument | Expert (rule Based) Controller | -AI algorithms & Data structures | -"Smart Controller" capable of controlling 30 loops with adaptive tuning | -Improved market position with new product |
| (THIS TABLE IS <u>NOT</u> APPLICABLE TO THE CENTER AT THIS EARLY STAGE --See Explanation provided in "C" on Page 22) | | | | |
| | | | | |
| | | | | |

# Table 6. Technology Transfer Activities of First 3 Years (1991-94)

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

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

3. Conducted preliminary investigation of two potential sites for field test of coal log pipeline technology (Williams Pipe Line and MAPCO).

4. Visited and interacted with companies for information dissemination and fund raising for the Center (TVA, Western Energy, Associated Electric, Union Electric, Wilbros Butler Engineering, Burns & McDonnell, Arch Mineral, Georgia Power, Southern Company Services, Houston Power & Light, 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 (2,000 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. CLP technology also was featured in the 1994 McGraw-Hill Yearbook of Technology.

13. Send survey forms to utilities to encourage submission of projects for demonstration projects.

14. Conducted three work sessions with companies on special aspects of CLP.

15. Center was featured in the bulletin of the Associated Industries of Missouri which has more than one thousand members.

**E. Industrial Advisory Board (IAB) Activities**

The Center being involved in mission-oriented research relies heavily on the guidance received from its Industry Advisory Board (IAB). The IAB members consist of large and small companies each contributing between $5,000 to $30,000 a year. The Chairman of the IAB is elected by members. The current Chairman is Richard Smith of the Union Electric Company in St. Louis. The Board meets twice a year in Columbia, Missouri. Past meetings were held on the following dates: 5/21/92, 10/8/92, 5/18/93 and 10/5/93. The minutes of the latest Board meeting is attached in Appendix 2.

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 <u>Analyst's Report</u> starting on page 33 addresses the interaction and relation between the Center Director and the IAB.

The Center Director takes advice from the IAB very seriously, and carries the recommendations out as much as practical. For instance, at the most recent meeting (October 5, 1993), the IAB recommended that the Center conducts work sessions, prepare R&D plan with a Gantt chart, and conducts an industry survey to determine the best commercial demonstration project of CLP. The first two recommendations have been carried out, and the third is being implemented. On rare occasions, however, the Director could not and hence did not accept recommendations from the Board. This happened in 1991 when some Board members wanted to restrict membership. It was not only against the self interest of the Center and the University, but also against the Center's federal and State sponsors' wish of broadening industry participation. Then, at the October 8, 1992 Board meeting, the former IAB chair directed the Center Director to use the money to be received from a DOE contract to build a coal log fabrication machine by an outside contractor. The Center Director did not comply because at that time the coal log fabrication process was still ill-defined. To build a machine before the process is defined would be a total waste of money and effort. In both cases, the Director explained his decisions to the former Board Chairman and the Board. It is believed that the vast majority of the Board Members understood the decisions taken by the Director, did not complain, and did not have hard feelings resulting from the decisions.

Participation of IAB meetings is usually very high--80 to 90%. Those members who could not attend usually sent a representative to the meeting.

**F. Other Accomplishments and Contribution to Education**

In addition to the aforementioned accomplishments made in research to advance the state-of-the-art of CLP and HCP, and in technology transfer to disseminate information to industry and the engineering community, in the last 2 1/2 years the Center also accomplished and contributed the following:

**(a) International Exchange**--Dr. George Round, Professor of Mechanical Engineering, McMaster University, Canada, served as Visiting Professor for a Semester (January 1-May 15, 1993). Dr. Round is a renouned expert in slurry and capsule pipeline. During his stay he taught a course "Solids Transport" which benefited many students.

Mr. Yuyi Lin, a Visiting Scholar from the People's Republic of China, has been with the Center since 1992. He has contributed to the study of slurry transport of coal logs, and is currently investigating the zeta potential effect on coal log compaction.

**(b) Student Participants:** During the last 2 1/2 years, a total of 56 students (20 undergraduates, 2 high-school students, and 34 graduate students) were supported by and participated in the Center's research (see Table 7). The two high school students were exceptionally qualified and each worked for one or two summers in the Coal Log Fabrication Laboratory as research interns. One of the two (Clark Darrah who was a straight-A Senior from a local high school) entered the UMC Mechanical and Engineering Department as a result. Eight of the 20 undergraduates later became graduate students at UMC, a much higher percentage than other undergraduates at UMC. Of the 34 graduated students, 14 were able to complete M.S. degree and one completed Ph.D. Two others are expected to receive Ph.D by the end of May 1994. This shows the contribution of the Center to education.

**(c) Faculty Participants:** A total of 13 faculty members (3 in CE, 3 in ChE, 4 in MAE, 1 in IE, 1 in Mining and one in Law) participated in the Center's research, and the Center paid at least part of their salaries, mostly during summer.

**(d) Honors/Awards:** During the last 2 1/2 years, the Center Director received the Bechtel Pipeline Engineering Award from the American Society of Civil Engineers (1992), the Outstanding Faculty Research Award from the Burns & McDonnell Foundation (1992), and the Faculty/Alumni Award from the Alumni Association of UMC (1993).

**(e) Pipeline Courses:** The Center offered two courses in pipelines. One is CE/MAE 345 Pipeline Engineerign (3 credit hours), taught by Dr. Henry Liu, and the other is CE/MAE 401 Solids Transport (3 credit hours), taught by Visiting Professor George F. Round. The syllabi of the two courses are listed in Appendix 2. During this semester (Winter 94), 28 students (both undergraduates and graduates) are taking CE/MAE 345.

**Table 7: Student Research Participants**
**(September 1, 1991 through 3/16/94)**

| Graduate* | Undergraduate* | High School* |
|---|---|---|
| Dave Berg | Lauren Abbott | Clark Darrah |
| Chih-Chiang Cheng | Dwayne Bargfrede | Anne Tillema |
| Feng Chen | Jeff Bennett | |
| Susan Chen | Ivan Bird | |
| Nicole Cress | Daniel Carney | |
| Qingwen Deng | Erika Carter | |
| Yungchin Ding | Gordon Carter | |
| Hengliu Du | Thomas Eckhoff | |
| Majed El-Bayya | James Eichelberger | |
| Randall Harris | Anthony Eves | |
| Xin Huang | Allison Hjelmfelt | |
| Gouping Ji | Michael Holder | |
| Robert Jones | Mark Kersting | |
| Jayanth Kananur | Brent Leonard | |
| Jim Kelly | Becky Clarkson-Smith | |
| Zhuoxiong Liang | Rosa Camp-Soldano | |
| Pamela Luchon | Trent Stober | |
| Sermsak Outangoun | Andrew Rockabrand | |
| Pituk Paksanonda | Hui Zhu | |
| Eileen Petito | Robert Zuniga | |
| Elizabeth Phillips | | |
| Anna Phimjaichon | | |
| James Richards | | |
| Choung-Yaw Shieh | | |
| Pat Sullivan | | |
| Ssu-Hsueh Sun | | |
| De-Xiang Sun | | |
| Jun Jun Tang | | |
| Liqin Wang | | |
| Guoping Wen | | |
| Jianping Wu | | |
| Gang Xu | | |
| Eng-Senog Yap | | |
| Bing Zhao | | |
| | | |
| No. of Students 34 | 20 | 2 |

* Each category counted at the time when the student was first employed by the Center; the student may have moved to a higher category or graduated later.

## COMMERCIALIZATION PLAN

The Center's plan for commercializing the CLP and HCP technologies is a three-prong program consisting of a **commercial demonstration project**, a **full-scale test/demo facility** and the formation of a **Capsule Pipeline Company (CPC)**. They are discussed separately next.

### A. Commercial Demonstration

The Center is in the process of preparing a questionnaire for sending to all the major electric utilities and coal companies in the nation. The purpose of the questionnaire is to determine the most promising site for commercial demonstration of the coal log pipeline (CLP) technology. Each company will be requested to submit one or two potential sites for consideration; a questionnaire must be filled out for each site to be considered. The questionnaire will ask many questions pertaining to the practicability of building a coal log pipeline, such as the quantity (throughput) of coal that needs to be transported, the transportation distance, whether the power plant or coal mine is currently served by railroads or trucks or not, what the current transportation tariff is, etc.

Approximately five projects will be selected for detailed screening and investigation. An engineering consulting firm with extensive experience in planning power-plant projects will be retained to screen and investigate these projects*. Then, the company will rank the five sites in terms of their desirability as a commercial demonstration project. The Center can then negotiate with the companies whose sites have been selected and, based on the negotiation, select a project as the commercial demonstration project. The Center will then assist the company that has been selected and is willing to pay for the project to plan and design the coal log pipeline. The Center will also assist this company (or a consortium interested in the project) to apply for government aid such as provided by the Clean Coal Technology Demonstration Program of the U.S. Department of Energy. Such subsidies will enhance the economic attractiveness of the demonstration project, and reduce the financial risk to private companies participating in the demonstration.

### B. Full-Scale Test/Demo Facility

The Center has contacted the U.S. Department of Energy for the funding of a full-scale test/demo facility consisting of a 12-mile-long, 8-inch-diameter coal log pipeline (CLP). The proposed pipeline will have all the components of a commercial CLP, including a coal log manufacturing plant, a capsule injection system, a capsule ejection system, a booster pump station (the pump bypass), and a computer system for

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* Burns & McDonnell Company in Kansas City, very experienced in power plant siting and screening, has tentatively agreed to help in this endeavor as its $30,000 annual in-kind contribution to the Center. Contract with the Company is pending.

automatic control of the CLP system. The total estimated cost of the project, without counting overhead, is approximately $10 million.

The aforementioned large facility is needed for testing the whole system of CLP at full-scale. The facility makes it possible to obtain test data on important aspects of CLP that cannot be obtained from laboratory test of scale models of the whole system, and from testing large (full-scale) components alone. The facility can be used for testing not only CLP but also other types of HCP (Hydraulic Capsule Pipelines) for transporting solid wastes, grain and other materials or commodities. Once a special type of HCP such as CLP is tested and demonstrated in such a full-scale facility, industry will then be more willing to use or try this technology. This shows that although this is not a commercial demonstration facility, it greatly enhances the likelihood of early commercial use of CLP and HCP.

As indicated in Appendix 2, the Center has proposed to locate this large facility on the inactive coal mines of the Thomas Hill Power Plant in Missouri located 60 miles north of Columbia. The Associate Electric Cooperative, which owns the power plant and the coal mine, is cooperating with the Center in planning this facility.

**C. Capsule Pipeline Company (CPC)**

During the next two years, the Capsule Pipeline Research Center will draw up a business plan (prospectus) for starting a new company--the Capsule Pipeline Company (CPC). This will be a privately owned company with money derived from stocks issued. It is estimated that a minimum of $30 million capital is required to start-up and operate the company for its first three years--the time required for the company to gain sufficient business and become profitable. It is anticipated that the stockholders will be private companies with business tied to the materials transported by CLP and HCP--coal, grain and solid waste, or pipeline and utility companies. Companies that are already supporting the Center will be given first preference to buy the stocks. The establishment of such a company will mark the beginning of a capsule pipeline industry in the United States, and will make the nation the world's leader in this field.

Note that all the three parts of the Center's commercialization plan can be and will be pursued independently and simultaneously. They reinforce rather than duplicate each other. While the success of any one of the three parts (projects) will lead to commercialization of CLP and HCP, having succeeded in more than one projects will speed up the commercialization process. For this reason, all three projects will be vigorously pursued by the Center in the coming years.

## INFRASTRUCTURE AND MANAGEMENT

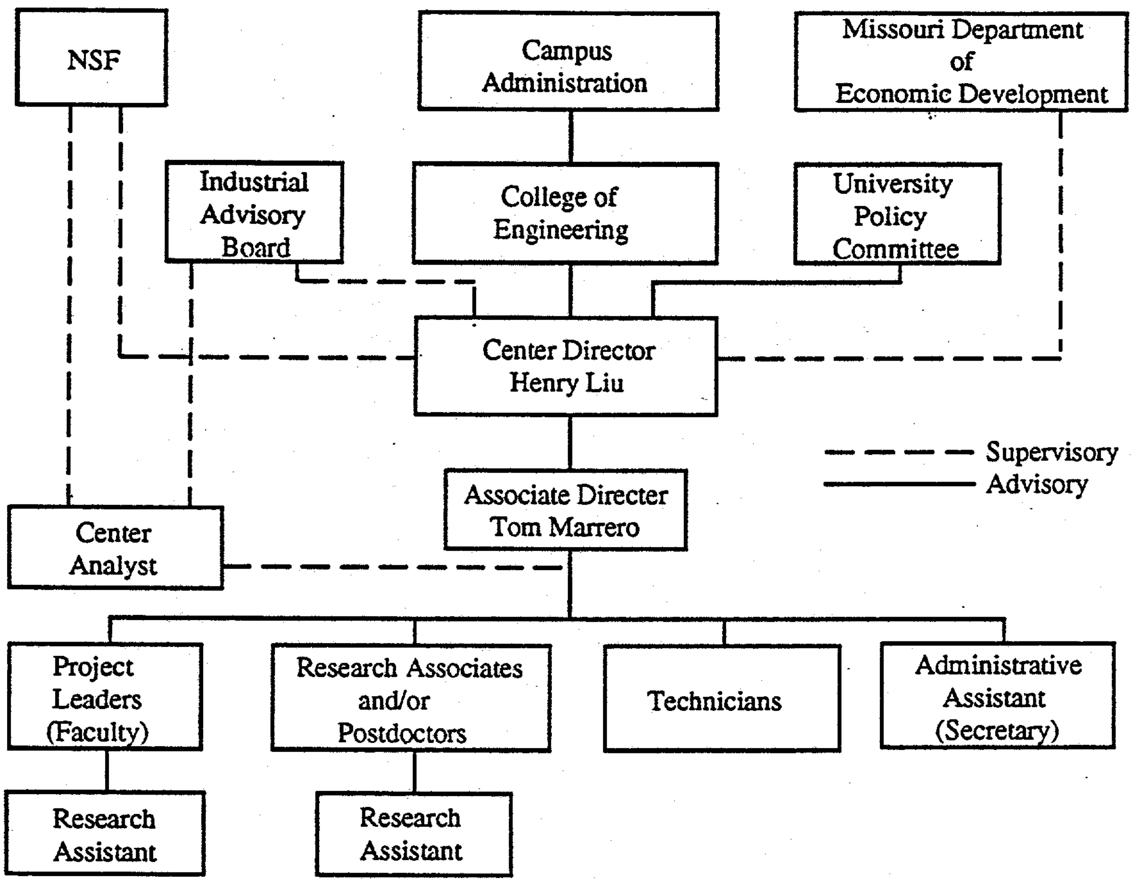
The Center planning involves every researcher. Each week there is a meeting for each group such as the Hydraulics/Control Group, and the Coal Log Fabrication Group. Besides reporting on the progress made each week, the meetings also involve planning. Each researcher is required to reveal his (her) plan 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.

The Center also has a carefully prepared written R&D plan which is revised periodically, usually once a year. The Industry Advisory Board (IAB) is closely consulted in preparing and formulating the plan. The latest plan, including a Gantt chart, is given in Appendix 5.

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

The current organizational chart of the Center is given in Table 8. The Center Director and the Associate Director share administrative duties. The Associate Director has been tremendously helpful in reducing the Director's administrative chores such as supervising laboratory and shop services, signing purchase orders, attending some routine university/college meetings, dealing with personnel problems, etc. This has made it possible for the Director to concentrate on his teaching and research, planning and coordinating R&D, preparing quarterly and annual reports, and writing proposals. Still it is highly desirable to hire a manager to reduce both the Director's and the Associate Director's administrative duties. This will enable them to devote more time to research, teaching and advising students. However, due to funding uncertainties in the last 2 1/2 years, especially the uncertainty in the State matching fund, the hiring was postponed. It appears that the State funding for the third year is now secured, and the State plans to fund the Center in the future by including it as a Center of Advanced Technology (CAT)--see Governor's budget recommendations included in Appendix 2. Therefore, the Center will recruit and hire a manager in 1994. The duty of the manager includes coordinating research, preparing quarterly and annual reports, scheduling and supervising shop services, dealing with various personnel matters, managing the budget, etc. The type of personnel associated with the Center, and the personnel characteristics (statistics) are reported in Table 9.

**Table 8. Organizational Chart of Capsule Pipeline Research Center**



## Table 9: STATE/IURC: PERSONNEL - FIRST 3 YEARS (1991-94)

| | # | Sex | | Minority Stat.[1] | | | | | Disabled | Disciplines |
|---|---|---|---|---|---|---|---|---|---|---|
| | | M | F | 1 | 2 | 3 | 4 | 5 | | |
| Faculty | 13 | 12 | 1 | 0 | 3 | 0 | 1 | 10 | 1 | Engineering & Law |
| Research Staff[2] | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | Engineering |
| Visiting/Foreign Faculty[3] | 2 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 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 | 3 | 1 | 2 | 0 | 0 | 1 | 0 | 2 | 0 | None |
| Technical Staff | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | Engineering |
| Students:[5] HS | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | Engineering |
| UG | 17 | 13 | 4 | 0 | 1 | 1 | 1 | 14 | 0 | Engineering |
| MS | 29 | 22 | 7 | 0 | 17 | 0 | 0 | 12 | 0 | Engineering & Law |
| Ph.D | 6 | 6 | 0 | 0 | 6 | 0 | 0 | 0 | 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.

5. Students are counted according to their status when started to work at CPRC.

ANALYST'S REPORT

# Capsule Pipeline Research Center

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

## INTRODUCTION

The Capsule Pipeline Research Center (CPRC) at the University of Missouri-Columbia is in its third year of operation. Four Advisory Board meetings have been conducted since the inception of the Center, and these meetings were attended by CLP Consortium members, small business participants, representatives from the National Science Foundation (NSF), a representative of the Missouri Department of Economic Development, the Center Analyst (formerly called "Evaluator"), and the faculty, students and staff of the CPRC. The meetings featured technical presentations relevant to the research activities of the Center and business meetings to discuss the progress and direction of the Center. Dr. Liu sincerely invites the ideas and opinions of all participants. Many issues raised at these meetings required conscientious and reflective examination by both the Center Director and Associate Director. They have responded to all the issues raised in a thorough and expeditious manner. Dr. Liu is sensitive to the necessity to balance the needs and goals of the entire consortium, while maintaining a sound leadership position.

## EVALUATION SURVEY RESPONSES

The Center staff and the Center's industry members have grown and matured in both their understanding and appreciation of the potential of the new technologies advanced by the Center's accomplishments. They also are aware of the many research thrusts underway, but some are becoming increasingly anxious about progress in specific areas. One group seems frustrated that it cannot be mandated that scientific research will produce the desired results in a specific timetable, as determined in their own planning. Timetables for scientific research are planning tools which must be flexible to address needs produced by the results of the ongoing research.

The successful fabrication of viable coal logs is the primary concern of approximately half of the members. The other half seems to believe that a greater potential for capsule pipeline utilization lies in the transportation of agricultural products and other bulk items. These differences in opinion are caused by the diverse nature of the consortium membership and their needs. The Center's mission for the second for years includes broadening and expanding the research to cover additional types of uses for capsule pipelines.

While the survey results are less superlative than the last survey (second annual report), the support for both the Center and the Center Director has not waned. The results of the most recent survey reflect the following:

- **Technical Quality** - 29 % of the respondents rated *"Completely Satisfied"* and 71 % rated *"Considerably Satisfied"*

- **Communications between Center Staff and Your Company** - 50 % rated *"Completely Satisfied"* and 50 % rated *"Considerably Satisfied"*
- **Center Administrative Practices** - 22 % rated *"Completely Satisfied"*, 56 % rated *"Considerably Satisfied"*, and 22 % rated *"Somewhat Satisfied"*
- **Responsiveness of the Research to Industry Needs** - 11 % rated *"Completely Satisfied"*, 56 % rated *"Considerably Satisfied"*, 11 % rated *"Somewhat Satisfied"*, 22 % rated *"Not at all Satisfied"*
- **Innovative Quality of Research** - 56 % rated *"Completely Satisfied"*, 33 % rated *"Considerably Satisfied"*, and 11 % rated *"Somewhat Satisfied"*
- **Project Selection Process** - 11 % rated *"Completely Satisfied"*, 56 % rated *"Considerably Satisfied"*, 22 % rated *"Somewhat Satisfied"*, 11 % rated *"Not at all Satisfied"*.

*Further, it is the unanimous opinion of the membership that the quality of the research is excellent, the approaches used are highly innovative, and the dedication of all Center personnel is stellar.*

## *FUTURE PLANNING*

The planning document, "Coal Log Pipeline Research and Development Planning for the Next 20 Months", connects the activities of the Center for the first three years to the plans for the next progression of endeavors. The shift from basic and core research to focusing on methodologies for the commercialization of CLP technology is the basis of this plan. This should serve to address the issues and/or concerns of all the consortium's partners, but it also will move closer to the accomplishment of the Center's original goal. The document includes a detailed outline of 21 tasks required to accomplish the original goal of readying CLP technology for commercial use. The document also addresses the plan to pursue a full-scale demonstration project and to broaden and/or expand the research to cover additional types of uses for capsule pipelines. Transporting agricultural products, such as grains and other commodities, is of vital interest to several of the Center's members. Using CLP technology to transport processed refuse, hazardous wastes and hazardous materials, as well as, power-plant ashes, appears to offer additional opportunities to safely and economically move by-products which have an impact on our environment. The plan also addresses the development of a Manual of Practice for Coal Log Pipeline and the presentation of a workshop on CLP technology (technology transfer). The time lines, activities, milestones, and completion dates have been generated for the use of all Center members. The plan includes a budget for each of the 21 tasks. The Center Director has shared this plan with all members of the consortium, and he pledged to respond to all inquiries and to consider all recommendations that he receives.

The College of Business and Public Administration (B&PA), University of Missouri-Columbia, is currently working with the center on the marketing issues and opportunities for the commercialization of CLP technology and for the application of capsule pipeline technology for transporting agricultural products and other commodities, as well as, waste materials. The exploration of opportunities for small business ventures is being pursued. The issue of technology transfer also is being addressed by a team of business students. The leadership for these activities presently is with the Small Business Development Center within the College of B&PA.

## FINANCIAL ISSUES

The CLP Center experienced some financial problems during the second year of operation. The first problem was the delay in funding of $250,000 (for the 3rd year) from the state of Missouri. A new governor was elected last year, and it appears that Governor Carnahan is very interested in supporting the research activities of the Center. This interest stems from the commitment of his office to facilitate economic development in Missouri and to support higher education throughout the state. Supporting the activities of the Center satisfies both of the Governor's initiatives. In his budget submitted to the Legislature in January 1994, the Governor recommended not only a Supplementary funding of $200,000 for the Center for the current year, but also a budget of $250,000 for the Center for next year, and the inclusion of the Center into the state's existing Centers for Advanced Technology (CAT) program. Legislative action is proceeding to approve the Governor's recommendations.

The second financial problem was caused by the sudden withdrawal of two Consortium members, Kansas City Power and Light and Coal Services Corporation in 1993. This presented a net loss of $45,000 per year which has been more than remedied by a U.S. Department of Energy grant and the recent addition of four new companies. The new members are; T. D. Williamson and Inc., Erie Press, Wilbros Butler Engineers, and Burns and McDonnell Engineers.

Two Exit Interview Surveys were conducted following the withdrawal of Kansas City Power and Light and Coal Services Corporation. The Center Analyst had the opportunity to read several communications between the representatives of the two companies and the Center Director. The issues raised in the correspondences focused on the technical feasibility and the economic viability for the commercialization of coal log transportation. The validity of the Economic Analysis Study was challenged on several points by both ex-members. The Center Director painstakenly addressed every issue raised, but to no avail. The responses to the exit interview survey were inconsistent with the reasons cited in all the correspondence read. The issues highlighted in the surveys were: lack of faith in the ability to produce (fabricate) a coal log that would withstand the conditions of being transported over long distances, and lack of faith in the ability of transportation of coal using CLP technology to compete with rail transportation. Both ex-members suggested that they would consider re-joining the project, if viable coal logs could be produced economically and that an economic advantage of CLP can be proven. The leadership of the Center and the quality of the research of the Center were lauded by both ex-members. The conclusion that seems most reasonable is that these two members have withdrawn prematurely. The Center Director carefully and tactfully responded to the concerns of both ex-members, and he has invited them to continue communications with himself.

## TECHNOLOGY TRANSFER

Technology transfer issues have continued to be a high priority of the Center. Considerable effort has been expended to capitalize on the accomplishments at the CLP Research Center. The Center has produced the following; numerous technical presentations on the CLP, the completion of a video production about the Center's activities and potential for economic development, several newsletters to date, numerous publications, company seminars and company 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 CLP Research Center's agenda, as evidenced in the future plans for the Center, outlined in Dr. Liu's Strategic Plan.

## SUMMARY

The Center continues to grow and to operate in a smooth and efficient manner, in spite of the loss of three members and the burden of delayed funding from the State of Missouri. All of the faculty and staff of the Center have a clear sense of purpose and direction, as evidenced in the weekly meetings and other activities of the Center. The Center Director is an energetic and skillful leader. The activities of the Center are well documented in all areas and this will facilitate the tracking of its progress. The Center Director and the Associate Director maintain a strong and healthy relationship with the members of the IAB. They communicate with IAB members by telephone, by mail, and by FAX.

The success of the NSF Capsule Pipeline Center is of extreme interest to many diverse groups of businesses, industries, local and state governments, as well as to the general population. Future use of coal log pipelines in Missouri will save enormous transportation costs for coal, be it low-sulfur coal imported from western states, or high-sulfur coal mined in Missouri. The potential for transporting other products and industrial by-products underscores the tremendous value this new technology holds for the citizens of Missouri and for the country. Development of such a new pipeline industry in Missouri will also generate thousands of new jobs, and enrich the economy of the state.

The Center's Commercialization Plan outlines a strategy for promoting the acceptance and utilization of capsule pipeline technology in the industrial environment. The plan includes three elements as follows: a commercial demonstration project, a full-scale test and demonstration project, and the creation of a capsule pipeline company. The successful completion of any of the three programs will greatly enhance the probability of the commercialization of this new technology.

Budget info removed.

# Appendices:

# Appendix 1: Individual Project Descriptions

Beginning the next page, a description is provided for each individual project operating under the Center during the first 3 years (9/1/91-8/31/94). 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. Note that not all the listed projects started at the same time; the expenditure listed for each project is that for the life of the project until August 31, 1994.

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

**Principal Investigator:** Brett Gunnink, Assistant Professor of Civil Engineering

**Duration:** 9/1/91 - 8/31/94

**Expenditure:** $90,801

**Research Associates:** None
(0 person/years)

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

**Graduate Research Assistants:** J. Kanunar (0.5 person/year)
F. Chen (0.5 person/year)
Z. Liang (0.5 person/year)

**Other students who worked on project:** R. Camp (0.0625 person/year)
Clark Darrah (high school, two summers)
Anna Tillema (high school, summer)

**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 (9/1/91 -8/31/93):**

For first year of the project (9/1/91 - 8/31/92), work was focused on evaluating whether or not conventional methods for making binderless coal compacts could be applied to coal logs for pipeline transport. It was concluded that conventional binderless coal logs were not suitable for pipeline transport due to the significant strength loss that occurs when these logs are exposed to high pressure water. The most significant accomplishment during the second year (9/1/92 - 8/31/93) was the development of Hot Water Dried (HWD) coal logs. HWD logs are high strength water resistant logs. Work during the second 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 the durable coal log test performance 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 process for making HWD coal logs have not be reported due to patent disclosure considerations. Details of the strength and performance characteristics of HWD logs have been included in past progress reports. At the end of the second year it was concluded that HWD logs are probably durable enough for commercial pipelines as is. However, we remained somewhat concerned about the circumferential cracking and the resultant brittle fracture failure in these logs. Therefore, during the third year we explored eliminating this problem by investigating the effect of making coal logs in a multi-part mold (including a chrome plated mold) on the occurrence of circumferential cracking. We also investigated making HWD logs from various types of coal and the effect of compaction temperature on coal log quality. Finally, we completed the design of a mold for fabricating 5.3" diameter coal logs and are currently making this mold. This mold will be used to make the 5.3" diameter logs that will be tested in a commercial pipeline in Conway Kansas, during the summer of 1994.

We have investigated the effects of compaction temperature and pressure on the post adsorption tensile strength of HWD coal logs made from Powder River coal. We have successfully made HWD logs at temperatures ranging from 125 $^{o}$C to 200 $^{o}$C and at pressures ranging from 10,000 psi to 20,000 psi. Log strength and density decrease with decreasing temperatures and pressures. However, all logs are water-resistant. We have made logs at 200 $^{o}$C and 20,000 psi that have a post-adsorption tensile strength of 180 psi (solid cylinder, unplated mold). We have made logs at 125 $^{o}$C and 20,000 psi that have a post adsorption tensile strength of 74 psi. And we have made logs at 150 $^{o}$C and 10,000 psi that have a post adsorption tensile strength of 78 psi. The results of these parametric studies lead us to believe that satisfactory coal logs can be made at 150 $^{o}$C with a compaction pressure of 10,000 psi.

We have completed our study concerning the applicability of the HWD process to various coals. We have successfully made HWD coal logs using five different coals (solid cylinder, unplated mold). These coals ranged form low rank subbituminous coal to high rank bituminous coal. Post adsorption log specific gravity increased with coal rank, whereas, log strength decreased with rank. In all cases there was coal benefaction associated with the log making process (decrease in equilibrium moisture content). This benefaction was largely insignificant for high rank bituminous coal, but significant for low rank sub-bituminous coal. The characteristics of Powder River HWD logs have been compared with Illinois HWD logs and Arch Mineral HWD logs for logs made at 200 $^{o}$C and 20,000 psi in a solid cylinder mold. The HWD log fabrication process lowers the equilibrium moisture of the Illinois coal from 17.0% to 10.2% and the Arch Mineral coal from 14.7% to 13.9% In contrast, the Powder River Basin coal's equilibrium moisture content is lowered from 30% to 21%. The initial densities of Arch Mineral logs and Illinois logs are somewhat higher than Powder River Basin logs, 1.310, 1.286 and 1.260 g/cm$^3$ respectively. Post adsorption densities are equal for logs made from Powder River Basin and Illinois coals (1.323 g/cm$^3$). However, Arch Mineral logs are heavier (1.354 g/cm$^3$). Powder River logs are significantly stronger than Illinois and Arch Mineral logs. The pre-adsorption compressive strengths are 3457 psi, 1164 psi, and 1634 psi for Powder River, Illinois, and Arch Mineral, respectively. The post-adsorption tensile strengths, which are the more critical strength parameters, are 97 psi, 77 psi, and 44 psi for Powder River, Illinois, and Arch Mineral respectively. These results indicate that durable coal logs can be made from many types of coal.

We have made 10 HWD logs using a multi-part mold. We believed the use of this type of mold (or perhaps a tapered mold) would eliminate or at least minimize the detrimental circumferential cracks that we had observed in logs made using the solid cylinder mold. Apparently, this belief was well founded. We have made 10 HWD logs at 200 °C and 20,000 psi compaction pressure in a multi-part mold. The logs were made from the Antelope coal (subbitumious Powder River Basin coal). All but one of these logs exceeded the CPRC durability criteria (circulation for 1 hour, with less than 3% weight loss). Log strength (post adsorption tensile strength) and durability are significantly improved when a multi-part mold is used and the propensity for cracking is greatly reduced. Preliminary data indicate that if the mold is chrome plated, wall friction and adhesion is reduced and higher quality coal logs result. Coal logs with higher strengths and densities can be made at 150 °C and 10,000 psi in a chrome plated mold than can be made at 200 °C and 20,000 psi in a mild steel mold.

We have completed the design of a mold for making 5.3" diameter coal logs. The mold is currently being fabricated. This is will be a chrome plated multi-part mold. It will be used to make the 5.3" diameter logs that will be circulated in the 6" diameter pipeline in Conway, Kansas, this summer.

**Significant Accomplishments:**

The most significant accomplishment of this project is the development of HWD coal logs. HWD logs are high strength water resistant logs. Work has been 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 the durable coal log test performance criteria adopted by the CPRC in May of 1992. A patent disclosure form has been filed and a patent application for this process is being prepared. It has been demonstrated that HWD logs can be made with a wide range of coals. Further, logs made in a chrome plated split mold are of superior quality when compared to logs made in solid cylinder or unplated molds.

**Future Plan:**

Work for the first three quarters of 1994 will refine the HWD process for making coal logs and scale up production from laboratory scale logs to commercial scale logs. Much of what is learned during this time will directly impact machine design. It is anticipated that by the end of the third quarter of 1994, our knowledge of the HWD process will be sufficient to make final machine design decisions at this time. The should allow machine design and construction to keep pace with commercialization deadlines. Publications reporting the development of HWD coal logs and a patent application will be prepared by the end of the third quarter of 1994.

**Publications:**

Kanunar, J., (1994) "Development and Evaluation of Hot Water Dried Coal Logs", thesis presented to the University of Missouri-Columbia, at Columbia, Missouri, in partial fulfillment of the requirements for the degree of Master of Science. (in preparation, to be completed in May 1994)

Gunnink, B.W. and Liang, Z., (1994) "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:**

Gunnink, B.W., Kanunar, J., and Liang, Z. "Compaction of Hot Water Dried Coal Agglomerates", Preliminary Invention Disclosure, April 15, 1993.

**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 Logs**

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

**Duration:** 1/1/92-8/31/94

**Graduate Research Assistants:** Liqin Wang (0.45 person/year)
Guoping Wen (0.25 person/year)

**Other students who worked on project:** Shannon Eckhoff (undergraduate 0.1 person/year)
Brent Leonard (undergraduate, 0.20 person/year)
Dwayane Bargfrede (undergraduate, 0.20 person/year)

**Expenditure:** $45,993

**Purpose of Research:**

The purpose of underwater coal log extrusion research is to explore the feasibility of extrusion of coal logs with minimum amount of binder or without binder, and quality improvement of extruding coal logs into pressurized water directly. Water is used both as the lubricant and the binder for extrusion, and it helps to provide buoyancy to extruded logs and to control the extruder exit pressure.

**Need for Research:**

The fabrication of strong coal logs that 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.

**Research Progress (1/1/92-8/31/94):**

(1). We succeeded in extruding binderless logs at room temperature. We also tested the binderless extrusion technology on coal fines from a tailing pond. The fines had about 13% of moisture before extrusion. We were able to extrude binderless logs with such fines, and again the extrusion resulted in dewatering which is a fringe benefit.

(2). Designed and tested various extrusion dies. Now the extrusion process on an auger type extruder is relatively stable, and extruded logs are physically strong. We found also that water assisted coal log extrusion changed the property of manufactured logs, enabling the logs to maintain strength in 500 psi water for over a week.

(3). Designed fixture and tested underwater extrusion on a 2" auger type extruder. The process showed promise. However, due to the limiting power of the extruder, exit water pressure was too low to provide conclusions on underwater extrusion. We will try it with the ram extruder which can generate much higher pressure.

**Significant Achievements:**

The water assisted extrusion shows some promise. The process is not sensitive to particle size so that the material preparation costs can be reduced. The process requires no heating other than the heat generated by the process itself. The process uses no binder, and is stable. A research paper is under preparation; an invention disclosure is being filed.

**Plan for Future (4/1/94-8/31/95):**

For long range plan from Jan. 1 1994 to Sept. 31, 1995, please refer to the CPRC master plan developed by Dr. Liu. The items listed below have more detail, but are consistent with the master plan.

(1). A new graduate student, Mr. Guoping Wen, has just started working on extrusion. He will conduct a series of binderless coal log extrusion to find out the optimal set of parameters for the auger-type extruder. If the quality of logs fabricated this way is good enough for long-distance transportation and handling, the process will be practical and economical. The center is considering to apply for a patent on this process.

(2). Some extrusion with the auger type machine using only a small amount of binder emulsion (1%-3%) will be conducted. If the result is promising, then underwater extrusion of 2" log with low binder will be tested. It is believed that the binder not only makes the logs stronger but also expels water from logs due to the hydrophobic nature of the binder.

(3). Design a fixture to conduct underwater extrusion with the 100 ton ram extruder.

(4). Develop a theoretical model for extrusion that can be used with finite element analysis. This model will be useful for die design for future commercial mass production machines.

(5). Consider modification of commercial extruders to make them more suitable for underwater extrusion of coal logs. This center will provide the Center with an alternate commercial process for coal log fabrication. Cost of making coal logs using extrusion process and machine will be estimated, for comparison with the compaction process.

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

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

**Duration:** 1/1/92-8/31/94

**Graduate Research Assistants:** Liqin Wang (0.5 person/year)
Guoping Ji (0.5 person/year)

**Expenditure:** $24,771 (cash); $25,000 (in-kind)*

**Other Students Worked on the Project:** Brent Leonard (undergraduate, 0.25 person/year)

**Purpose for the Research:**

The main objective of machine design project is to design a machine of coal log fabrication at commercial mass production rate. Coal log surface treatment equipment and other accessories are also included in the design. At this early stage the design is more conceptual. Later the design will have more production details, as a result of coal log fabrication process converging to mass production process and the prototype of crucial components.

**Need for the Research:**

The machine design can suggest desirable improvements of laboratory coal log fabrication processes, and provide a basis for better estimation of the fabrication rate and cost of coal logs in commercial systems of CLP. It is also a necessary step toward building large coal log machines for commercial use.

The fabrication of strong coal logs that 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 surface treated if necessary, and then injected directly into a pressurized, water-filled pipeline, so that the coal logs are not exposed to atmospheric air after fabrication.

**Research Progress (1/1/92-8/31/94):**

(1). The conceptual design of a coal log compaction machine was revised several times. Now the design is moving from conceptual design to parametric design. The cost of the machine designed was estimated; it appears to be economical for CLP applications. During the January 1994 workshop with industrial members, the design was discussed in detail. We need more details for the design, and more support data from prototype and testing of key components. We also need

* Three companies (Ramer and Associates, Gundlach Machine Company, and Erie Press, Inc.) have provided services on this project totaling $25,000—as in-kind contribution to the Center.

to prove to our existing and future sponsors that this machine will work as specified, in terms of speed, quality, and cost.

(2). The center has designed and manufactured five 1.8" two-piece molds, with different configurations. We have learned invaluable lessons and gained experience from designing and using these molds. The mold is the most important component in the commercial machine. The major challenges about mold design are: as light-weight as possible but yet very rigid, it must withstand creep under elevated temperature, and it must be easy to operate.

(3). Completed the design of an improved 5.3" split-mold design. We applied advanced finite element analysis and optimization tools in the design. This mold will be built and tested at our Rolla Campus by Dr. Wilson and Dr. Ding. Information gained from such tests will be of great value for designing the final split mold for commercial production of coal logs.

**Significant Accomplishments:**

We have participated in two coal log compaction machine design contests. One is to compete with another design furnished by two industrial members of the CPRC (Capsule Pipeline Research Center)—the Ramer and Associates, and the Gundlach Machine Company. The other is a nation-wide collegiate design competition—BF Goodrich Collegiate Inventors Program. Our design has passed the first round of the competition and the outcome is pending for the second competition. Due to the proprietary nature of the design work, most of the reports are now internal, and we hope to file a patent as the result of the design works. Related publications:

1. Yuyi Lin and Liqin Wang, 1992, <u>Coal Log Compaction Machine Design and Cost Estimation</u>, CPRC Internal Report.

2. Guoping Ji and Yuyi Lin, 1993, <u>Three-Section 1.8" Mold Design</u>, CPRC Internal Report.

3. Yuyi Lin and Guoping Ji, 1994, <u>Coal Log Manufacturing Machine Design Report—Capped Mold Approach</u>, CPRC Internal Report.

**Plan for Future (4/1/94-8/31/95):**

For long range plan from Jan.1 1994 to Sept. 31, 1995, please refer to the CPRC master plan developed by Dr. Liu. The description below has more details than and is consistent with the master plan.

(1). Considering current coal log fabrication processes developed here at CPRC, the mold is a key component in any future commercial, mass production machine. Each mold needs to be trouble-free for life time, and inexpensive. The mold needs to be rigid under elevated temperature and high pressure. We have learned lessons from smaller molds designed and used. The most recent design is a 5.3" mold, which is a transition design between the lab process and mass production process. The finite element method was applied to reduce the weight, increase the rigidity, and improve the piston shape. After manufacturing and using this 5.3" improved mold, we shall be able to design a commercial, mass production, 8" mold factory that can produce 2 million tons of coal logs per year.

(2). More details, such as mold moving mechanisms, will be included in the 8" machine design. This design needs to have sufficient details so that experienced peers can be convinced that a plant that has 10 such machines can produce 2 million ton/year of throughput for an 8" pipeline, and that the cost is economical for CLP applications.

(3). My colleague, Dr. Alley Butler has started working on a vacuuming system, which upon completion can enhance the loading speed, and the log quality of compaction machines. His design will become a sub-system of the commercial machine in my design.

(4). A patent application will be filed based on this commercial, mass-production machine design.

**Industry Involvement:**

There has been extensive industry involvement in this project. For instance, both the Ramer & Associates and the Gundlach Machine Companies have helped Dr. Lin in his design, and have investigated an alternative design of a coal log manufacturing machine. The Erie Press, Inc. has reviewed Dr. Lin's design and provided detailed comments and suggestions. Furthermore, all three companies attended a one-day work session in Columbia focused on machine design. The total services provided as in-kind contribution are, as of April 1, 1994, approximately $25,000.

**Project Title: Extrusion of Coal Logs**

**Principal Investigator**: Thomas R. Marrero, Associate Professor of Chemical Engineering

**Duration**: 9/1/91-8/31/94

**Expenditure**: $46,500

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

**Post-Doctoral Fellows**: None

**Graduate Research Assistants**: D.M. Berg (0.5 person/year)
S-H. Chen (0.5 person/year)
Q.W. Deng (0.5 person/year)

**Other Students who worked on project**: R. Harris (hourly)
M. Kersting (hourly)
A. Rockabrand (0.4 person/year)
H. Zhu (hourly)

**Purpose for the Research:**

To investigate extrusion processes to improve the extrudability of coal log, log properties applicable to hydrotransport, and to obtain information suitable for estimating extrusion costs.

**Need for the Research:**

The manufacture of coal logs may be commercially done by extrusion. Many factors affect the extrusion process and the extrudate behavior in pressurized water. The major process variables are: die design, pressure, temperature, coal particle size distribution, saturated moisture content, and binder content. In addition to the variables listed above, extrudability of coal logs is affected by the tempering of the feed material and the type of coal.

**Research Progress (9/1/91-8/31/94):**

The coal log extrusion studies now have two, 2-inch auger type extruders, and one large (10 inch, 100 ton) ram type extruder. These apparatus are installed and operating. The smaller, auger-type extruders can be heated. In November 1993, a large 100-ton ram extruder was installed capable of making 8" logs. An oil heating system allows temperature to 140° C to be explored. This extruder has a new automatic temperature controller. The system has been checked out and set up to make 5.5" diameter logs with a 8" mud-pot using the die which was part of the purchased package.

Types of coal that have been extruded are lignite (Texas), subbituminous (Wyoming), and bituminous (Kentucky, Maryland and Illinois).

Extrusion temperatures have been investigated from 200°C down to room temperature. Lower temperatures are more economical as less heating is required.

The binder concentration was explored from 8% to 2%. As a means to reduce the adsorption of binder into pores the use of water-saturated coal and emulsified asphalt binder are being tested. Results to date appear promising. Using an emulsion asphalt formula logs have been made with a particle size as large as 3/8". This formula uses excess water to furnish additional lubrication properties to the coal. Only checkout debugging runs have been made and although logs have been produced they have not arrived at a optimum set of conditions.

The purchase costs of binders have been obtained; a new product (Orimulsion) may be significantly less costly than AC-20, a commercial road asphalt.

It is believed that coal with a low-pore volume can be manufactured into coal logs with an economic amount of binder.

**Significant Accomplishments:**

Coal logs have been made with less than 3 weight percent emulsified asphaltic binder in a ram type extruder.

A large extruder system was purchased, installed and operating that has produced coal logs as large as 5.3 inches in diameter.

The comparison f coal logs produced by auger-type and ram-type extruders indicates that the ram type produces a more economical log better suited for hydraulic transport.

Work indicates that an auger-type extruder can produce logs with large particle size but requires an uneconomical amount of asphalt binder for most coal(s).

**Plan for the Future (4/1/94-8/31/95):**

The future plans include extensive use of the large 100-ton ram-type extruder to produce 5.3 inch diameter coal logs for the 5 mile straight pipe test in Conway, Kansas during the summer of 1994. In addition studies will be conducted to optimize extrusion conditions in terms of material and machine variables. These tasks will lead to several publications and at least one thesis.

Confirmation of the amount of road asphalt needed for different types of coal is planned as this formulation produces light log (SG=1.1) that requires less transport energy.

Future extrusion tests will produce large, 7.4-inch-diameter coal logs for testing at the UMC loop. The large logs will be made both by using our large ram extruder and by auger-type extruders. The Bonnot Company will make the auger-type extruder logs for us using the formulation and conditions developed at the University. This project is listed under Task 6 of the Center's 20-Month R & D Plan in Appendix 5.

**Publications:**

1. Berg, D.M., Hot Extrusion of Coal Logs, M.S. Thesis, Department of Chemical Engineering, University of Missouri-Columbia, August 1993, 187 pages. (Adviser: Thomas R. Marrero).

2. Burkett, W.J., and Marrero, T.R., "Extrusion of Coal Logs with Coal-Asphalt Mixtures," Proceedings of the Institute for Briquetting and Agglomeration, Volume 22, 1992.

3. Marrero, T.R., Burkett, W.J., Berg, D.M., and Nikda, K., "Coal Log Fabrication by Extrusion," 7th International Symposium on Freight Pipelines, Wollongong, Australia, July 6-8, 1992.

4. Marrero, T.R., Burkett, W.J., and Berg, D.M., "Extruded Coal Log Performance Characteristics," 17th International Conference on Coal and Slurry Technology, Clearwater, Florida, April 28 - May 1, 1992.

**Industry Involvement:**

The small extruder used in extruding coal logs was donated by the Bonnot Company. The Bonnot Company also extruded logs for the Center, and has been advising the Center on extrusion technology. Two other companies that cooperated with the Center on extrusion are J.C. Steele & Sons (Statesville, N.C.) and Macrotech, Inc. (Paris, Tennessee) over three years.

**Project Title: Surface Treatment of Coal Logs**

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

**Duration:** 9/01/91 - 8/31/94

**Expenditure:** $129,175

**Research Associates:** None

**Post-Doctoral Fellows:** None

**Graduate Research Assistants:** Daniel Carney, Rebecca Smith, S-H. Sun (0.5 person/yr for each)

**Other students who worked on project:** Rockabrand, James Eichelberger, Gordon Carter (hourly)

**Expenditure:** $129,175

**Purpose of the Research:** To treat coal log surface by various means to prevent water infiltration.

**Need for the Research:**

The manufacture of coal logs using the "hot water drying" method, described elsewhere in this report, produces coal logs that retain their strength even when infiltrated with water at high pressure. That method does not use a binder which is important because the cost of a binder can become prohibitive if it exceeds about 4%. These logs are feasible candidates for use in certain commercial pipelines. However, since the density of these logs is high at pipeline water pressures, the required "lift-off" velocity is relatively high which adversely affects the economics of a coal log pipeline.

Coal logs can be made also without binder using dried coal (0-3% moisture). Logs made from dried coal have lower densities and hence lower lift-off velocities and thus may be attractive candidates for the larger diameter and longer distance pipelines. Coal logs from dry coal have another potential bonus. Compared to the "hot water dried" logs with 15-22% moisture, the dried coal logs have an obvious heating value advantage and this advantage is also enhanced by longer distance transport.

Logs made from dried coal without binder, however, have one serious disadvantage. They absorb moisture rapidly when immersed in water at high pressure. Water enters the voids in a coal, and then the pores in coal particles and expands them causing a loss of most or all of the log tensile strength. Therefore, if logs made from dried coal are to be used in a commercial coal log pipeline, it is essential to prevent water infiltration into the coal log for reasons of strength as well as density.

The objective of this research is development of a practical treatment process for the outer layers of the coal log to retard moisture infiltration so that both the dry strength and the lower density properties of logs made from dried coal can be retained. Several treatment processes were tested, including heat treatment of coal log surfaces (Sun's initial work), coating logs with asphalt or wax impregnation of logs with coal-water slurry (Smith's work) and coal-asphalt slurry (Smith & Carney), etc. Some treated dry logs have shown improved abrasion and impact resistance during pipeline endurance tests and some did not.

**Research Progress (9/01/91 - 8/31/94):**

**A. Asphalt Impregnated Logs: Logs made at 200°C and 20,000 psi**

We have demonstrated high strength and adequate water resistance using dried coal in small (1.75" diam x 3" long) logs by impregnating logs with asphalt. Asphalt impregnated coal logs were made under a variety of conditions. The following results were found:

1. The amount of asphalt absorbed during the impregnation step varied from 2% to 7%. It appears that the lower levels of asphalt are as effective as the higher levels.

2. None of these logs failed in the 5+ hr high pressure static water immersion test.

3. None of the logs failed in the 1+ hr pipeline circulation test. None broke or lost large chips.

4. Abrasion (wear) losses in the pipeline were very low (0.5% to 1.5%).

5. In the post-circulation (static) high pressure water immersion test, some failed in about 1 hr (additional) while others did not.

It should be noted that all of these tests were made while there was some misalignment in the test pipeline that was causing premature failure with test logs produced by other methods. This indicates a substantial safety factor in strength for the impregnated coal logs.

These results indicate that, from the standpoint of strength and water resistance, coal logs produced by some variation of the above procedure may be promising candidates for transporting Powder River Basin coal to the midwest in a commercial coal log pipeline.

1. Scale-up from 1-3/4" diam tests logs to 20" diam commercial pipeline is beneficial since the rate of water flow into the log is proportional to the square of the diameter (and length). Thus if a similar log to the above is prepared at the larger diameter, the 5 hour endurance time scales to over 650 hours. This is far greater than the 150 to 175 hours transport time from Wyoming to Missouri. Alternatively, the amount of asphalt required for the casing could be a smaller fraction of the total mass of the large log than of the

smaller.

2. The 2" diam. capsule test pipeline is much more abrasive than large commercial pipelines. We believe that logs that endure for over one hour in the test line will last many more hours in the larger commercial pipelines. Actually, none of the test logs failed and probably would endure much longer times in the test line.

**B. Asphalt Impregnated: Lower Densities**

Coal log compaction for the above results was carried out at high temperatures and pressures so that the specific gravity before impregnation was 1.23 to 1.28 (and 2 to 5% greater after impregnation). This represents, at best, only marginal improvements in lift-off velocity for this log over those produced with other methods. With procedures established for adequate strength and water resistance, impregnation of lower density logs was then investigated.

A broad range of combinations of maximum mold temperatures and maximum ram compression forces were considered. Logs with densities ranging from 1.005 to 1.30 (non-impregnated) were produced. The low density logs are generally weaker than those made at the higher pressures and temperatures but acceptable combinations of strength and density were found.

As expected, the low density (i.e., high porosity) logs absorb a large fraction of asphalt during the impregnation process. If the log is fully impregnated, the post-impregnation density is similar to that of the less porous logs. As was not expected, even the large fraction of asphalt (20-30%) sometimes failed to protect the logs from damage during the high pressure static water immersion tests. Seven of eight logs impregnated at low initial densities did not pass these high pressure tests. As was even less expected, the logs often appeared to be damaged by the asphalt impregnation process itself. Not only did surface cracks often appear after the impregnation procedure, but in some cases fracture of the logs occurred during asphalt impregnation.

After the above impregnation studies, the pool of remaining asphalt was observed to be noticeably softer than asphalt as received. In normal procedures, the pool of asphalt is retained in the impregnation apparatus with new material added only to replace the amount used. After total replacement with fresh asphalt, two more logs have been made which passed the high pressure water and test pipeline circulation tests. Therefore, it appears that poor performance noted above may be due to degradation by repeated heating of residual asphalt in the impregnation vessel.

**C. Impregnation with a Slurry of Coal Fines**

Coal fines (smaller than 38 microns) were used in a 20% slurry with various impregnating mediums in an attempt to reduce the amount of liquid and to more effectively plug the pores in the coal structure. When used with a crystalline impregnate like stearic acid, the logs were resistant to water infiltration at high pressures but failed in the pipeline test when abrasion perforated the coating.

A slurry of coal fines in asphalt yielded results very similar to what was found with asphalt alone. Low density coal logs absorbed enough asphalt (and coal fines) to increase the specific gravity to 1.21-1.25. As with the logs described above, these logs failed until fresh asphalt was used for impregnation. Subsequently three logs all passed the high pressure water immersion and the pipeline circulation tests.

### D. Heat Treatment of Coal Log Surface

Heat treatment of coal log surfaces were studied for approximately a year by S.H. Sun under the guidance of Dr. Marrero. Two means of heat treatment were tested: **microwave heating** and **radiant heating**. To avoid combustion, the microwave heating tests were conducted in both an oxygen depleted air system and in a system purged by nitrogen. The radiant heater was constructed to allow immersion of coal logs inside a cylinder inerted with nitrogen. Heater surface temperatures were up to 1000 °C and the logs were immersed for less than 30 seconds. All the heat-treated logs failed to produce an impermeable surface. The treated logs absorbed water under pressure at a rate as fast as or faster than the untreated logs. Due to this negative test result after a year's effort, the project was discontinued and Mr. Sun was directed to a more productive research which is to study the heating, cooling and drying of coal logs, a subject that needs good understanding.

### E. Remaining Work

There are several problems yet to be solved before implementation to large logs is commercially feasible. The impregnation process as realized in the laboratory is complicated and possibly expensive. Dried coal introduces an expense to the coal log pipeline unless the coal is separately upgraded. Coal compaction requires temperatures in excess of 110°C and maximum pressures on the coal in the log of over 7500 psi. Impregnation of the formed coal log is a three step process: (1) evacuating the air from the pores of the log, (2) immersing the log in molten asphalt, and (3) using either atmospheric pressure or elevated pressure to force asphalt into the pores of the hot log.

Successful scale-up of the laboratory process will require further (non-trivial) development of procedures. The logs as demonstrated contain 15-25% asphalt which is dispersed throughout most of the interior of the small test logs. For a commercial sized (20" diam) log, the asphalt impregnated layer would be confined to only the outer 1" inch or so of the log. This would reduce the amount of asphalt per log to 3-4%. Such a result seems achievable but has not been demonstrated.

### F. Collateral Results

Research on this topic has generated needed information in the area of coal log manufacture by compaction (in cooperation with other groups studying coal log compaction):

1. Production of compacted logs without observable surface flaws (at high pressures and

temperatures) were made reproducibly by using a programmed sequence of temperature and pressure combinations.

2. Coal logs are now being made in chrome-plated molds that split into two parts to release the log rather than requiring it to be forced out of the barrel with an axial ram. This procedure eliminated internal cracks which were foci for log breakage.

**Significant Achievements**

Several impregnation techniques have been developed to make strong, durable, water resistant coal logs. Consistently robust logs were obtained at conditions where the specific gravity of the logs have been greater than desired (1.20 - 1.30). At the lower densities, the loss of consistency with respect to water resistance at high pressures appears to have been related to changes in the asphalt. Recent results indicate that satisfactory logs is obtained also with impregnation of coal logs initially at low density. This method may be important in future applications.

Two research papers describing this work are currently in preparation.

**Plans for Future**

Although asphalt impregnation produces the highest quality coal logs, currently it appears that other methods for log manufacture are adequate and more economical. An commercial process design for economic comparisons will be completed by 8/31/94.

Also to be completed during this period include:

1. Characterization of tensile strength modifications engendered by impregnation.

2. Feasibility study on (on paper) of methods to impregnate only the outer section of large coal logs.

No further study of coal log surface treatment is planned; the work will be completed by 8/31/94.

**Project Title**: **Vacuum Systems to Enhance Coal Log Production and Quality**

**Principle Investigator**: Alley C. Butler, Asst. Professor, Mechanical & Aero. Engineering

**Duration**: 1/1/94 - 8/31/95

**Expenditure**: $22,308

**Research Associates**: None (0 person/year)

**Post Doctoral Fellows**: None (0 person/year)

**Graduate Research Assistant**: J. Tang (0.5 person/year)

**Other students who worked on the project**: None

**Purpose of the Research**:

To investigate the effects of vacuum on the fabrication of coal logs, as a means of improving the speed of manufacture as well as increasing coal log quality. The primary focus will be on improving compressive processes as a method for coal log fabrication.

**Need for the Research**:

Compression and extrusion processes in related industries, such as the fabrication of carbon and graphite products, benefit from the application of vacuum prior the compression or extrusion. However, no data exists regarding the effects if vacuum on the fabrication of coal logs. Therefore, this task seeks to characterize and then quantify the benefits of applying vacuum prior to and during the compression process.

**Research Progress (1/1/94 - 4/1/94)**:

Although this issue has been under active examination for only three months, progress to date includes: 1) completion of a literature search, 2) discussions with internal, advisory board, and external experts in the field, 3) an examination of quantitative and qualitative procedures for analysis of gasses which may be extracted from coal under various temperature and vacuum conditions, 4) development of a conceptual design for a research apparatus, and 5) commencement of detailed design of the research apparatus.

**Significant Accomplishments**:

Partial specification of process variables and equipment capability for testing the effects of vacuum on the fabrication of coal logs by compression has been completed. Additionally, a bibliography of relevant literature has been developed.

**Plan for the Future:**

Research efforts for this investigation will be developed in two phases. In the first phase, manufacture of coal logs in a vacuum environment will be investigated with emphasis on determining the effect of a range of vacuum, moisture, and temperature conditions on the strength and durability of the resulting coal logs. Optimization of these process variables will be undertaken with the goal of finding upper limits to coal log quality under vacuum manufacturing conditions. In a related second phase, the effects of vacuum on the speed of manufacture will be determined. The emphasis in this second phase will be rapid fabrication of coal logs, and proving that the vacuum technology provides an economically viable advantage within the context of the overall coal log pipeline system.

**Industry Involvement:**

Discussions both in person and over the telephone have been held with a number of people in industry regarding the addition of vacuum systems to coal log manufacture. The sessions have included the following individuals and organizations: Ken Keppel, Draeger; Ted Jaenke, Pro-Mark Process Systems; Dr. Ravi Puri, Environmental Trace Substances Research Center and H. Joe Poole, PVI Systems.

In addition, the subject was explored in depth at the January 12, 1994 Work Session on machine design with four industry members: Fred Infield, Erie Press; Mike Barron and Kathy Frost, Gundlach Machine Co.; James Ramer, Ramer & Associates.

**Project Title: Zeta Potential Effect on Coal Log Fabrication**

**Principal Investigator:** Henry Liu, Professor of Civil Engineering

**Duration:** 9/01/93-8/31/94

**Expenditure:** $9,663

**Research Associates:** Yu Lin ( person/year)

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

**Graduate Research Assistants:** None (0 person/year)

**Other Students who worked on project:** None (0 person/year)

**Purpose of the Research:**

To investigate the feasibility of altering the zeta potential of coal particles in contact with water in order to enhance coal log compaction and extrusion.

**Need for the Research:**

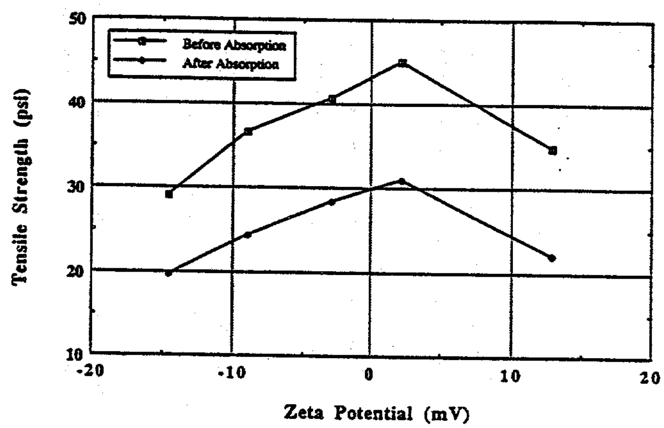
Whenever a solid such as coal is in contact with water, preferential adsorption by the solid surface causes electrical charges to be separated at the solid-liquid interface, generating an electric potential difference across the interface called the "zeta potential." This is a well-known phenomenon discussed in texts of physical chemistry and colloidal science. Higher zeta potential reflects a larger amount of charges accumulated on the surface of coal, which in turn may make compaction and extrusion of coal logs more difficult. Based on this understanding, it is hypothesized that the best condition for coal log compaction/extrusion is zero or vanishing zeta potential. This hypothesis needs to be tested because it may provide a new means to make better coal logs, especially the binderless logs made at low temperature.

**Research Progress (9/1/91-8/31/94)**

A detailed literature search, focused on the zeta potential of coal, has been completed. The study found that there is a wealth of published information on the zeta potential of coal, and ways to alter the zeta potential, but no study was found on the zeta potential effect on coal log compaction and extrusion. It was apparent that some tests must be carried out to determine whether zeta potential affects coal log agglomeration (compaction/extrusion) the way we anticipated or hypothesized.

Mr. Yu Lin, a Visiting Scholar from the People's Republic of China, carried out two sets of tests. The first set was to determine the zeta potential of the Powder River Basin coal used in most of the Center's coal agglomeration studies. It was found that water quality has some impact on the zeta potential. Three ways to alter the zeta potential were tested and evaluated. They included change of pH, use of electrolytes and use of surfactants.

Based on the result of the first set of tests, it was decided that Polyox, the same substance used for drag reduction in CLP, appears to be a practical material for use to neutralize the zet potential of coal in contact with water. Therefore, a second set of tests were conducted t evaluate the effectiveness of Polyox in making better coal logs. The logs were made at roo temperature without binder except for the Polyox that altered the zeta potential. As shown in th sketch below, the tensile strength of the logs consistently increased with decreasing zeta potential reaching a maximum strength when zeta potential is zero.




## Significant Accomplishments:

The preliminary result as illustrated in Fig. 1 is promising. It shows that stronger coal logs can be made by adding a very small amount of chemicals such as Polyox to neutralize the zet potential.

## Future Plan (4/1/94-8/31/94):

The plan for the immediate future is to conduct more tests on other types of coal and i extrusion process, to demonstrate that neutralizing zeta potential is effective not only fo Wyoming coal compacted into coal logs, but also for other types of coal both compacted an extruded into coal logs. Once the general applicability of method is ascertained, then all th binderless coal logs made in the future will incorporate this method to increase coal log strength Work is also needed to investigate whether this method also can produce stronger logs whe some binder is used, especially at low concentration:

## Publications:

1. Lin, Yu (1994). Effect of Zeta Potential of Coal on Strength of Compacted Coal Logs CPRC Internal Report, 21 pages.

2. Lin, Yu (1993). Zeta Potential of Powder River Basin Coal, CPRC Internal Report, 3 pages.

**Project Title**: **Heating, Cooling and Drying of Coal Logs**

**Principal Investigator**: Thomas R. Marrero, Associate Professor of Chemical Engineering

**Duration**: 9/1/93-8/31/94

**Expenditure**: $20,785

**Research Associates**: None

**Post-Doctoral Fellows**: None

**Graduate Research Assistants**: S-H. Sun (0.5 person/year)

**Other Students who worked on project**: None

**Purpose for the Research:**

To develop a valid theoretical model that can be used to predict the temperature and moisture transfer changes that will occur in a coal log during its manufacture or while being stockpiled.

**Need for the Research:**

During the manufacture of coal logs the feed mixture containing coal, binder, water and air, will be subjected to heating. Quantitative estimates need to be made of the rate of temperature increase and its effects on the coal-log manufacturing rates and the coal-log quality, handling and storage. How fast coal logs will cool down and how fast they will dry also must be predicted.

**Research Progress (9/1/93-8/31/94):**

The general equations for heat and moisture transfer in coal logs have been formulated. These equations are a set of coupled non-linear differential equations, sometimes called the Luikov equations. In a coal log, moisture flow is related to the temperature profile which is a function of the heat flux. For this type of transport process a mathematical model has been defined including initial and boundary conditions.

The coal log is considered to be a homogenous porous media.

The solutions of the Luikov equations have been generalized by the use of dimensionless groups, in a cylindrical coordinate system. Initial solutions have been computer generated for the temperature and moisture distributions as a function of time.

The effects of different actual processes on temperature and moisture content in a coal log will be predicted by the proper solutions of the Luikov equations.

**Significant Accomplishments:**

An internal paper (25 pages) has been written that rigorously generates the general equations (a mathematical model) for heat and moisture transfer in coal logs

**Plan for the Future (9/1/94-8/31/95):**

The mathematical model will be validated and modified by experiment. An experimental system is being designed for verifying the theory; the system will be fabricated before June 1994. In addition to the model validation, a coal property data base will be experimentally developed; this task is scheduled to begin September 1, 1994 and continue through August 31, 1995. As a result of this project at least two papers will be submitted for publication and a Ph.D. dissertation written. This project is listed as Task 12 in the Center's Master Plan (20-month R & D Plan). The subtasks and schedule are listed as follows:

Task 12: Heating, Cooling and Drying of Coal Logs

Subtasks:

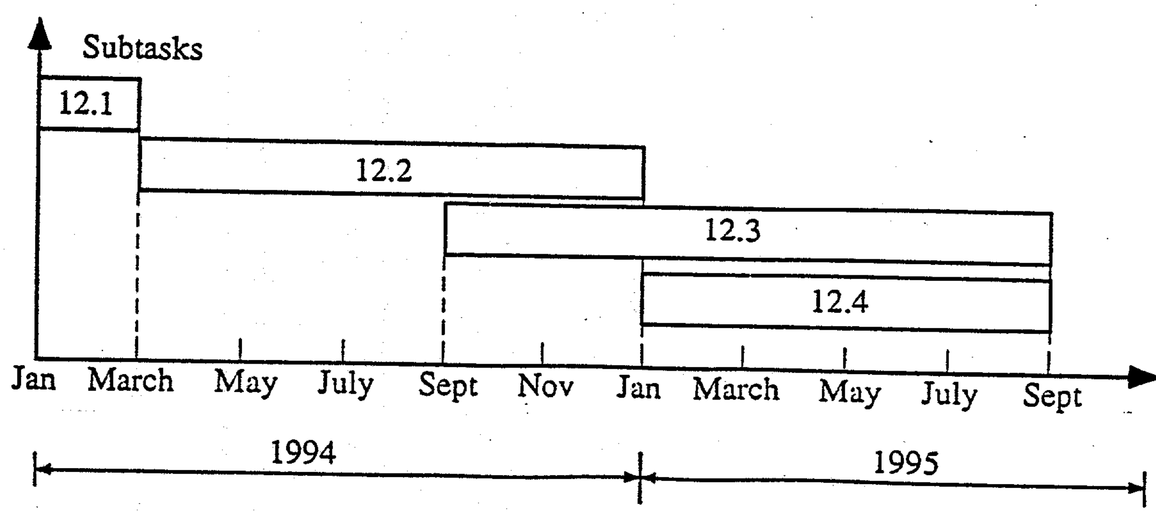
(12.1) Set up a mathematical model for predicting the heating, cooling and drying of coal logs.

(12.2) Conduct experiments to check the validity of the model prediction, and to improve the model based on experimental evidence.

(12.3) Measure the heating, cooling and drying rates of various types of coal logs under different controlled conditions to establish a large data base for future applications

(12.4) Complete a paper and a dissertation on heating, cooling and drying of coal logs:

**Schedule:**



**Project Title: Hydrophobic Binder Coal Log Fabrication**

**Principle Investigator**: John W. Wilson, Professor of Mining Engineering

**Duration**: 1/01/93-8/31/94

**Expenditure**: $135,000

**Post-Doctoral Fellows**: Yungchin Ding (1 person/year)

**Graduate Research Assistant**: Bing Zhao (0.25 person/year)

**Purpose for the 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 the 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 (1/01/93-8/31/94)**:

A. Performance of coal logs made with Powder River Basin Coal:

The coal logs produced using a compaction method and asphalt emulsions were evaluated to determine the optimum fabricating parameters, including compaction time, heating temperature, compaction pressure and binder concentration, this information is necessary for coal log manufacturing considerations.

1-3/4" coal logs were fabricated at compaction times (peak loading time) of 5 to 20 min. (6000 psi and 80$^{\circ}$C). According to the test results, The duration of compaction time has only a slight influence on the properties of the coal logs. In general, it was found that the longer the compaction time, the stronger the coal logs.

In order to evaluate the role of compaction temperature in the coal log fabricating process, compaction temperatures in the range of 40 to 100$^{\circ}$C were used to determine their influence on the properties of the coal log. By examining the test results, it was found that the higher the temperature applied during the compaction process, the more dense and water resistant are the coal logs produced.

Compaction pressures ranging from 4,000 to 10,000 psi were used to evaluate the influence of compaction pressure on the properties of the coal logs. The test results showed that the compaction pressure has only slight influence on the water resistance of coal logs. The tensile strength test results showed that the higher the compaction pressure, the stronger the coal logs produced (10,000 psi compaction pressure, 88 psi tensile strength).

When evaluating the effect of binder concentration on the performance of coal logs, it was found that the higher the binder concentration, the higher the tensile strength and better water resistance of the coal logs. From practical and economic view points, 1 to 2% of asphalt concentration are sufficient to meet the pipeline transportation requirements.

B. Performance of coal logs made with Mettiki Coal:

The coal from the Mettiki operations of Mapco Coal Company are currently being tested for coal log fabrication. It is found that the coal logs made with Mettiki coal possesses better water resistance and greater strength than coal logs made with Powder River Basin Coal, under the same fabricating conditions (see Table below). This is probably due to the Mettiki coal having better quality (higher BTU and more hydrophobic) than Powder River Basin Coal.

Test conditions: 2% asphalt emulsion, 5 min. compaction time and 6,000 psi compaction pressure.

| | Heating Temp, $^{o}C$ | Density | Tensile Strength, psi |
|---|---|---|---|
| PRB coal | no heating | 1.13 | 16.6 |
| Mettiki coal | no heating | 1.29 | 27.0 |
| PRB coal | 80 | 1.18 | 36.4 |
| Mettiki coal | 80 | 1.29 | 60.0 |

C. Comparison of asphalt emulsion and Orimulsion

A new emulsion binder, named Orimulsion, was tested for use in coal log fabrication with Mettiki coal. A comparison of the test results of coal logs made with asphalt emulsion showed that the coal logs made using Orimulsion had slightly lower water resistance and tensile strength than coal logs made using asphalt emulsion.

**Significant Accomplishments**:

A. The bench scale coal log (1-3/4" in Diam.) fabrication experiments using PRB coal have been completed. From the test results, the coal logs manufactured under 6,000 psi compaction pressure and 80$^{o}$C compaction temperature have met the pipeline transportation requirements in a 2" test pipeline loop.

B. Because of the promising results obtained to-date, it is anticipated that better water resistance and stronger coal logs can be manufactured using Mettiki coal at lower compaction pressures and temperatures.

C. The use of the new emulsion (Orimulsion) was found to be successful for coal log fabrication. Because of its low price ($50/ton), the cost of the binder for coal log fabrication can be greatly reduced.

**Plan for Future (4/1/94-8/31/95)**:

A. Selection and modification of bitumen emulsion binders (4/1/94-8/31/95).

Based on the test results obtained from the bench scale experiments, one of the emulsion binders will be selected and used for large coal log (+6" Diam.) fabrication.

Modification of the emulsion binders will also be conducted to improve the water resistance and robustness of coal logs, and at the same time, to reduce the compaction pressure and temperature.

B. The optimum operating parameters of the coal log compaction process, including but not limited to compaction pressure, temperature, and binder dosage, will be studied to comply with CLP economic requirements.

C. Commercial size coal log fabrication (completed by 8/31/95).

Based on the test results obtained from the above-mentioned tasks, large size coal logs will be manufactured to satisfy the needs of commercial applications.

**Industry Involvement:**

The hydrophobic binder R & D project has been substantially assisted by three companies: Macrotech Corp. (Paris, Tennessee), Koch Materials (Kansas City, Missouri and Terre Haute, Indiana). These companies have provided samples of hydrophobic binders and pertinent compaction knowledge. The Macrotech Corporation was visited by Drs. Ding, Marrero and Wilson on a few occasions. During these visits the use of binders from waste sources was observed during the extrusion of coal logs. The visits usually lasted one or two days. The second company, Koch Materials has provided an array of emulsified asphalts for testing purposes. The effectiveness of this type of binder depends on the electrical surface charge. The Bitor America Corp. provided low cost samples of emulsified asphalt; these samples are very costly to package and ship from the high Orinoco River, Venezuela to Missouri.

As needed industrial involvement will be maintained and extended.

**Publications**:

Wilson, J.W., "End-of-Pipeline Requirements for Coal Log Pipeline Technology," Proceedings of 4th International conference on Bulk Material storage, Handling and Transportation and 7th International Symposium on Freight Pipelines, July 6-8, 1992, Wollongong, Australia.

Wilson, J.W., "Studies of the Probable Impact on Utility Plants of A Coal Log Pipeline Transportation System," Proceedings of the 17th International Conference on Coal & Slurry Technologies, Apr. 28-May 1, 1992, Florida.

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

Wilson, J.W. and Y. Ding, "A Technical and Economic Assessment of Coal Log Pipeline Technology at Electric Power Generating Plants," Proceedings of the 18th International Conference on Coal & Slurry Technologies, Apr. 26-29, 1993, Florida.

Ding, Y. and J.W. Wilson, "Evaluation of hydrophobic Binders for Use in Manufacturing Coal Logs for A Coal Log Pipeline System," Proceedings 10th Annual International Pittsburgh Coal Conference, Sep. 20-24, 1993, Pittsburgh.

Marrero, T.R. and J.W. Wilson, "Coal Log Pipeline Transport System and Technology," Proceedings, ASME/IEEE Power Generation Conference, Kansas City, Oct., 1993.

Wilson, J.W. and T.R. Marrero, "Concept and Performance of Coal-Log Pipelines," Journal of the South African Institute of Mining and Metallurgy, Oct. 1993, pp. 267-271.

Wilson, J.W. and Y. Ding, "The Influence of Binders on the Performance of Coal Logs in A Pipeline Transportation System," Proceedings, International Mechanical Engineering Congress and Exhibition, The Institution of Engineers, Australia, will be published in May 1994.

**Project Title: Hydrodynamics of CLP**

**Principal Investigator:** Henry Liu, Professor of Civil Engineering

**Duration:** 9/01/92-8/31/94

**Expenditure:** $115,258

**Research Associates:** Mike Holder (1.0 person/year)
James Richards (0.5 person/year)

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

**Graduate Research Assistants:** C.C. Cheng (0.5 person/year)
X. Huang (0.5 person/year)
James Richards (0.5 person/year)

**Other Students who worked on project:** Mike Holder (0.3 person/year)
P. Paksanonda (0.2 person/year)

**Purpose of the Research:**

To investigate important features of the hydrodynamics of CLP and HCP previously unexplored, or insufficiently explored. To derive the hydrodynamic equations and to collect the experimental data required for efficient design and operation of CLP.

**Need for the Research:**

Prior to the establishment of the Capsule Pipeline Center, many important aspects of the hydrodynamics of CLP (Coal Log Pipeline) and HCP (Hydraulic Capsule Pipeline) were either unexplored or poorly understood. For instance, there was no reliable method or equations that can be used to predict the pressure gradient and the capsule velocity in HCP or CLP under various conditions of commercial operations. No information existed as to whether polymers that are effective for drag reduction (energy conservation) in ordinary liquid pipe flow are also effective in CLP or HCP. How coal logs are damaged in pipe by wear-and-tear and how to minimize such damage was not explored at all. How coal logs and capsules can get jammed in a pipe and how to prevent such jamming from occurring was unexplored and so forth. All these required attention and research.

**Research Progress (9/1/91-8/31/94)**

**(a) Theory/Equations for Predicting Behavior of CLP and HCP**

An effort has been made to formulate a theory and derived a set of equations for accurate prediction of the behavior of capsule flow in HCP which is the same as for CLP. As a result of this effort, a new theory and a set of equations have been derived [1]*. The new theory is based

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* Numerals in [ ] refer to corresponding items in <u>Publications</u> listed at the end of this individual project report.

on the realization that there are four distinctly different regimes of capsule flow, and the equations for predicting pressure gradient, capsule velocity and so forth differ for different regimes. Experimental data were also collected to verify the accuracy of the theory; the theory showed good agreement with data—see example in Fig. 1.

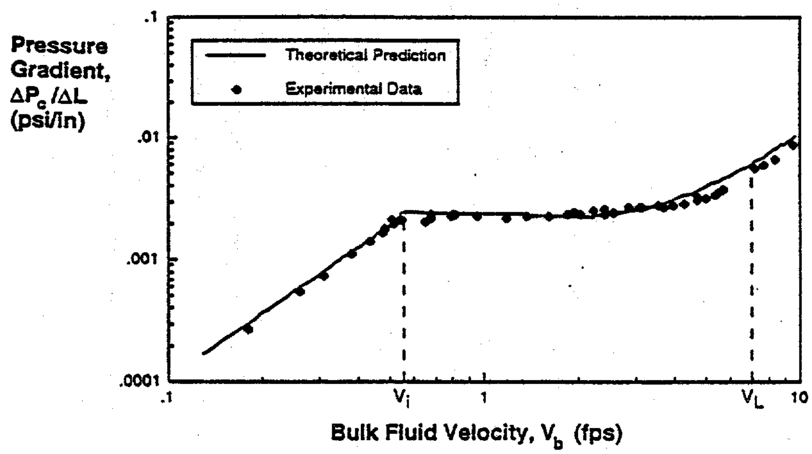



Fig. 1 Variation of Pressure Gradient with Velocity in a 2" Coal Log Pipe: Comparison of Theory with Test Data

A theory and associated equations have also been derived to predict the pressure gradient, capsule incipient velocity, and capsule drag coefficient for a stationary capsule in pipe [2]. This information is needed to analyze capsule (coal log ) motion in pipe during start-up and shut-down of the pipeline system. Again, the theory was substantial by experimental data.

## (b) Drag Reduction

The energy consumed by a pipeline depends on the drag or resistance to the flow—higher drag causes greater energy consumption. Long-distance liquid pipelines such as the Trans Alaska Pipeline routinely use an additive to the flow to reduce drag and conserve energy from pumping. The additive commonly used is a polymer such as polyethylene oxide. It has been reported that Canadian researchers tried drag-reducing additives in HCP in the 1970's but found them ineffective. The P.I. suspected that the Canadian study was done at a time when the knowledge of drag reduction and the knowledge in HCP were both immature. For instance, the concept of capsule lift-off and the fact that drag reducing additives are effective only for reducing fluid drag (turbulence) and ineffective for reducing drag caused by contact friction between solids (capsule and pipe) might not be known to the earlier researchers. In any event, the Center was undaunted by the negative test results report in Canada and tried the polymer in HCP at and near lift-off condition. Very positive results were produced. We found that as much as 400% reduction in energy (drag reduction = 0.75) is possible by using polyethylene oxide at very small concentration (25 ppm) [3]. This result has strong practical implications.

**(c) Coal Log Abrasion (Wear) in Pipe**

This part of the research is focused on understanding the various ways (modes) coal logs can be damaged during hydraulic transport through pipe, understanding the damage mechanism of each mode, deriving equations and collecting test data on the damage caused by each mode, and finding ways to mitigate coal log damage/wear through design changes and special operational strategies. So far, the various modes of coal log damage in pipe have been identified. They include: (1) erosion of coal logs by water, (2) abrasion by coal particles in water, (3) abrasion by rough joints, (4) abrasion by jet pumps (only in laboratory systems), (5) abrasion by pipe bends, (6) impact of coal logs on a partially closed valve in an accident, (7) impact (collision) between coal logs, and (8) impact due to water hammer. Experiments to explore some of the most important modes (such as abrasion by rough joints) are currently underway. The research will be completed in the Spring of 1995 when the Research Assistant (C.C. Cheng) completes his Ph.D. research in coal log wear [4].

**(d) Absorption of Water by Coal Logs in Pipe**

Considerable amount of data on coal log water absorption have been gathered and reported by various researchers in our Coal Log Fabrication Group. An example is [6]. A theory is needed to interpret the test data and to predict the rate of coal log water absorption based on the fundamental properties of the log such as porosity and permeability, and on the water pressure the coal log is exposed to. Such a theory and the related hydraulic equations based on 2-phase flow through porous medium have been derived [7]. The P.I. plans to engage a research assistant to conduct some carefully planned experiments to check the validity of the theory, and to use the verified theory and equations to predict the absorption of water by coal logs moving through a pipe under various conditions. The work will start in the Summer 1994.

**Significant Accomplishments:**

1. Established a theory and derived a set of equations for predicting the headloss (pressure gradient) and capsule velocity in HCP and CLP. Verified the theory by experiments.
2. Derived a set of equations to predict the headloss, drag coefficient and incipient velocity for stationary capsules in pipe. Verified the theory by experiments.
3. Demonstrated the effectiveness of using a small amount of polymer to reduce energy consumption (drag reduction) in CLP and HCP.
4. Developed an understanding as to how coal logs can be damaged in pipe and how to mitigate such damage—see attachment to this project report.
5. Developed a theoretical model and derived the equations for flow through a porous log [5]. The equations can be used to predict the rate at which water is absorbed into logs and expelled from logs, depending on ambient pressure variations.
6. Resulted in a number of publications, including those listed herein.

**Future Plan (4/1/94-8/31/95):**

For the next 17 months (until August 31, 1995), the Center's research in hydraulics will be focused on the following:

1. Extend the drag reduction study to large (8") pipe and test the effectiveness of combining polymer with fiber which is believed to further increase drag reduction and reduce polymer degradation rate. Another type of polymer (Chemlink) which may be more effective than

polyethylene oxide will also be tested.

2. Complete the coal log damage/wear study.
3. Conduct a coal log wear test in an existing commercial pipeline in Conway, Kansas.
4. Study the effect of pipe bends and slopes on capsule hydraulics.
5. Conduct experiments to verify a theory and a set of equations for predicting water absorption into coal logs.
6. Conduct capsule jamming research. This is listed as a separate project headed by Dr. Seaba.

**Publications:**


1. Liu, H. (1993). "Hydraulics Behaviors of Coal Log Flow in Pipe," Freight Pipelines (Editor: G. F. Round), Elsevier Science Publishers, pp. 215-230.
2. Liu, H. and Richards, J.L. (1994). "Hydraulics of Stationary Capsule in Pipe," Journal of Hydraulic Engineering, ASCE, Vol. 120, No. 1, pp. 22-40.
3. Huang, X., (1994). Polymer Drag Reduction in Hydraulic Capsule Pipeline, M.S. Thesis Department of Civil Engineering, University of Missouri-Columbia (To be submitted in May) (Adviser: H. Liu).
4. Cheng, C.C. (1994). Wear and Damage of Coal Logs in Pipeline, Ph.D. Dissertation Proposal, 51 pages. (Adviser: H. Liu).
5. Liu, H. (1993). A Preliminary Theory to Predict Water Absorption Rate of Coal Logs, CPRC Internal Report (July 1993), 20 pages.
6. Chen, S.H. (1993). Effects of Particle Size, Binder Concentration and Compaction Pressure on Selected Properties of Coal Logs, M.S. Thesis, Department of Chemical Engineering, University of Missouri-Columbia, 102 pages (Adviser: T.R. Marrero).
7. Liu, H. (1992). "Design and Operational Considerations of Hydraulic Capsule Pipelines," proceedings of the Workshop on Capsule Pipelines, Japanese Society of Multi-Phase Flow, Tokyo, Japan, pp. 26-50.

**Project Title: Slurry Transport of Coal Logs**

**Principal Investigator:** James Seaba, Assistant Professor of Mech. & Aero. Engineering

**Duration:** 2/1/92 - 8/31/93

**Graduate Research Assistant:** Gang Xu (0.5 person/yr)

**Expenditure:** $24,634

**Purpose of the Research:**

To study the feasibility of using coal slurry in place of water as the transporting medium in the CLP. A commercial coal slurry from Williams Technologies Black Mesa pipeline was used.

**Need for the 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. 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 (2/1/92 - 8/31/93):**

This project was 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 external proposals have been submitted which include the acquisition of a new viscometer.

Coal slurry models coupled with the capsule pipeline model have been studied to provide insight into Coal-log/coal-slurry hydrodynamics. 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.

An extensive test facility has been designed and built for this project. 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. 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" H2O) in a relatively high pressure system (~120" H2O) is difficult. The present system uses two differential pressure transducers to measure the pressure change caused by the coal log train within ±0.04" H2O. This is a significant improvement compared to the previous method.

Capsules with an aspect ratio of 2 and 4, and diameter ratio of 0.8 have been tested in both water and coal slurry using the new system. The results show a significant decrease in the capsule lift-off velocity, as well as other interesting hydrodynamic transport effects, refer to the publications section for further details. From a hydrodynamic standpoint, coal slurry transport of coal logs is promising especially for denser coal logs (S>1.25) and more research in this area is required to fully understand its potential.

**Significant Accomplishments:**

For the first time, capsules in coal slurry have been tested and evaluated for possible CLP applications. The test results are very promising, but further work is required to fully assess the possible impact of using coal slurry in place of water. The test data showed that coal slurry could transport dense coal logs (S>1.25) that water could not transport in a commercial pipeline. Present manufacturing techniques produce dense coal logs (S>1.3) which only coal slurry can transport. During the testing of the capsules in coal slurry a novel pressure measurement technique was developed to accurately measure the capsule pressure drop.

**Future Plan:**

The coal slurry effects on coal-log transport is not the current emphasis of the CPRC. This project was terminated on August 31, 1993. However, proposals have been submitted to other funding agencies to investigate this concept.

**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

Seaba, J.P., and Xu, G. "A Novel Method to Measure Pressure Gradient in Capsule Pipeline" ASME Journal of Fluids Engineering, submitted 11/1/93.

Seaba, J.P., and Xu, G. "Capsule Transport in Coal Slurry Medium" ASME Journal of Fluids Engineering, submitted 1/2/94.Xu, G., "Behavior of capsules in slurry medium in a pipe," M.S. Theses, Dec. 1993.

**Industry Involvement:**

The support of Williams Technologies Inc. is greatly appreciated, in particular Hank Brolick, Joe Anderson, Lowell Hinkins and Jack Tennant provided the coal slurry used in the test and technical insights which proved helpful for this study.

**Project Title: Coal Log Jam Prevention**

**Principal Investigator:** James Seaba, Assistant Professor of Mechanical and Aerospace Engineering

**Duration:** 1/01/94-8/31/94

**Expenditure:** $21,367

**Research Associates:** None (0 person/year)

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

**Graduate Research Assistants:** E. S. Yap (0.5 person/year)

**Other Students who worked on project:** None (0 person/year)

**Purpose for the Research:**

To investigate the various ways that coal logs may jam in a pipe and to develop effective strategies to prevent such jamming. How to best unclog a jammed underground pipeline will also be studied.

**Need for the Research:**

Laboratory tests of coal logs and capsules in pipelines have revealed that under adverse conditions coal log and capsules may jam in the pipe. While jamming in a laboratory pipe presents no serious problem, jamming in a commercial underground, long-distance pipeline can be difficult to unclog and hence its poses serious threats to the reliability of CLP and HCP systems. While many ways to prevent coal logs and capsules from jamming in pipe are known through years of experience in operating laboratory CLP and HCP systems, a thorough and systematic investigation of the subject is justified. Effective measures to prevent jamming can be developed only after the subject is clearly understood.

**Research Progress (1/1/94-8/31/94)**

This research project started only recently (1/1/94). A plan has been developed to test both simulated coal logs (plastic logs) and true coal logs in a 2-inch-diameter pipe recirculating loop. The pipe is transparent so that any capsule or coal log jammed in the pipe can be observed and photographed from outside. The simulated coal logs will be tested first; they are cut from plastic rods of different diameters and different specific gravities. The aspect ratio (i.e., length-to-diameter ratio) of the logs will also be varied. The test will be carrier out at different linefill rates—up to 95%. After the plastic logs have been tested, selected tests will be carried out with true coal logs.

Preparation is underway for the tests. The plastic rods used for making the simulated test logs have been purchased. More than 500 simulated logs have been fabricated from the rods. The first test is expected to take place in April.

**Significant Accomplishments:**

Since the project started only recently, there is no accomplishments to mention other than the fact that a good test plan has been developed and good progress has been made in preparing for the tests.

**Future Plan (4/1/94-8/31/95):**

Testing will start in April and will continue through the summer of 1994. Different logs will be tested at different velocities and linefill rates. Whenever jamming is produced, the location of jamming will be pinpointed, observed by eye and photographed. Then, a momentary reverse flow will be produced to unclog the jam. How to best apply a momentary reverse flow such as generated by water hammer to unclog the jam will be studied. It is planned that testing of the plastic logs will be completed by 8/31/94. Then, real logs will be tested in the same pipe loop. An effort will also be made to analyze the various conditions of jamming and to derive equations that can be used to predict jamming of coal logs in pipe.

**Publications:**

Since this research is new, it has not yet resulted in publications. However, one M.S. thesis and more than one paper are expected to result from this study in a year.

**Project Title: Unsteady Flow and Water Hammer in CLP**

**Principal Investigator:** Charles W. Lenau, Professor of Civil Engineering

**Duration:** 9/01/91-8/31/94

**Expenditure:** $105,130

**Research Associates:** None (0 person/year)

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

**Graduate Research Assistants:** Majed M. El-Bayya (0.5 person/year)
Rattanathip (Anna) Phimjaichon (0.5 person/year)
Jianping Wu (0.5 person/year)

**Purpose of the 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 the 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 and coal log location be predicted. Much can be learned about the transients without actually considering the interaction of the water and the coal logs. However, predicting the coal log locations requires consideration of the coal-log water interaction. Hence the need for a mathematical model for coal-log water interaction to check designs before a coal log pipeline is built.

**Research Progress** 9/01/91-8/31/94:

Unsteady Flow of Coal Logs

Majed M. El-Bayya designed and built an apparatus for studying hydraulic transients in coal log pipeline. With this apparatus he tested single coal logs with various aspect ratios, diameter rations and densities. El-Bayya also tested trains containing two and three coal logs. Pressure heads at two locations where measured with pressure transducers and capsule location was tracked with the use of six photocells located along the pipe. Measurements were recorded at closely spaced time interval via a data acquisition computer. The coal logs were released from rest near an upstream head tank and moved downstream where they were recovered in a downstream head tank. The water was flowing through the system before coal log release.

El-Bayya compared the measured coal log velocities, coal log displacements and pressures with theoretical values predicted by a slight modification of the rigid capsule model described in his M. S. thesis [El-Bayya, M., 1991]. He found that the theoretical and experiment values were in good agreement for a diameter ratio of 0.85 but only fair for a diameter ratio of 0.7. El-Bayya suggests that the rigid capsule model be modified to account for certain coal log end affects that had been neglected in the model.

At this time (March 94) El-Bayya is working on what we hope will be his final draft of his dissertation. He should graduate in May 94.

(2) Pump Bypass and injector Systems

Rattanathip (Anna) Phimjaichon completed her M. S. thesis in August 92 [Phimjaichon, 92]. She studied the hydraulic transients generated by the valve switching in a pump bypass system. For this analysis the coal-log water interaction was neglected. Because her work was reported in detail in the Two Year Report it is not included here.

Jianping Wu studied unsteady flow associated with an injector system with and without consideration of the water 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 (locks). 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 where never cross-connected. Modifications of the original injector design where made to avoid other cross-connection problems that were discovered.

Wu also found that during valve switch-over the pressure in certain pipes drop so low that column separation occurs. Thinking that column separation may have certain advantages he also investigated the injection system used a column separation model (without coal logs). He found that column separation only caused problems and had no advantages. The column separation was eliminated by adopting a two stage valve closure strategy.

Wu also studied the passage of trains through a pump bypass system. He found that there was some expansion and compression (an increase or a decrease in coal log spacing) as the train approached, moved through, and moved downstream of the bypass. There was however, very little net change in the train length as a result of passing through a bypass system.

At this time (March 94) Jianping Wu is also completing his dissertation. He should graduate in May 94.

**Significant Accomplishments:**

Majed M. El-Bayya's experimental work verifies the rigid capsule model that was used by Wu and will be used in the future by others. As the rigid capsule model is modified El-Bayya's data can be used to see if the modifications are appropriate.

Jianping Wu uncovered a number of potential problems with the original concept of the injection system. He has changed the design to avoid some of these problems and has worked out a practical valve closure strategy that eliminates others. His work also demonstrates when the water coal-log interaction is important and when it can be neglected.

**Plan for Future** (4/1/94-8/31/95):

**Tasks:**

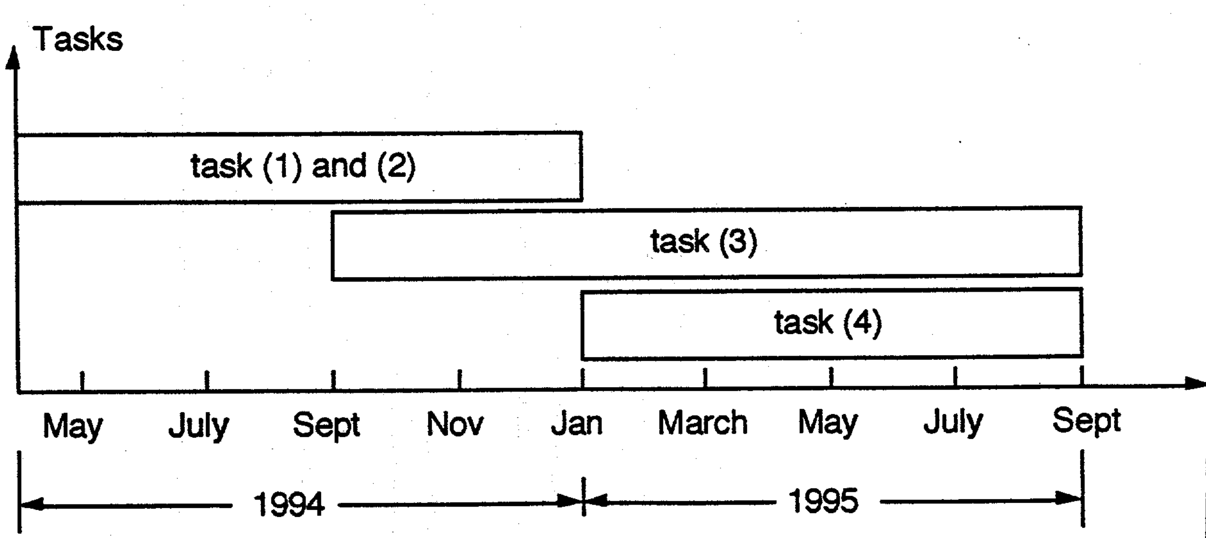
(1) The rigid capsule model will be modified to include pipe slope and coal log end effects.

(2) Perform dynamic analysis of proposed 8 inch 12 mile long test loop.

(3) Analyze various scenarios for startup, shutdown, restart, and emergency shutdown.

(4) Prepare a manual of practice for dynamic analysis.

**Schedule:**




**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 has been accepted for publication.

**Patents:** none

**References:**

El-Bayya, M.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 CLP**

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

**Duration:** 9/1/91 - 8/31/94

**Expenditure:** $93,244

**Research Associates:** None (0 person/year)

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

**Graduate Research Assistants:** J. Wu (0.5 person/yr; co-advised by Liu, Lenau, and Nair)
C. Y. Shieh, D-X Sun, and H. Du (0.25 person/yr each)

**Other students who worked on the project:** None (0 person/yr)

**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. Issues include mechanical hardware design, valve and sensor design requirements, their reliability, and distributed control architecture and strategy design. Incorporation of safety features into the control design is also of considerable importance.

**Research Progress (9/1/91 - 8/31/94):**

<u>Year I</u>: A demonstration unit of the entire Coal Log Pipeline (CLP) system was built to study the coordinated control and operational strategies and issues. The total length of the automated small-scale 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. The ejection system consists of a conveyor belt which transports the coal logs out of the reservoir for storage. A 486-based IBM compatible computer with data acquisition and control cards was selected as the control and coordination platform. The control decisions are based on the sensor

data input from approximately 16 optical sensors throughout the system. This involves careful coordination of over 40 devices, and also incorporation of possible experimental vagaries.

Although the implementation worked, the Y-shaped joints at the inlet and by-pass sections often caused jamming of the capsules. The reasons for this are a combination of air entrainment through joint leak spots, as well as the joint geometry itself. Similar jamming problems occurred at the divertor part of the pump bypass system also. A mechanical redesign of the entire system was undertaken to ensure rugged and reliable mechanical functioning prior to control implementation.

Year II: 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. 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. The control software was also upgraded considerably with user friendly modules for individual device operation and check, as well as trouble shooting. Two students, C-Y Shieh and D. X Sun completed their MS Reports the details of which are as given below:

[1] Shieh, Choung-Yaw, "Computer Control of a Small Scale Pipeline System," MS Report, August 1993.

[2] Sun, De-Xiang, "Design of Certain Mechanical Subsystems for an Automated Capsule Pipeline," MS Report, August 1993.

These reports dealt with two separate issues concerning the computer controlled small-scale pipeline system. One dealt with the computer system, interfacing, control algorithm and program development aspects while the other pertained to the mechanical design aspects for several subsystems. Both the studies provided considerable experience with several issues regarding the design of such systems at a large scale level, which was the main objective in each case.

Shieh's report dealt with computer hardware configuration and software design issues, including relevant literature review; a comparison of distributed control architectures using PLCs, RTUs and microcontrollers; a comparison of SCADA options; software design for real-time control and monitoring; implementation of multi-tasking control for simulating actual injection system functioning; incorporation of safety features such as controlled startup and emergency shutdown; development of diagnostic routines; and finally, extensions to commercial pipeline systems and future research.

Sun's report included mechanical design issues such as design, implementation and testing of Y-joints (4); design, implementation and testing of a high performance divertor ; design, implementation and testing of prebent pipe sections; two proposed designs for train separator -

electromagnetic brake and flow by-pass types; a proposed design for automatic injection subsystem; observational studies using the computer controlled testbed system based on upwards of 50 runs; extensions to large scale systems and future research.

Both studies, in addition to reporting the improved designs and projected use in commercial pipelines, also documented carefully all details regarding the test bed system which included mechanical drawings, control program documentation, specification sheets for all sensors and proposed computer configuration, etc. This provides an excellent source for developing operational manuals, both hardware and software, at a later stage of the project where the test bed system is envisaged to be used for training purposes.

Year III: After the conclusion of Sun's study, it was felt that the design of a train separator was the most critical, since, in comparison, the other issues were understood better. Hongliu Du, a Ph.D. student started on the project in Aug. '93. The first step in the design of the train separator was a good understanding of the conditions under which it would operate. Much time was spent on analyzing this realistically. The following objectives for the design were finalized: (i) the system should be capable of operation with any inter-capsule and intra-train spacing, i.e., assume that the capsules will be 'all together' as they arrive at the pump bypass system, with random spacing between them. (ii) the design should be simple, rugged and 'fail-safe'. (iii) pipeline operational velocity is 8 ft/s. (iv) an emergency stop procedure is required.

After considerable work, a design was arrived at that appears to be 'simple' and rugged, which would make the control easy and reliable. Note that, although fancy designs are easy to arrive at, for reliable functioning of the system over long periods, it is necessary to have the least reliance on sensors, computers, etc. and to let the mechanical design itself do 'most of the work.' It consists of two flow bleed systems with water valves, a train stopper, and an emergency stopper. This design was worked out in concept and preliminary mathematical modeling has been performed using the method of characteristics.

**Significant Accomplishments:**

In addition to gaining considerable theoretical insights concerning modeling and control strategy design, a very important overall accomplishment has been 'experiential' knowledge, i.e. continued modification of the designs based on experiments. This has continually gone on for three years resulting in a large body of knowledge regarding the design and functioning of such a system. Specifically, they include:

(i) The successful redesign of the mechanical subsystems of the test bed system contributed to reliable automatic operation for long periods; more than a year. 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. The small scale system now continues to serve as a test-bed for a host of relevant studies including high speed operation, subsystem design modifications, and strategy design. New ideas in system integration, which is a complex issue have been gained, and have been published.

(ii) Insights into control strategy design have been obtained that are significant for the development of the large scale system. This has been coupled with a 'design for control' approach, with significant emphasis placed on the mechanical design of the subsystems, which considerably minimizes the control overheads i.e., complexity of the control strategy and the control hardware, making the overall system rugged and reliable. Such an approach is being

pursued with the train separator design where a novel design is being studied that relies minimally on sensors and computers for reliable operation. A patent application is also being developed for the design.
(iii) A better understanding of the computer and sensor needs for such systems have been developed so that the important and complex issues of redundancy in devices, sensing and control, as well as safety issues can be addressed in a systematic manner.

**Future Plan (4/1/94 - 8/31/95):**

(i) One of the important subsystems the design of which is critical for reliable CLP operation is the train separator. The main function of the train separator is to ensure adequate spacing between trains as they enter the pump bypass system through the divertor. Several designs have been proposed for such a separator and the most promising one, a flow-bypass type design, will be investigated in detail. A detailed simulation model of the flow-bypass design will be developed using the method of characteristics for studying transient problems when valves are switched and the stopper is engaged.
(ii) The separator design will be tested using the automated small-scale system in the hydraulics laboratory. This will involve adding a recirculating line in the test loop. Since it is very difficult to predict intra and inter-train spacing dynamics using simulations, observation experiments on the small-scale system will be conducted including investigating train spacing changes during long duration travel, effectiveness of flow bypass in reducing capsule speeds, energy loss analysis, etc.
(iii) The computer hardware requirements including distributed control architecture, as well as sensor requirements, etc. (refer to the attached minutes of the control work session) will be investigated by another student.
(iv) The complete control hardware-software design for an 8 inch, 12 mile long test loop will be developed.
(v) Finally the findings will be documented in theses and manuals, and submitted for presentation at appropriate forums and for publication.
Tasks (i) and (ii) will be performed by one student while tasks (iii) and (iv) will form another student's research. Both students will contribute towards the completion of task (v).

## 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.

## INDUSTRY-CPRC WORKSESSION ON CONTROL

A full-day work session was organized devoted solely to Control-related issues, to facilitate interaction between industry and CPRC and to obtain input from industry. Specifically, the objectives were to review progress in CLP control research, to plan for future research, and to obtain input for the design of a control system for commercial operation of CLP. The session was very successful and the details have been documented in the attached minutes of the session.

**Publications and Graduate Student Theses/Dissertations:**

[1] Sun, D-X. and Nair, S. S., June 1994, "Design of Certain Mechanical Subsystems for an Automated Capsule Pipeline," *International Conference on Advanced Technology and Equipment in Material Handling*, China (accepted for publication).

[2] Nair, S. S. and Wu, J. P, April 1993, "Theoretical and Experimental Considerations for Coal Log Pipeline Control Systems - Preliminary Study," *International Technical Conference on Coal Utilization and Fuel Systems*, Clearwater, Florida, pp. 747-758.

[3] Shieh, Choung-Yaw, "Computer Control of a Small Scale Pipeline System," *MS Report*, August 1993.

[4] Sun, De-Xiang, "Design of Certain Mechanical Subsystems for an Automated Capsule Pipeline," *MS Report*, August 1993.

[5] Wu, Jianping, "Dynamic Modeling of an Hydraulic Capsule Pipeline System and its Control," *Ph.D. Dissertation*, NSF Capsule Pipeline Research Center, pending (co-advisor with H. Liu and C. Lenau)

**Project Title: Legal Research in CLP**

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

**Duration:** 9/01/91-8/31/94

**Expenditure:** $53,262

**Research Associates:** None (0 person-year)

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

**Law Research Assistants:** Beth Phillips (3L: 1991-92) (0.2 person-year)
Nicole Cress (3L: 1992-93) (0.2 person-year)
Pat Sullivan (2L: 1992-93) (0.2 person-year)
Jim Kelly (3L: 1993-94) (0.2 person-year)
Eileen Petito (2L: 1993-94) (0.2 person-year)

**Other Students who worked on project:** Paul Rechenberg (0.1 person-year)

**Purpose for the Research:**

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

**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 (9/01/91-8/31/94):**

During the first three years of the project, several legal investigations were begun, many of which were completed. Some of these topics were identified at the beginning of the project; others were identified as a result of early research or comments by evaluators. They are:

Eminent domain topics:
(1) coal pipeline eminent domain statutes (right of way) -- completed.
(2) public use requirement for eminent domain -- completed.
(3) government eminent domain over government land -- completed.
(4) public utility acquisition of rights-of-way over federal land -- completed.

Pipelines crossing railroads topics:
(1) general case law of one utility right-of-way crossing another -- completed.
(1) pipeline/railroad crossing statutes -- completed.
(2) pipeline/railroad crossing cases -- completed.
(3) Pacific Railroad Act pipeline/railroad crossing cases -- completed.

Pipeline conversion topics:
(1) general law on easement reversion upon use conversion -- completed.
(2) general law on defining scope of easement -- completed.
(3) obtaining texts of typical oil & gas pipeline easement forms -- completed.
(4) obtaining texts of *Williams Pipe Line* easements in Boone County MO -- completed.
(5) analysis of *Phillips Natural Gas* decision -- completed.

Water rights topics:
(1) riparian rights law (eastern states) -- completed.
(2) eastern state diversion permit statutes -- completed.
(3) prior appropriation law (western states) -- completed.
(4) groundwater diversion law -- completed.
(5) transfer of eastern water rights -- completed.
(6) transfer of western water rights -- completed.
(7) coal pipeline eminent domain statutes (water rights) -- completed.
(8) state water export regulatory statutes & interpretative cases -- completed.
(9) federal authority to authorize diversions of water from federally navigable waters contrary to state law -- comnpleted.
(10) federal licensing of diversions from federal reservoirs -- completed.
(11) Indian reserved water rights and relation to state water rights systems -- completed.
(12) transfer of Indian water rights to non-Indians -- completed.
(13) analysis of interstate equitable apportionment cases -- preliminary analysis completed.*
(14) public trust doctrine and effect on diversion rights -- completed.*

Water pollution topics:
(1) analysis of brine discharge lawsuits -- completed.*
(2) regulation of brine discharges -- in progress.
(3) jurisdictional waters cases under federal Clean Water Act -- completed.
(4) "pollutant" definition cases under federal Clean Water Act -- completed.
(5) "point source" definition cases under federal Clean Water Act -- completed.

Environmental assessment topics:
(1) NEPA thresholds for EIS preparation -- completed.*
(2) NEPA requirements for EIS analysis -- completed.*
(3) identification of pipeline construction EISs -- in progress.

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.

Miscellaneous topics:
(1) analysis of proposed state "property rights" taking definition statutes -- completed.
(2) railroad authority to operate coal pipelines under Interstate Commerce Act -- completed.

Remedial legislation topics:
(1) identification of hearings of past federal coal pipeline eminent domain bills -- completed.
(2) obtaining texts of prior proposed federal and state remedial legislation -- in progress.

*Note* *: research derived from other unfunded non-CLP projects of principal investigator.

**Significant Research Findings (9/1/91-8/31/94):**

Eminent domain topics. Coal pipelines have right-of way eminent authority in 22 states. Rights-of-way across federal land are obtained from the administering federal agency. The licensing procedures are generic, regardless of the type of right-of-way requested. To minimize environmental effects, the federal agencies prefer to place new rights-of-way parallel and contiguous to existing rights-of-way.

Pipelines crossing railroads topics. 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.

Pipeline conversion topics. Many oil and gas pipeline, particularly odler ones, use easement forms whose purpose clauses do not encompass coal transport. Pipeline easements limited to transport of "oil and gas" will revert if converted to coal transport use; pipeline easements authorizing transport of "liquids, gases, and solids" or "anything transportable in a pipeline" will not revert. We obtained the texts of typical oil & gas pipeline easements to determine the likelihood of reversion upon conversion oil and gas pipelines to coal transport use. Some easements restrict use to oil & gas pipelines, other allow any pipeline use. The former would revert, the latter would not.

Water rights topics. Coal pipelines have water rights eminent domain authority in 1 state and are denied such authority in 2 states. Eminent domain must be exercised if water rights cannot be obtained under water rights law. In the eastern states, water rights are an incident to ownership of the bank of a stream; the riparian has a right to make a reasonable use, provided that the uses of other riparian's are not unreasonably affected. Water must be used on riparian land. The case law is mixed whether riparian water rights can be transferred to nonriparians in the eastern states. Although the diversion permit statutes in half of the eastern states allow nonriparian uses, the relationship between permit and common law rights has not been established. In the western states, waters rights are obtained by diverting or impounding water for an economic use. Time of first use determines the priority between conflicting uses, the prior use being fully satisfied before later uses get any water. These water rights are initiated by obtaining a state permit. There are no place of use restrictions in prior appropriation states. All western prior appropriation permit statutes allow transfers; but they are allowed only if the rights of other appropriators are not significantly affected. Thirteen states regulate interstate exports of water; there are no cases interpreting those statutes. The federal government does not have general authority to authorize diversions from navigable waters contrary to state law. Water can be diverted from federal reservoirs for domestic and industrial purposes, provided the diversions do not interfere with primary reservoir purposes.

Miscellaneous topics. Indian tribes are water rights generally superior to rights granted to non-Indians under prior appropriation law, because the Indian reservations in the West were established before significant irrigation was begun. The tribes regulate water use and diversions on the reservation by Indians, but not be non-Indians. It is not clear that the tribes can transfers their rights to non-Indians for use off the reservation.

**Publications and Lectures (9/1/91-8/31/94):**

(1) *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 Engineers, Australia, Rpt. No. 92/7, June 1992). This 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 at Wollongong NSW, Australia, on July 6, 1992, I discussed the eminent domain statutes in all 50 states.

(2) *Legal Aspects of Coal Pipelines in the United States -- Preliminary Findings*, On April 29, 1993, in Proceedings of 18th International Technical Conference on Coal Utilization & Fuel Systems, at 735-46 (Coal & Slurry Technology Ass'n, April 1993). This later version of the first paper was prepared with the assistance of my research assistants, Nicole Cress and Pat Sullivan, and was presented in Clearwater FL on April 29, 1993. It covered the same topics, 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.

(3) J.P. Sullivan, *Regulatory Takings--The Weak and the Strong*, 1 MISSOURI ENVT'L LAW & POLICY REV. 66-73 (Fall 1993). Prepared by one of my research assistants, this article analyses various state "property rights" taking definition statutes. These statutes would specify the circumstances under which administrative regulatory action would be considered excessive under the Fifth Amendment and would constitute a taking requiring either invalidation of the action or compensation to the adversely affected landowner. If enacted, these statutes could influence the way the states administered varous permit statutes (such as, right-of-way permits, water diversion permits, water rights transfers permits, and water export permits).

**Plan for Future (4/01/94-8/31/95):**

Eminent domain topics:
(1) coal pipeline as a public use.

Water rights topics:
(1) use of brine for coal pipeline: permitting.

Water pollution Topics:
(1) rights of riparians below waste discharge point.*
(2) NPDES permitting topics.*
(3) coal leachate disposal requirements.

Environmental assessment topics:
(1) identification of typical pipeline construction environmental effects requiring EIS analysis.

Miscellaneous topics:
(1) effect on coal pipeline regulatory issues of proposed state "property rights" taking definition statutes.
(2) railroad authority to operate coal pipelines under state statutes.
(3) anti-trust issues in railroad ownership and operation of coal pipelines.

<u>Remedial legislation topics</u>:

(1) analysis of committee hearings on prior proposed federal remedial legislation.

(2) identify legal issues requiring remedial legislation.

(3) draft remedial legislation:

  (a) right-of-way eminent domain,

  (b) water rights eminent domain,

  (c) pipeline use conversion/easement reversion,

  (d) other problem areas.

<u>Publications</u>:

(1) 4 law review articles on coal pipeline legal topics:[1]

  (a) eminent domain, pipelines crossing railroads, and pipeline conversion topics,

  (b) water rights topics,

  (c) Indian water rights issues (by J. Kelly),

  (d) remedial legislation topic.

(2) legal manual discussing all topics.

*Notes* *: research derived from other unfunded non-CLP projects of principal investigator.

[1]: there is not enough new material in the water pollution and environmental assessment topics to justify inclusion in a law review article, but will be included in the legal manual. We do not know whether we will be able to obtain the material needed for an article on the ETSI v. RR conspiracy litigation topic.

**Project Title: Economics of CLP**

**Principal Investigator:** Henry Liu, Professor of Civil Engineering

**Duration:** 9/01/91-8/31/94

**Expenditure:** $62,876

**Research Associates:** James Richards (0.5 person/year)

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

**Graduate Research Assistants:** Robert Zuniga (0.5 person/year)

**Other Students who worked on project:** None (0 person/year)

**Purpose for the Research:**

To perform a detailed analysis of the economics of using CLP to transport coal, and to compare the CLP coal transportation costs with other modes of transport including truck, unit train and coal slurry pipeline.

**Need for the Research:**

All the sponsors and potential sponsors of the Center's research would like to know the anticipated cost of transportation of coal by CLP as compared to other modes of transport including truck, unit train and slurry pipeline. The economic analysis also helps to determine the focus of our CLP research and to optimize the design of future commercial CLP systems.

**Research Progress (9/1/91-8/31/94)**

The economic research is based on engineering economic analysis using a life-cycle-cost method—the same method used by the Office of Technology Assessment (OTA), U.S. Congress, for assessing coal slurry pipeline economics. All the anticipated costs of the CLP system, including coal preparation cost, coal log fabrication cost, binder cost (if any), pipeline construction cost, right-of-way cost, end-of-pipeline cost, water cost, energy costs, operation cost, interest rates, profits and so on are included in the model. The model calculates unit transportation cost for CLP in mills per ton-mile as a function of transportation distance by slurry pipeline, truck and train.

**Significant Accomplishments:**

The study resulted in a 2-volume, 248-page report [1]* that serves several purposes including the following:

(1) It helps researchers to determine the cost of various components of a CLP system so that they know where the research emphasis should be in order to accomplish greatest cost savings.

(2) It helps planners of future commercial projects of CLP to determine which projects are potentially economical and which are not. This helps greatly in initial screening of economically feasible projects for future (more detailed and site-specific) economic studies.

(3) It shows the conditions (ranges of throughput and transportation distance) under which CLP is more economical than rail, truck and slurry pipeline.

(4) It forms the basis of future site-specific economic studies that must be performed for every promising project to be developed.

**Future Plan (4/1/94-8/31/95):**

(1) Based on the current cost model, conduct a sensitivity analysis to determine the degree of influence of various factors (such as inflation rate, discount rate, water cost, etc.)

(2) Conduct a detailed comparison of the UMC model (based on the OTA model) with the pipeline industry (PI) model and the EPRI (Electric Power Research Institute) model. Assess their similarities as well as differences. Offer perspectives and comparisons.

(3) Revise and update the 1993 report [1] by incorporating latest research findings and improved understanding of the CLP technology. Include all the three cost models (OTA, PI and EPRI), and give separate results based on the three models.

(4) Conduct research to determine increases of rail tariffs under various conditions.

(5) Starting 1/1/94, the Center has engaged Dr. James Noble, Assistant Professor of Industrial Engineering, to help in the economic analysis. Dr. Noble will play an increasing role in the economic analysis.

---

* Numerals in [ ] refer to corresponding items in <u>Publications</u> listed at the end of this individual project report.

**Industry Involvement:**

The Williams Technologies, Inc., Tulsa, Oklahoma, was intimately involved in this economic study. The company checked the validity of our draft economic report, offered oral and written comments and suggestions, and provided an analysis of a few cases using the Pipeline Industry (PI) model so that the results could be compared with the UMC/OTA model. Model comparison was discussed in detail at the January 11, 1994 Work Session in Columbia. Hank Brolick of Williams Technologies, and Dennis Turner of Williams Pipe Line, attended the one-day Session.

**Publications:**

1. Liu, H., Zuniga, R. and Richards, J.L. (1993). Economic Analysis of Coal Log Pipeline Transportation of Coal, CPRC Report No. 93-1, 248 pages.

2. Liu, H. (1993). "Coal Log Pipeline: Economics, Water Use, Right-of-Way, and Environmental Impact," proceedings of the 10th International Pittsburgh Coal Conference, pp 23-29.

3. Liu, H. (1994). "Coal Log Pipeline: Implications for Electric Utilities, paper presented at the American Power Conference, Chicago, Illinois, 4 pages.

**Project Title: End of Pipeline Requirements for Coal Log Pipeline Technology**

**Principal Investigators:** Thomas R. Marrero, Associate Professor of Chemical Engineering
John W. Wilson, Professor and Chairman of Mining Engineering

**Duration:** 9/01/92-6/30/93

**Expenditure:** $50,000

**Research Associates:** None (0 person/year)

**Post-Doctoral Fellows:** Yungchin Ding (1 person/year)

**Graduate Research Assistants:** Yungchin Ding (0.5 person/year)
Pamela Luchon (0.25 person/year)

**Other Students who worked on project:** None (0 person/year)

**Purpose of the Research:**

The purpose of this research is to explore and define the end-of-the-pipeline requirements for the handling and utilization of coal logs at electric utility plants. The pulverized coal, cyclone and fluidized-bed coal combustion furnaces are anticipated to utilize the transported coal logs.

**Need for the Research:**

The research is designed to evaluate the influence that coal logs may have on the existing coal storage, handling, and combustion systems at utility plants. Possible modifications to existing coal handling facilities at utilities to accommodate the pipeline transported coal logs, are a major concern to the utility companies. So this study focuses on defining the possible impact of using coal logs on the crushing, pulverizing, combustion and water treatment facilities existing at the utility plants.

**Research Progress (9/1/91-8/31/94)**

In this project, a team at both the Columbia and Rolla campuses, prepared extruded coal logs from bituminous, sub-bituminous and lignite coals using up to 7 weight percent binder. The coal logs were immersed in water for 5 days at 500 psi, and the logs were tested for grinding and combustion characteristics after removal from the pressurized water. The water was analyzed for pH, dissolved substances, biological oxygen demand, and free available chlorine. These data were compared to environmental regulatory criteria. The end-of-pipeline functional requirements for systems to handle coal logs and treat water were specified for pipeline systems with throughputs of 2.2-, 8.5-, and 20 million tons/year. For these systems the capital and operating costs were estimated.

The results of this research indicate that coal logs can be used by utilities with a minimum of additional equipment such as roll crusher to reduce the delivered logs to 2- in x 0 coal (the size of coal currently supplied to power plants by rail). To ensure satisfactory grinding efficiency coal logs must contain no more than 5% asphalt binder by weight. Water treatment is needed to remove dissolved iron, manganese, and zinc from the pipeline water. The end-of-pipeline total unit costs for coal log handling and water treatment range from 13 to 47 cents per ton of coal. The cost depends on coal throughput and treatment requirements.

A final report was completed and published by the Electric Power Research Institute.

**Plan for the Future:** None, at this time.

**Publications:**

1. Wilson, J.W., Ding, Y., and Zhao, B., "The Influence of Binders on Performance of Coal Logs in A Pipeline Transportation System," MECH'94 International Mechanical Engineering Congress and Exhibition, May 1994 (submitted and received in April 1993).

2. Marrero, T.R. and Wilson, J.W., "Coal Log Fuel Handling and Treatment at Power Plants," Electric Power Research Institute, Final Report EPRI TR-102701s, July 1993.

3. Wilson, J.W. and Ding, Y., (1993). "A Technical and Economic Assessment of Coal Log Pipeline Technology at Electric Power Generating Plants," Proceedings of the 18th International Technical Conference on Coal Utilization and Fuel Systems, April 1993, pp. 759-770.

4. Wilson, J.W., "End-of-Pipeline Requirements for Coal Log Pipeline," Presented at the 7th International Symposium on Freight Pipelines. Wollongong, Australia, July 6-8, 1992.

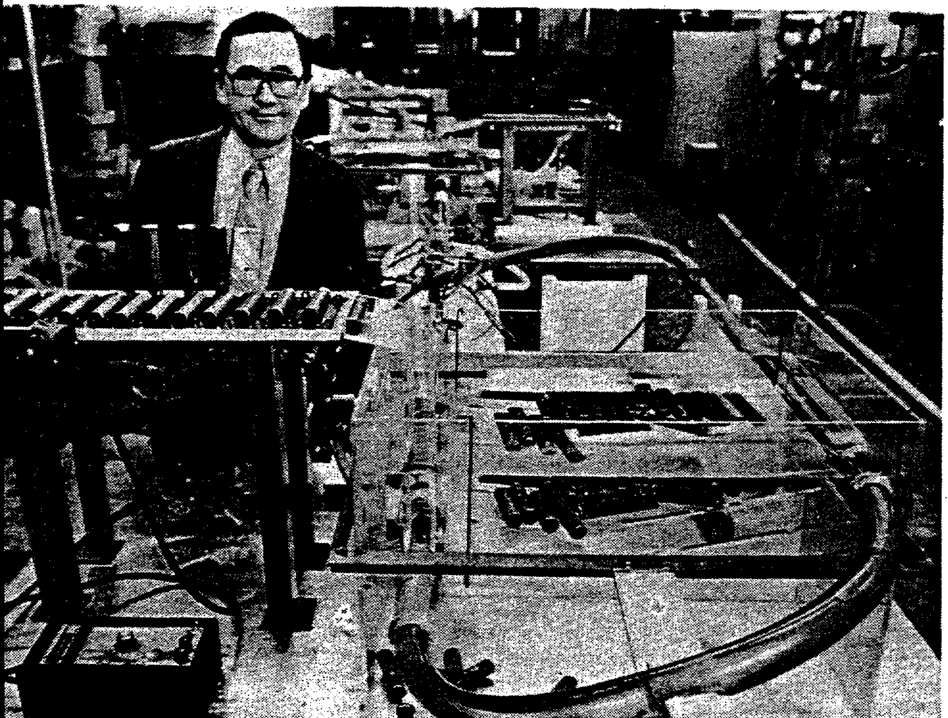
# Appendix 2: Attachments

Montana Grain Growers Association

JUNE 1981

# WHEAT SCOOP

Volume 25, No. 4



. Henry Liu, University of Missouri civil engineering professor says the concept of moving eight, such as grain or coal by hydraulic capsule pipeline has been studied here and in anada for over 20 years, but lack of promotion and the lobbying efforts by railroad and highay interests has made research funding difficult to obtain. Proponents say the system has een proven feasible and would drastically cut freight shipping costs, use less energy and iminate pollution and environmental problems associated with rail and truck movement of eight. Although the system uses water for its transport medium, the water is re-useable and ould not deplete or waste water like the slurry system that is used for coal.

## PIPELINING: DREAM OR REALITY?

With freight movement being concentrated in fewer and fewer rail lines, the competitive factor is being lost as a means of keeping a lid on rates. For Montana, there is no effective competition against rails in shipping grain. Shipping grain by pipeline has been espoused before, but they have been found to have some technical problem that made it impractical. These disappointments, plus many persons believe the idea just sounds too preposterous has prevented acceptance of the idea, let alone support for it. However, a system that has over 20 years in development, shows promise of giving rail carriers some much-needed competition — especially in Montana.

This exciting concept for pipelining grain not only has over 20 years of development behind it, but a working model

See PIPELINING page 4

### *. . . BUT WERE AFRAID TO ASK*

## All About MGGA, MWR & MC

It is apparent there is some confusion bout the functions and difference etween the Montana Wheat Research d Marketing Committee (MWR & MC, so called the "Wheat Commission") d the Montana Grain Growers Association (MGGA) when discussing this with me grain producers. In fact, some owers have told us they thought they tomatically became a member of IGGA when they paid their wheat or rley assessment, and a few considered em the same organization.

The MWR & MC and MGGA are two stinct and separate organizations with fferent missions. Some of the confusion ay be because MGGA initiated and was strumental in the formation of the WR & MC. The Wheat Commission is tached to the Montana Department of griculture for administrative purposes, bookkeeping, checking accounts, audits, etc. MGGA is strictly a voluntary, dues paying association of wheat producers. As an agricultural commodity organization, MGGA can be likened to any special interest group such as the Stockgrowers or the American Medical Association.

Although two different groups, the Wheat Commission and MGGA cooperate closely and support each other in many endeavors. However, they are careful not to duplicate each other's efforts — only to give the type of help that gives the effort more clout or so more can be done; thereby, making these endeavors more effective. A case in point is the work both groups did to retain a USDA Spring Wheat breeding program at Montana State University because of the retirement

See MGGA, MWR & MC page 6

## MGGA OPPOSES BN HOLDING CO.

MGGA's concern about the formation of a holding company by the Burlington Northern was expressed in letter by transportation committee chairman Viggo Andersen to the Interstate Commerce Commission. The letter pointed out that the Milwaukee, Penn Central, and Rock Island Railroads all failed after forming holding companies. The reason for failure is that a holding company structure facilitates and makes it more tempting to transfer rail assets to other more lucrative investments. Holding companies downgrade the role of management in making an operation profitable and make investment decisions the dominating factor in profits.

The letter asked the ICC for an investigation to pinpoint possible holding company actions that would be detrimental to rail operations and in turn to shippers and taxpayers. □

# Is Pipelining Grain a 'Pipe Dream?'

**PIPELINING** from page 1

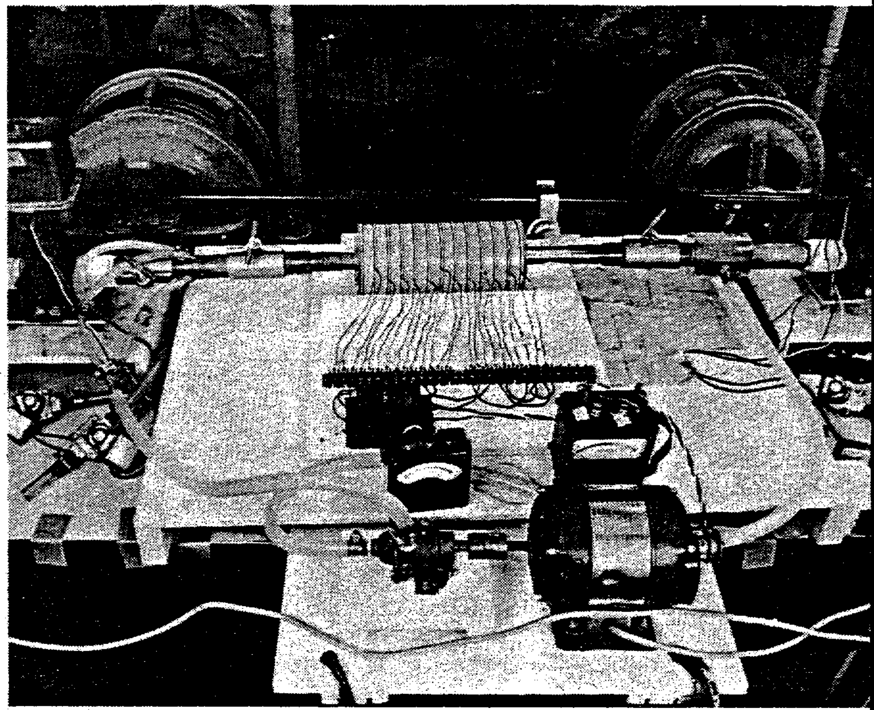
*Editor's Note: We want to thank Dick Hanson, Jr. for allowing us to use material from two articles he wrote on pipelining. Dick is a free lance agricultural writer and has a regular Sunday column in the Great Falls Tribune.*

has been made. Professor of Civil Engineering at the University of Missouri, Henry Liu and his group, recently made a breakthrough in their work that makes pipelining of grain a practical reality. The breakthrough was the invention of a simple, low operating cost pump that is the key to the system. The work at the University of Missouri by Liu and his group is perhaps the only research still underway in pipelining in the U.S.

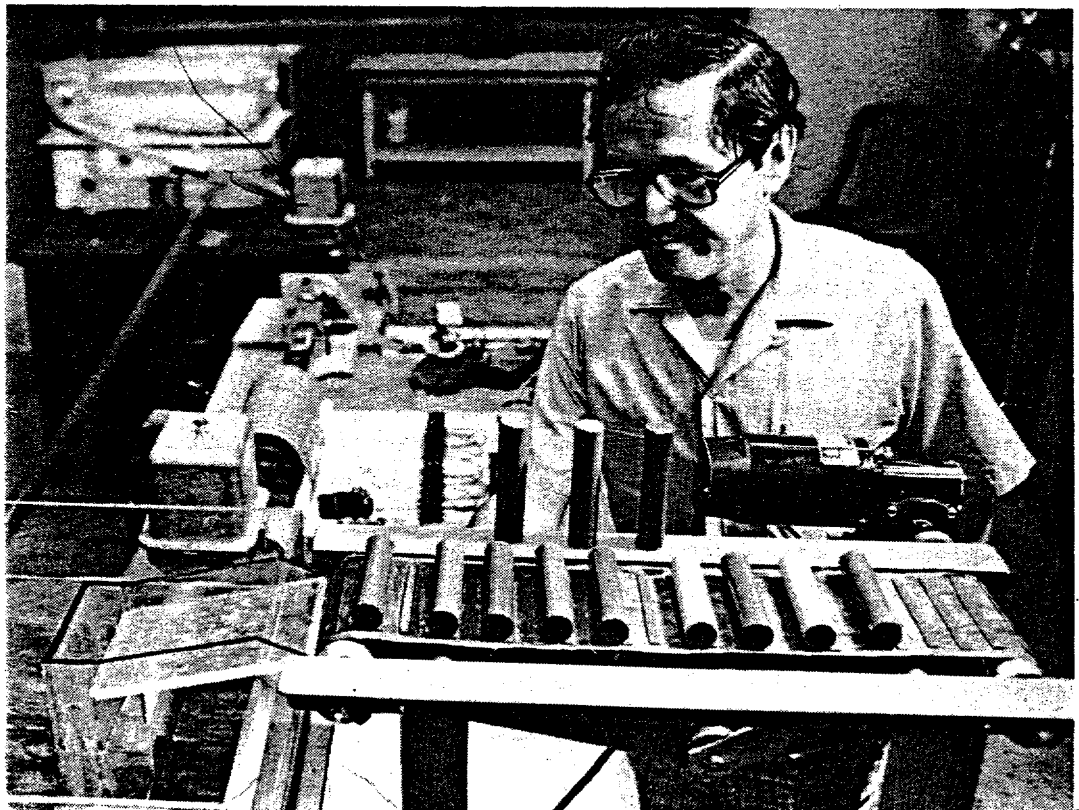
Liu's model is made up of two pipes, 1½ inches in diameter, so the capsules or containers are able to be returned for re-use or with a return load. The loading and unloading system is simple and even allows for temporarily diverting capsules while others pass them. The capsules are watertight and are moved by water in the pipe system, which is pumped by the pump they invented, and is patented. The injectors or loading points are controlled automatically by a laser beam photo cell system. The pump uses a linear induction motor mounted around a segment of the pipe. The electromagnetic field pulls the capsule through the pump making the capsule act like a piston, pushing the water forward.

The water used in the system is re-used, which eliminates depleting water reserves in water short areas and the contamination as in slurry pipelines now used for coal. Liu also said there could be s[...] benefits to the system such as de[...] water to municipal systems or fo[...] tion. The system is energy efficie[...] polluting, and low in noise. Th[...] capsule concept is called "hydra[...] sule pipeline" (HCP), and is ea[...] cheaper to build over rough, irreg[...] rain. Also the capsule system c[...] many other items besides grain, [...] more versatility and by making ba[...] practical, which gives it more [...] potential along with keeping s[...] costs down.

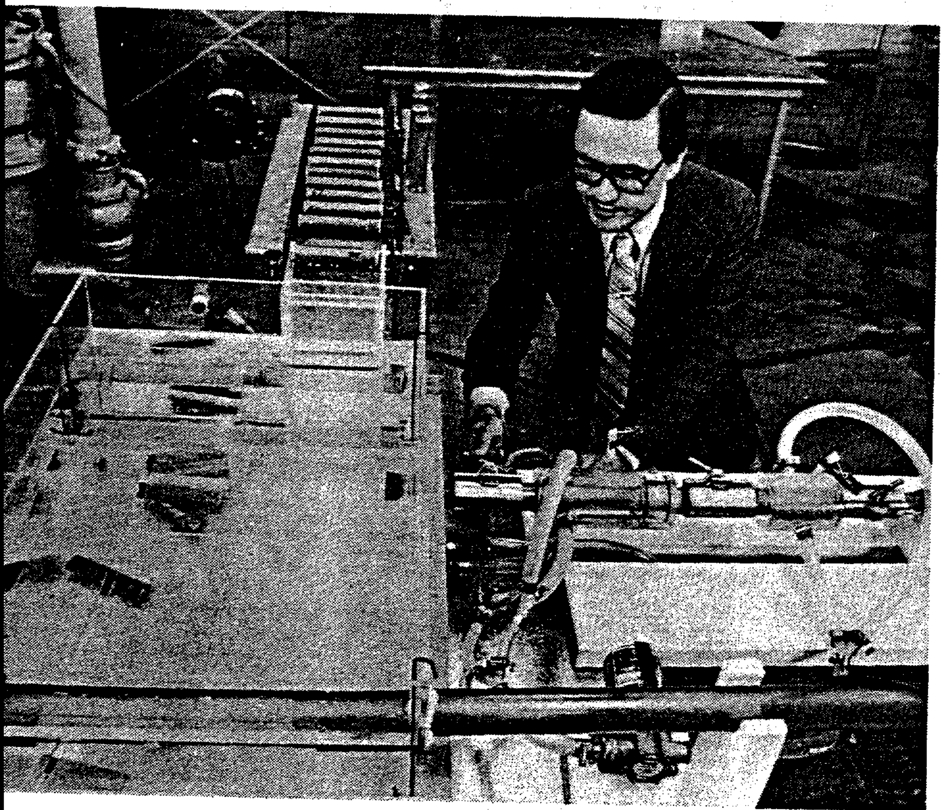
With all that potential, why ha[...] pipelining not received more s[...] "Simply because government at[...] levels and capital sources have no[...] idea explained and sold to them,"[...] ing to one researcher. With unit [...] the picture, and coal demanding [...] the resources and equipment of [...] roads, a more serious look should [...] of HCP. Even the designing of ele[...] handle HCP should probably [...] sidered now. "It's only a matter [...] optimistically states Liu, when [...] will be moving some, if not mos[...] grain and other freight."



The heart of the HCP system is the pump invented by Liu and his group. It is an ele[...] netic unit, which uses a linear induction motor mounted around a segment of the[...] where the line is slightly reduced in diameter. The electromagnetic field pulls the[...] through the pump, and the capsule then acts like a piston, pushing the water forward.

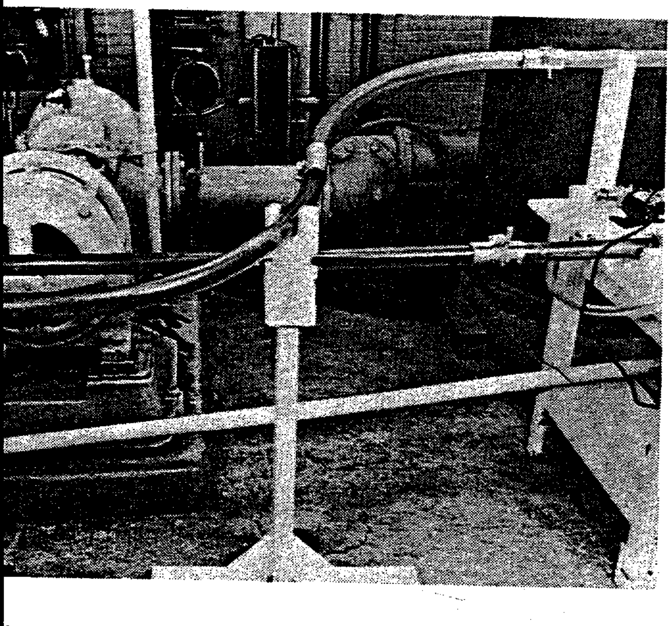


Dr. Henry Liu views the hydraulic capsule pipeline model at the loading or inlet point.

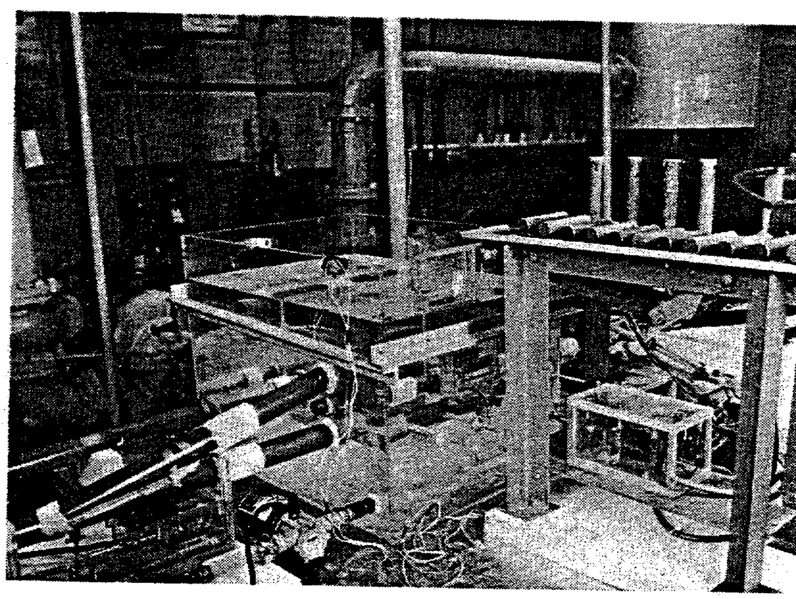


Dr. Liu adjusts a capsule pipeline inlet regulating water flow through the model.

# 'It's only a matter of time . . . . until pipelines are moving some, if not most, of our grain'



lope and bends of the HCP model demonstrates that difficult
n can be easily traversed.



This is an intermediate station of the HCP model which has the functions of both loading and unloading the capsules, and re-directing the capsules to other branch lines of the system.

Attachment 2: DOE Proposal on Full-Scale Facility
(Cover Letter & Abstract)

UNIVERSITY OF MISSOURI-COLUMBIA

College of Engin

Capsule Pipeline Research

E2421 Engineering Buil
Columbia, Misso
Telephone (314)
FAX [314] 8

February 18, 1994

Mr. Ken Askew
U.S. Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940
Pittsburgh, PA 15236-0940

Dear Mr. Askew:

As per Mr. Jack Siegel's instruction and subsequent telephone conversation with you, I am submitting to you the proposal "Full-Scale Test/Demonstration Coal Log Pipeline Planning and Design." The work is to be completed in 14 months, and the budget requested from DOE is $296,265.

The proposed large test/demo facility is an integral part of our plan to complete the R & D and commercialization of the coal log pipeline (CLP) technology in the next three years. Any delay in funding the enclosed proposal will result in a delay in commercial use of this technology. For this reason, I request that this proposal be considered for funding under DOE's current fiscal-year budget, if possible.

We greatly appreciate DOE's interest in helping the University of Missouri and the CLP Consortium to develop and commercialize the CLP technology.

Sincerely yours,

Henry Liu

Henry Liu, Director
Capsule Pipeline Research Center

HL/vb

cc: Mr. Jack Siegal
Mr. George Rudins
Mr. Marvin Singer
Dr. S.W. Chun
Dr. Ralph Carabetta
Mr. Gary Staats
CLP Consortium Members

# TECHNICAL INFORMATION


## Abstract

Coal Log Pipeline (CLP) is an innovative new clean coal technology far superior to coal slurry pipeline for reasons such as:

1. It uses less energy and less water than slurry pipeline.
2. It costs much less to transport coal by CLP than by slurry pipeline.
3. It restarts easily.
4. Dewatering coal is an easy task for CLP.
5. It uses regular water pumps instead of slurry pumps.
6. Coal logs are easy to handle and can be transported by any mode including pipeline, truck, rail, barge, ship and conveyor belt.
7. Coal logs are a versatile fuel that, upon simple crushing, can be burnt in any type of boilers including fluidized-bed, stoker, cyclone and pulverized-coal.
8. Cleanup following any accidents is easy for CLP.
9. CLP can compete economically with trucks for distances as short as 20 miles, and with existing railroads for distances as short as 100 miles. Slurry pipeline is economical only at long distances and for large throughput.

Due to the foregoing reasons, CLP potentially can penetrate a large market that the coal slurry pipeline cannot penetrate. Therefore, when fully developed, the CLP technology can play an important role in transporting coal. The use of CLP in the future for coal transportation not only saves money but also reduces the number of trucks on highways and streets, and reduces the frequency of freight trains passing through cities and road crossings. Consequently, air pollution, traffic jam and accidents on highways and railroads will be reduced, resulting in greater safety and a better environment. <u>CLP is an environmentally friendly new technology vital to national interests</u>.

The CLP technology has been under intensive research and development (R & D) at the University of Missouri-Columbia (UMC). The research has been sponsored not only by government agencies (including NSF, DOE and State of Missouri), but also by more than ten private companies (including electric utilities, coal companies, pipeline companies, equipment manufacturers and consulting engineering firms), and the Electric Power Research Institute (EPRI).

The R & D at UMC has brought about great progress in advancing the science and technology of CLP. However, before the CLP technology can be commercialized it must be tested and demonstrated at full scale. <u>Without such full-scale test and demonstration a reliable commercial system of CLP cannot be built</u>.

The purpose of this proposal is to plan and design a full-scale demonstration CLP syste The system will be a closed-loop 8-inch-diameter pipeline having a total length of 12 miles. T length is needed in order to test the behavior of coal logs moving through pipe under hi (1,500 psi) water pressure—the kind of pressure that will exist in commercial CLP. The distar is the same as that between two neighboring pumping stations in a commercial 8-inch-diame coal log pipeline. The loop will have an injection station, a pumping station, and an ejecti station—all built in the same manner as for a commercial CLP. The entire system will automatically controlled by a computer. The facility can be planned and designed in 14 mont The proposed site is the Thomas Hill coal fields owned by the Associated Electric Cooperative company supporting the CLP research and development. The requested support is for detailed planning and design of the facility, not for construction which would cost approximat $10 million. <u>It is evident that such an expensive and important facility must be carefully plann and designed before it is built</u>.

Once built, the facility will allow the testing of many important aspects of CLP that cann be tested in small-scale loops, or in full-scale components. Theses important experiments incluc

1. Test of water absorption of coal logs moving through a pipe under the high pressu (1,500 psi) that will be encountered in future commercial CLP systems.
2. Test of coal log abrasion (wear) under conditions identical to those of commerc CLP pipelines.
3. Test of special construction techniques for commercial CLP, such as ultra-smo welded joints, precision bending of pipes, internal lining for protection agai abrasion, and so forth.
4. Test of coal log jamming in full-scale pipeline and how to unclog the jam.
5. Test of the effectiveness and the degradation rate of drag-reducing additi (polymers) in CLP.
6. Test of automatic control and operation of commercial CLP systems.

The aforementioned test facility is not only needed for testing coal log pipeline but also other types of hydraulic capsule pipelines that use capsules (cylindrical containers) to transp freights such as grain, flyash, other solid wastes, many minerals, and even finished products su as machine parts. <u>It will be a permanent facility for use by researchers for many years to come. will make the United States the world's leader in coal log pipelines and hydraulic caps pipeline—an advanced energy technology strategically important to the nation</u>.

EPRI
Electric Power
Research Institute

George T. Preston
Vice President
Generation and Storage

February 16, 1994

Dr. Henry Liu
Director, Capsule Pipeline Research Center
College of Engineering
University of Missouri
Columbia MO 65211

Dear Dr. Liu:

EPRI has been interested in your coal log pipeline (CLP) work for a number of years and we are pleased to have contributed financially and otherwise to your progress. We agree with you that if the CLP is developed and deployed the cost of long distance transport of coal will be reduced, either because of CLP use or because of the competitive pressures CLP would exert on railroads.

EPRI is undergoing structural changes in response to the emerging competitive environment in the electricity supply industry. As these changes pertain to your request for $180,000, you must have support from one or more of our customers whose collective funding would match that expected from EPRI. This approach to R&D funding also tends to insure that users are ready to apply a successfully developed technology.

In the meantime, I am aware that Shelton Ehrlich has suggested a meeting with Bill Slaughter at Panhandle Eastern. Bill was involved in the proposed ETSI pipeline and he will likely have valuable insights on commercializing CLP. Also, EPRI's Bill Weber can continue to participate in your utility seminars on the same basis as in the past.

Sincerely,

George Preston / DVH

c: Kurt Yeager
9848L.GTP.dvh

pg 138-139 removed.

3412 Hillview Avenue, Post Office Box 10412, Palo Alto, CA 94303, USA
Telephone: (415) 855-2461
Fax: (415) 855-2954

Attachment 5: Center Newsletter (sample)


# Capsule Pipeline Research Center NEW

COLLEGE OF ENGINEERING UNIVERSITY OF MISSOURI-COLUMBIA VOL. 1 NO. 1, SPRI


## National Science Foundation funds center

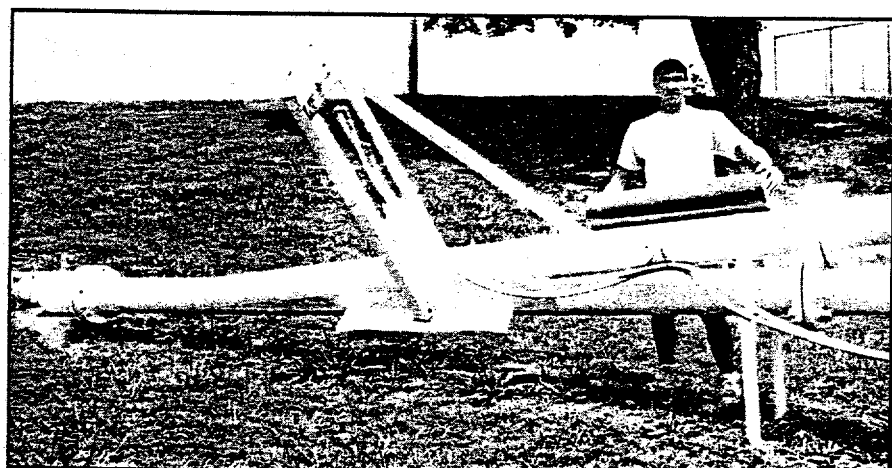
Capsule pipeline researchers at MU received a major boost in 1991 when the National Science Foundation selected MU's proposal to form a state/industry university cooperative research center in capsule pipelines.

The purpose of the Capsule Pipeline Research Center is to accelerate research so that this emerging technology can be developed and used commercially as soon as possible for transporting coal and other minerals, grain and other agricultural products, solid wastes including hazardous wastes, and many other materials and finished products — anything that can be loaded into a capsule of a diameter smaller than the pipe diameter.

## Pipeline demonstrated at dedicatio

*Researchers say they are safe, cost efficient and conserve energy*

The Capsule Pipeline Research Center was dedicated in September at the Freight Pipeline Research Laboratory located in the MU Research Park. About 70 guests, including civic leaders, state and industrial representatives, and research sponsors, attended. The keynote speaker was Sen. Roger B. Wilson, D-Columbia, chairman of the state Senate budget committee. In addition, former University of Missouri System President Peter Magrath, Interim Chancellor and Provost Gerald T. Brouder, and Dean Anthony L. Hines praised the establishment of the center and thanked the sponsors. A capsule pipeline demonstration took place after the ceremony.



*Mike Holder, a civil engineering senior from Shelbina, Mo., is holding one o the capsules he will inject into the 430-foot recirculating prototype pipeline used by the CPRC. These capsules, which could be loaded with solid waste, grain and other agricultural products, must be slightly smaller than the pip diameter. This prototype pipeline is located at the Freight Pipeline Research Laboratory.*

Compared to freight transport by trucks and trains, capsule pipelines incur lower costs, conserve energy, use electricity rather than imported oil and reduce air and noise pollution. In addition, pipelines are safer, more reliable, automatic, less vulnerable to cargo theft during transportation and weatherproof. Because capsule pipelines are underground, they do not interfere with land use for other purposes, do not disrupt highway and railroad operation and prolong the highway life and reduce highway maintenance costs due to reduced use.

Truckers and railroad workers should not anticipate losing their jobs due to competition from pipelines. The transition to them will be gradual. Fewer people will enter trucking or railroad jobs in the future; instead, more will be employed by pipeline companies a associated industries. History shows that whenever superior technology replaces or partially replaces old technology, more jo are created than lost. To maintai the world's highest standard of living and to improve the quality life, the United States must continue developing more efficient and more environmentally soun technologies.

# CPRC research goals include commercialization of pipeline for coal, grain and solid wastes

The Capsule Pipeline Research Center's mission for the first four years (1991-95) is to concentrate on the research and development of the coal log pipeline technol-
ogy. CLP is a new concept in capsule pipelines specifi-
ally for transporting coal. In this technology, coal
articles are first compressed or extruded into log
hapes – the coal logs. The logs, with a diameter
lightly smaller than the inner diameter of a pipeline,
re transported by water through the pipeline from
oal mines to power plants. The pipeline also may
erminate at a barge terminal, sea port or rail station
or further transport.

An economic study revealed that the cost of trans-
orting coal by CLP is much lower than by truck, train
nd coal slurry pipeline. Compared to coal slurry pipe-
ine, CLP has the additional advantage of using much
ess water (one-third to one-fifth of that for slurry pipe-
ines), which is important for pipelines originating in
tates such as Montana or Wyoming. These states have
rge reserves of low-sulfur coal but water shortages.
ince the 1990 Clear Air Act Amendment passed, the
emand for low-sulfur Western coal has been rising
apidly. Using the coal log pipeline will play an
nportant role in minimizing coal transportation cost
nd alleviating environmental problems caused by
sing trucks and trains for coal transportation.

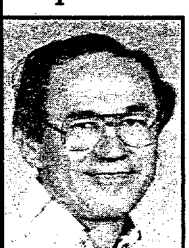
The coal log pipeline also can be used as a part of a strategy to reduce the cost of using high-sulfur coal, which exists in Missouri and many other states. With high-sulfur coal, limestone is added to make coal-limestone logs. When these are burned at power plants using fluidized-bed boilers, the sulfur is removed without using expensive and troublesome scrubbers.

Combining the coal log pipeline with limestone removal of sulfur results in reduced cost of coal transportation and reduced desulfurization cost – a double benefit for power plants. This also shows that coal log pipelines benefit the users of low-sulfur and high-sulfur coal.

After the coal log pipeline technology is developed in four years, the knowledge gained can be applied to transporting other cargoes such as grain and solid wastes. By using waterproof cylindrical capsules, any cargo slightly smaller than pipe diameter can be placed in a capsule and transported by capsule pipeline in much the same way coal logs are transported. After 1995, the research direction of the center will be developing special capsules and special pumps, such as the electromagnetic capsule pump invented at MU, for these special cargoes.

## Encyclopaedia Britannica taps Liu

Henry Liu, CPRC director, has been invited by
ncyclopaedia Britannica to write an article on freight
ransportation by pipeline. This is the first time an encyclopaedia will include a detailed discussion of pipelines and how this mode of transport has contributed to the world's economy and civilization.


Henry Liu

The article describes the strategic role played by pipelines worldwide in transporting water, oil, natural gas and many other materials. Pipelines including aqueducts, sewers, oil
ipelines, products pipelines, natural gas pipelines,
lurry pipelines, pneumatic pipelines, and capsule pipe-
ines also are discussed. This article will appear in the
993 edition. It is expected to help the public under-
tand the value of pipelines to modern nations and also
nfluence national transportation policies.

Liu has been selected by the American Society of
ivil Engineers to receive the Bechtel Pipeline Engineer-
ng Award for his contribution to freight transportation
y pipeline. In addition, he is chairman of the new Pipe-
ine Research Committee established in 1991 by ASCE.

## INTERNATIONAL SYMPOSIUM

The 7th International Symposium on Freight Pipelines, the biennial conference of the International Freight Pipeline Society, will be in Wollongong, Australia, July 6 - 8, 1992. The Australian Institution of Engineers and the University of Wollongong will co-host the event.

Henry Liu and Tom Marrero are the president and the secretary/treasurer of IFPS. The National Science Foundation program on fluid, particulate and hydraulic systems will sponsor 10 U.S. researchers, including MU researchers, to present papers at this important international conference.

To obtain a copy of the symposium program, contact:

**Professor Peter Arnold**
**Dept. of Mechanical Engineering, University of Wollongong**
**P.O. Box 1144, Wollongong, NSW 2500 AUSTRALIA**
**FAX: 61-42-213101**

# Interdisciplinary research includes two MU campuse

The current research and development program at the center is a mini crash program for early development so that the coal log pipeline technology can be used commercially in four years.

To achieve this ambitious goal, many research projects are under way simultaneously. Ten faculty members and more than 20 students from the Columbia and Rolla campuses are conducting center research. The faculty members involved and their respective research topics are described next.

***Brett Gunnink,*** assistant professor of civil engineering, studies the fabrication of coal logs by compaction. ***Peter Davis,*** professor of law, studies legal issues related to the use of coal log and capsule pipelines. ***Charles W. Lenau,*** professor of civil engineering, investigates the unsteady flow and pressure surges in capsule pipelines due to valve closure and pump startup/shutdown. ***Yuyi Lin,*** assistant professor of mechanical and aerospace engineering, investigates underwater extrusion of coal logs and machine design. ***Henry Liu,*** professor of civil engineering, studies the hydrodynamics of coal log flow, pumping, and economics.

***Richard Luecke,*** professor of chemical engineering, studies ways to minimize coal log water absorption. ***Thomas R. Marrer*** associate professor of chemical engineering, studies coal log fabrication by extrusion and binders. ***Satish Nair,*** assistant professor of mechanical and aerospace engineering, studies computer control and automatic operation of coal log pipelines.

***James Seaba,*** assistant professor of mechanical and aerospace engineering, investigates non-Newtonian coal log flow. Finally, ***John Wilson,*** professor and chairman, mining engineeri department, is evaluating coal lo handling and the treatment of C water effluent at power plants.

## CAPSULE PIPELINE RESEARCH CENTER SUPPORT

CPRC research sponsors and the funding for 1992 are summarized below.

| SUPPORTING AGENCY OR SOURCES | AMOUNT |
|---|---|
| National Science Foundation (State /IUCRC Program) | $175,000 |
| State of Missouri (Dept. of Economic Development) | $175,000 |
| U.S. Department of Energy (Energy Related Inventions Program) | $ 80,000 |
| Electric Power Research Institute (EPRI) | $ 50,000 |
| Arch Mineral Corp. | $ 30,000 |
| Associated Electric Cooperative Inc. | $ 30,000 |
| Kansas City Power and Light Co. | $ 30,000 |
| MAPCO Transportation Inc. | $ 30,000 |
| ARCO Pipe Line Co. | $ 15,000 |
| Peabody Holding Co. | $ 15,000 |
| Union Electric Co. | $ 15,000 |
| Williams Pipe Line Co. | $ 15,000 |
| Williams Technologies Inc. | $ 15,000* |
| Bonnot Co. | $ 5,000* |
| Gundlach Machine Co. | $ 5,000* |
| Ramers & Associates | $ 5,000* |
| TOTAL | $690,000 |

** In-kind contribution*

# Short course scheduled on *Pipeline Transportation of Solids*

As part of the technology transfer program mandated by the center's state and federal sponsors, MU will offer *Pipeline Transportation of Solids* June 8-9, 1992, in Kansas City.

This two-day short course includes the fundamentals and the state-of-the-art in pipeline design and application for hydraulic transport of solids such as coal, other minerals, sand, gravel, water and wastewater sludges, power-plant wastes, and many other materials or commodities. Conventional and new hydro-transport technologies will both be covered.

The course is designed for civil, chemical, mechanical, mining and environmental engineers interested in gaining basic knowledge in transporting solids by pipeline. Eight nationally prominent hydrotransport experts will teach this course.

Anyone interested in receiving a copy of the course program should write or call:

*Linda Rodden*
*Engineering Conferences*
*University of Missouri-Columbia*
*Columbia, Mo. 65211*
*Telephone: (314) 882-3088*

## Pneumatic capsule pipeline use expanding in Japanese industry

For years, Japanese industry and government have een actively engaged in research and development f capsule pipelines that use water to suspend and ansport un-wheeled capsules and air to transport heeled capsules through pipelines.

As a result, Japan now uses a three-mile long neumatic capsule pipeline constructed by the umitomo Metal Industries to transport limestone to a eel plant. Japan also is using PCP in other projects, nd is investigating the use of HCP in deep-sea mining f manganese nodules and solid waste transport. In ddition, PCP is used in the former Soviet Union for ansporting crushed rock for construction.

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.

**CAPSULE PIPELINE RESEARCH CENTER**
*College of Engineering*
*University of Missouri-Columbia*
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**ollege of Engineering**
**2421 Engineering Building East**
**olumbia, Mo. 65211**

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**Developi**
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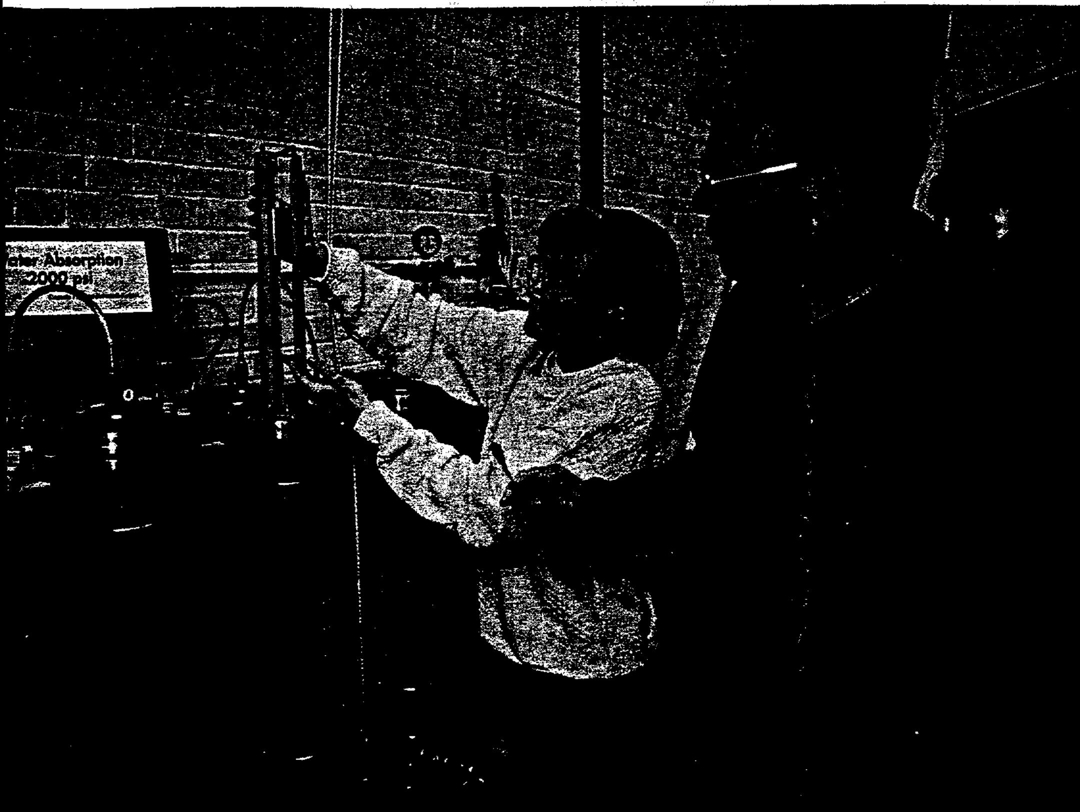
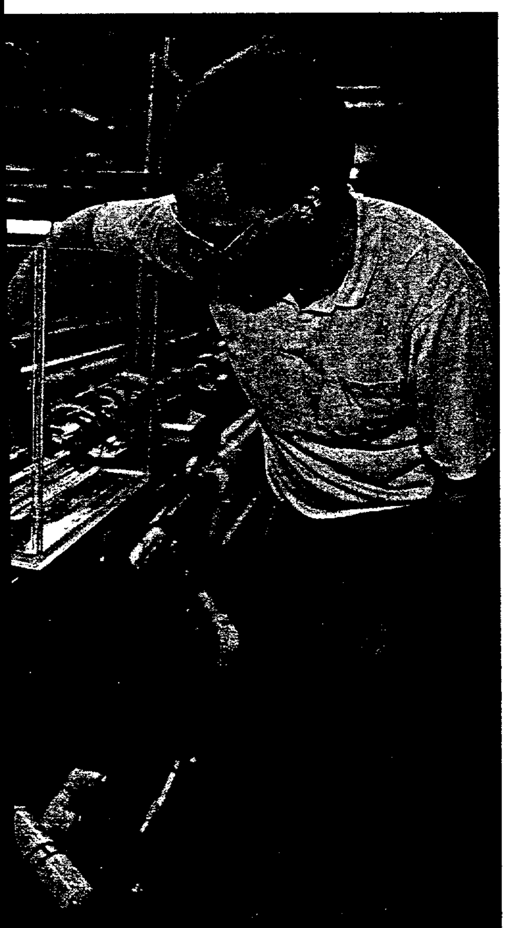
# CAPSULE PIPELINE RESEARCH CENTER

**University of Missouri-Columbia College of Engineeri**



Thomas Marrero, associate director of the CPRC, and research assistant Becky Smith carefully choose test cells of compressed coal logs for the water absorption test.



Research assistant Jim Richards feds coal logs into a 2-inch loop to start the pipeline test, which is 75 feet long and takes about 10 seconds to run.

Costs of goods are skyrocketing due to transportation charges. For example, in 1993, coal bought at Wyoming mines is only $5 a ton. Transported to a power plant in Missouri, it costs $20 a ton.

This means that 75 percent of the coal cost is transportation costs. Much the same is true for transporting grain and other freight over long distances. For this reason, the Capsule Pipeline Research Center has been established to study and develop new pipeline technology for transporting freight.

THE CPRC'S GOAL DURING ITS FIRST FOUR YEARS (1992-95) is to develop the coal log pipeline (CLP), which is an emerging technology for transporting coal. The University of Missouri holds the patent for CLP and two other patents related to capsule pipelines. The main task is developing an optimum system to manufacture coal logs and transport them through pipelines.

After developing the CLP technology, the CPRC will study other forms of hydraulic capsule pipeline (HCP) and pneumatic capsule pipeline (PCP) for freight transportation. These pipelines use cylindrical containers to carry grain, other commodities or solid waste. The PCP uses air instead of water as the transporting fluid.

The National Science Foundation, the CLP Consortium, which consists of utility, pipeline and mining companies, and the Missouri Department of Economic Development each provides annual funds of $200,000 to $250,000 for the core research conducted at the CPRC. In addition, the U.S. Department of Energy, MU's College of Engineering and the Electric Power Research Institute also have contributed significantly to this project. Funding since 1991 has totaled nearly $2 million.

***Current University of Missouri faculty conducting CPRC research***

**Peter Davis**
***Isidor Loeb Professor of Law***

**Brett Gunnink**
***Assistant Professor of Civil Engineering***

**Charles Lenau**
***Professor of Civil Engineering***

**Yuyi Lin**
***Assistant Professor of Mechanical & Aerospace Engineering***

**Henry Liu**
***Director & James C. Dowell Professor of Civil Engineering***

**Richard Luecke**
***Professor of Chemical Engineering***

**Thomas Marrero**
***Associate Director & Associate Professor of Chemical Engineering***

**Satish Nair**
***Assistant Professor of Mechanical & Aerospace Engineering***

**James Seaba**
***Assistant Professor of Mechanical & Aerospace Engineering***

**John Wilson**
***Chairman & Professor of Mining Engineering (UMR)***

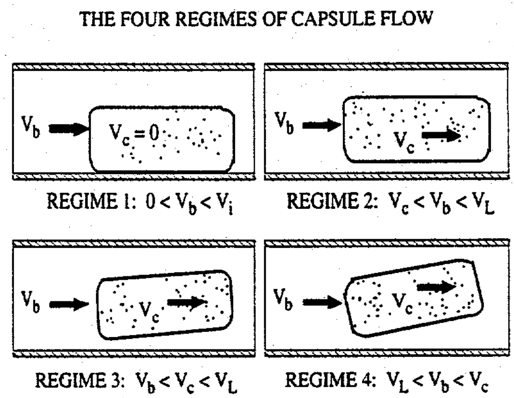
In the top picture, the HCP has circu-
lated grain in metal cylinders. K.H.
Rhea pours dry corn from the capsul
which indicates a successful run.

As the coal logs exit the extruder, L.C
Wang cuts and removes them, as in
the bottom picture. MU researchers,
including Assistant Professor Yuyi Lin,
have succeeded in extruding coal lo
at room temperature and without th
use of binders.

o accomplish the four-year goal of the
PRC, several projects are under way.

- Hydrodynamics of CLP
- Unsteady and Transient Flow in CLP
- Automatic Control of CLP Systems
- Extrusion of Coal Logs with or without Binder
- Underwater Extrusion of Coal Logs
- Vacuum-compaction of Coal Logs
- Large-Scale Coal Log Manufacturing Machine Design
- Coal Log Surface Treatment (Sealant)
- Legal Research
- Economics of CLP
- End-of-Pipeline Study

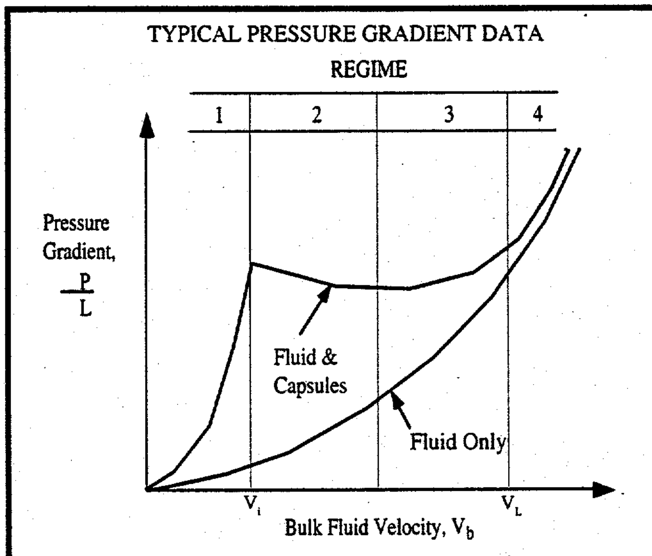
# The Four Regimes of Capsule Flow




Four regimes govern capsule transport through pipe. They are defined by: the bulk fluid velocity, $V_b$ (the average cross-sectional velocity of the fluid); the capsule velocity, $V_c$; the incipient velocity, $V_i$ (the bulk fluid velocity that occurs when the capsule starts to move); and the lift-off velocity, $V_L$. The figure to the left shows the pressure gradient for each of these regimes.

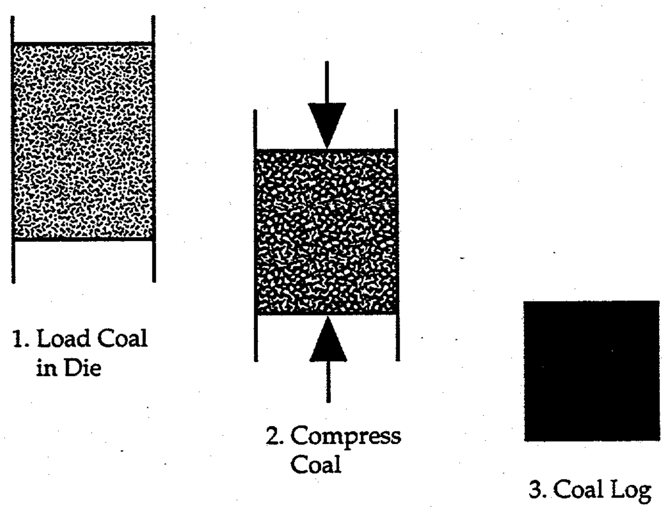
# *Typical Pressure Gradient Regime*

When capsules are introduced into a liquid-filled pipeline, the amount of pressure required to move them is greater than that required to move the fluid only, as shown in the figure to the right. However, at the lift-off velocity (also the operation velocity), the pressure due to the presence of the capsules is only about 30 percent higher than for the fluid. This means the pipeline system can operate with relatively low energy consumption at relatively high velocities–a special advantage of CLP.




## COAL LOG PIPELINE PROCESS

Coal logs that are durable for pipeline transportation have been produced successfully at MU using a binderless compaction process illustrated in the graph at the right. The process involves heating and compaction of coal in a mould (die) to form coal logs. Then the logs are injected into a pipeline using water to carry them to their destination, which is usually a power plant. Upon reaching the plant and exiting from the pipe, the logs are let dry before they are crushed and burned to generate power.

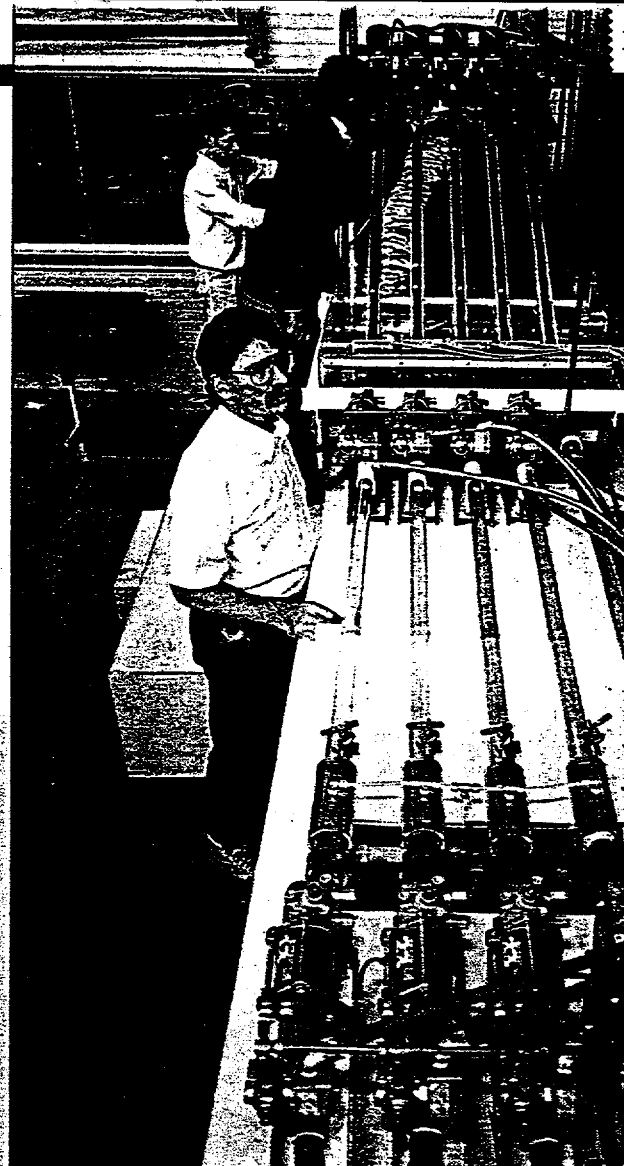



Coal Log Manufacturing Process

# Interdisciplinary Research

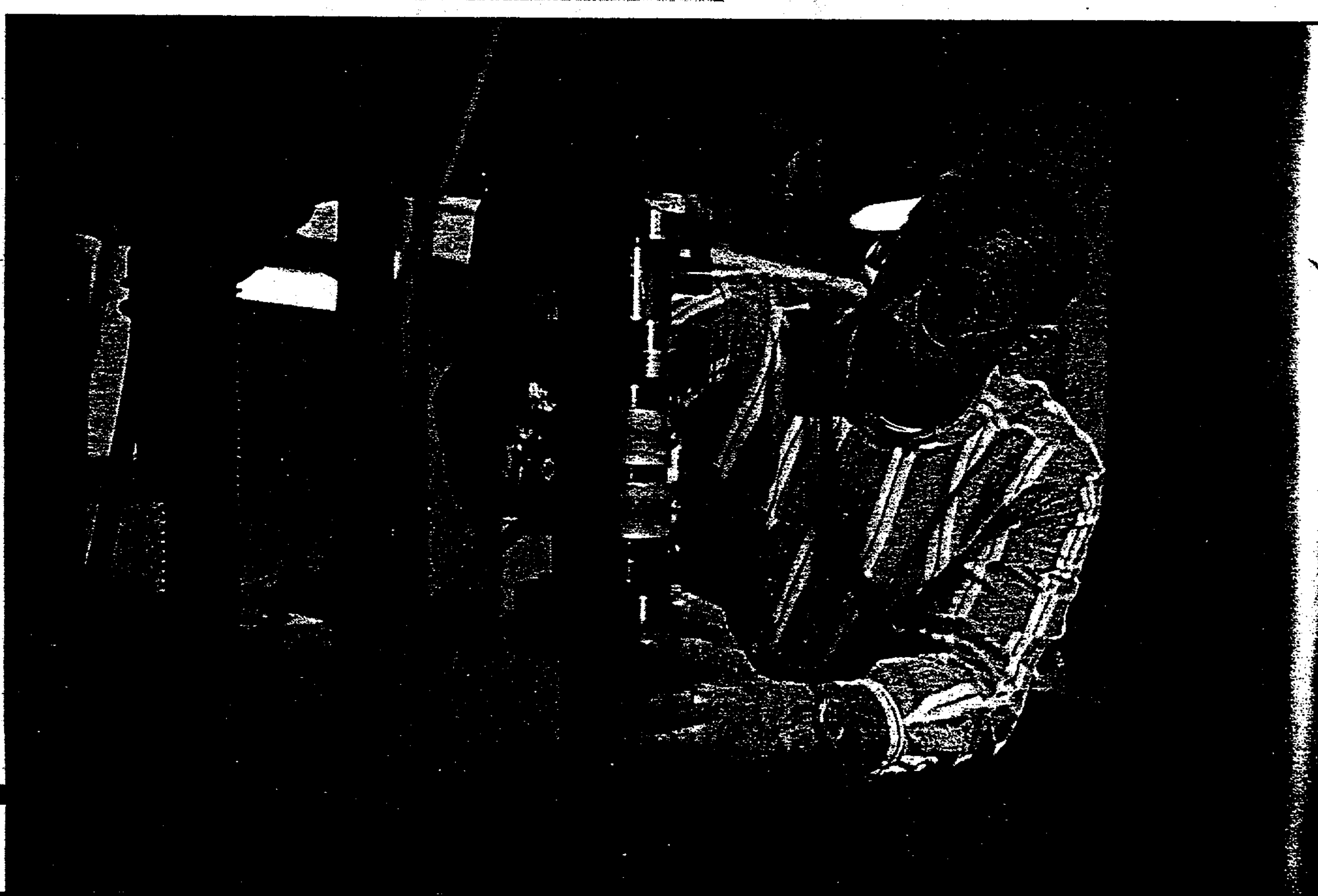
Research underway at the CPRC is highly interdisciplinary. Ten faculty members and about 30 students from four MU engineering departments, the MU law school and the mining engineering department located at MU's sister campus (the University of Missouri-Rolla) participate in the center's research.

Along with the major degree programs, the CPRC offers some pipeline-related courses unique in the nation and the world. These include courses such as Pipeline Engineering, Pipeline Transport of Solids and Suspensions, and Advanced Hydraulic Engineering (Unsteady Flow Through Pipelines).



The small-scale pipeline demonstrates the pumping and injection systems that will be used in commercial operation. Research assistant Jian Ping feds trains of logs into different lines from conveyor belts, being inspected by Assistant Professor Satish Nair. The logs are then pumped out into a single line, monitored by electronic technician Richard Oberto, for transport to their destination.

Below, Assistant Professor Brett Gunnick makes adjustments to a mold before binderless coal logs of varying strengths are made by compaction. Strong logs are compressed this way for long distance transportation by pipeline.



The CAPSULE PIPELINE RESEARCH CENTER supports graduate research assistantships, undergraduate research participation, post-doctoral fellows, research associates and, in special cases, visiting scholars or visiting professors. Those interested in particpating in the center's research should contact:

**Director**
**CAPSULE PIPELINE RESEARCH CENTER**
**E2421 Engineering Building East**
**Columbia, Mo. 65211**
**(314) 882-1810**
**[314] 884=4888**

The capsule pipeline system, which is 8 inches in diameter and 430 feet long, located at the University of Missouri Research Park, is unique in the world. The pipeline's advantages over truck or train transportation include low energy consumption, no air and noise pollution, improved transportation safety and less damage to streets and highways than by heavy trucks.

## Coal Pipelines

# Coal Logs To Move From The Powder River Basin By 2000?

If coal log pipeline technology can be developed for use commercially, and several parties are betting that it can, up to 25 million tons per year of coal could move via pipeline from the Powder River Basin (PRB) to Midwestern destinations. The only catch to this may be development of the technology itself; the issue of eminent domain is not applicable.

The eminent domain problem for new pipelines would be avoided since the coal would move through an existing pipeline or pipelines. These pipelines, which currently transport oil to the Kansas City and St. Louis, Mo. areas, were expected to be retired in 1995 due to dwindling domestic oil supplies. According to Dr. Henry Liu of the University of Missouri, developer of the coal log technology, members of the industry consortium supporting the technology are interested in moving PRB coal through the pipelines to Missouri as at least one of the pipelines runs close to the PRB in Montana and Wyoming.

Financial assistance for commercial development of the technology was recently gained through a National Science Foundation (NSF) grant to the university of $925,000, an amount which will be matched by funds from industry and the State of Missouri. The money was given to the university for the establishment of a national Capsule Pipeline Research Center (CPRC), which will focus on developing the coal log technology over its first four years. Liu said he hopes to have fully developed the technology for commercial use by then, at which time the CPRC would reapply for NSF funding.

The focus of the CPRC will initially be to utili technology to transport PRB coals to Missouri. The un states that the operation of such a project "is expected hundreds of millions of dollars" annually for Missouri u principally realized through a large decrease in transpo costs. The three Missouri utilities (Associated E Cooperative, Kansas City Power & Light Co. and Electric Co.) in the consortium received more than 7.1 tons of PRB coal in 1990, however this tonnage wi increase as the utilities take more PRB coal to comp acid rain legislation.

The other six members of the consortium are MAPCO Arch Mineral Corp., Peabody Holdings, ARCO Pipeli Williams Pipe Line Co. and Williams Technologi (operators of the Black Mesa pipeline). At least one c companies, Liu could not reveal which, has an interest of the pipelines slated to be shut down. Liu has receive than $200,000 from the consortium for development of technology.

According to Liu, the amount of coal that can be tran through a 20-inch diameter pipe using coal logs is 25 tons annually. This is higher than could be transport conventional coal slurries, as the coal log technolo approximately 20 percent water as opposed to the 50-5 coal ratios of slurries (CTR 3/30/90, p.1). Coal logs als at a faster rate (8 ft./second) than slurries (5 ft./secon ollution of the oceans and seacoasts, in an imbalance etween the conventional liner and tramps and the bulk, nit load, container, and roll-on, roll-off ships. New interational regulations are required, including those on pollution. This imbalance was particularly noticeable at the eginning of the 1970s, with an overcapacity of container hips, particularly on the North Atlantic routes, where ontainer capacity exceeded cargo availability by some 50 ercent. This led to withdrawal of some of the consortia om the trade. Equally, the ports of the world competing r the container trade were constructing the necessary cilities far in excess of requirements. At the same time, e industry faced rising costs in both ship construction nd operation. To help meet these higher operating costs, utomatic controls are being applied at every stage of a urney, and the randomness of operation is being elimiated at the same time as the ratio of manpower to vessel ze is being reduced.

The passenger trade faced a more serious and longersting problem. Competition from the airline industry, articularly on the longer sea voyages, had drastically educed demand for passenger accommodations. On the orth Atlantic routes, in 1970, scheduled and chartered rline flights carried 2,202,000 passengers between North merica and Europe, while ships carried only 249,000. To eet this challenge, which was growing with the advent f the jumbo jet, the passenger shipping companies were rning to car ferries and cruises. Their future appears to e in the leisure and holiday field.

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

The shipping industry is unique in that it has an ecoomic and strategic as well as a commercial importance, nd its operations are rarely free from political or strategic nterference by governments. For internal political reasons, ome states consider shipping services as a state monopoly. n practice, however, this is difficult to achieve because a tate's jurisdiction does not extend beyond its recognized erritorial waters. Nevertheless, various practices are oberved from time to time to protect the domestic shipping ndustry and to discriminate against other flags. Higher ort dues may be charged to foreign ships, or national flag hips may be favoured. In bilateral trade agreements it is ometimes stipulated that a fixed proportion of the cargoes nust be carried in ships of the national flag. A common nethod of assisting the domestic shipping industry is to eserve 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 he 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 rade for their own vessels. Assistance in the form of tax exemptions, preferential credit terms, direct subsidy of hipbuilding, or operating costs is often given to protect national fleets.

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 transporte long distances via pipelines. The mixture of oil and natura gas coming out of a well must be transported as two-phas flow by pipelines to processing facilities before the oil ca be separated from the gas. Liquefied natural gas (LNG transported by ships (tankers) also requires short pipeline to connect the ships to onshore storage tanks. Pipeline as long as 180 miles have been built in the United State to transport carbon dioxide to oil fields for injection int reservoirs to enhance oil recovery. Finally, on a smalle scale, most chemical, food, and pharmaceutical plants us pipe to transport various liquids and gases within th plants. When such fluids are corrosive or cannot tolerat impurities, the pipe must be of inert materials.

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

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

Long-distance transport of solids by slurry pipeline mus use relatively fine slurry. Existing coal-slurry pipeline carry fine slurry consisting of about 50 percent coal an 50 percent water by weight. The solid is first pulverize and mixed with water to form a paste. The slurry the enters a mixing tank, which contains one or more larg rotating wheels or propellers that keep the particles uni formly mixed. Next, the slurry enters the pipeline. Specia plunger or piston pumps are used to pump the slurr 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 lin was discontinued later when the competing railroad agree to lower its freight rate. The pipeline was then mothballe for years and used as a leverage against rail rate increases It was said to have prompted railroads to modernize an become more competitive, introducing the concept of th unit train, which employs about 100 cars to haul coa nonstop from mines to power plants.

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

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

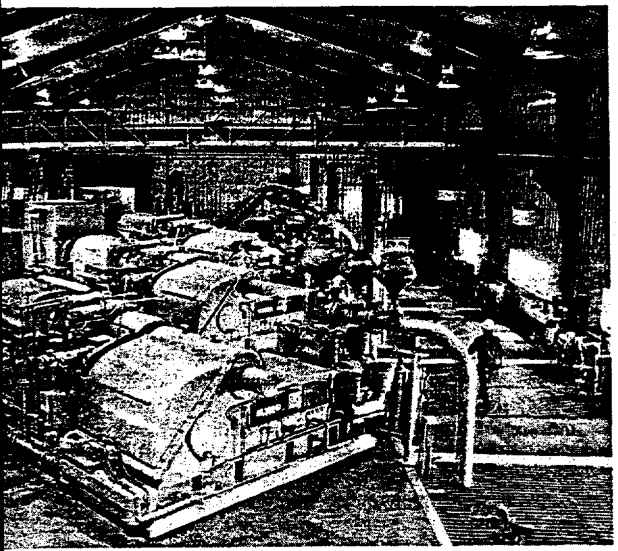


Figure 57: Pumping station (one of four) along the Black Mesa coal-slurry pipeline, running between Arizona and Nevada (see text).
Henry Liu

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.

Capsule pipeline research

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.

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

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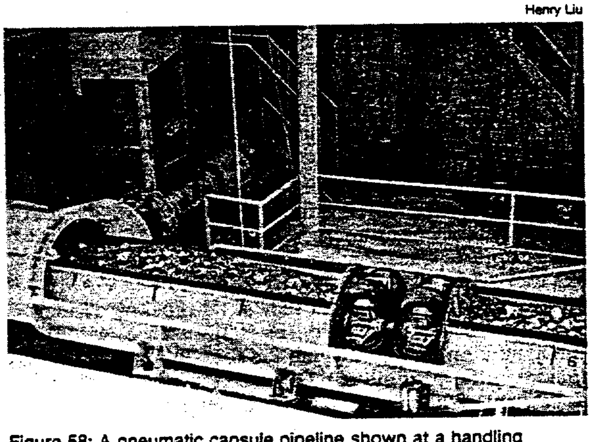

Figure 58: A pneumatic capsule pipeline shown at a handling station. The capsules feature a five-wheeled assembly and linkage at each end. This system transports crushed limestone to a cement plant.

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 the fluid in the pipe if the fluid is corrosive or cont water with dissolved oxygen, carbon dioxide, or hydr sulfide (internal corrosion). Pipeline companies take m measures to prevent corrosion, such as covering un ground pipelines with tape and using cathodic protec against external corrosion and adding special chem (corrosion inhibitants) to the fluid to prevent inte corrosion. Hydrazine ($N_2H_4$) and sodium sulfite ($Na_2$ are two chemicals commonly used to control inte corrosion of metal pipes that carry water. The chem reduce corrosion by reacting with and hence removing dissolved oxygen in water.

Finally, detection of leaks is done by computer m toring of abnormal flow rates and pressure and by fl aircraft along pipelines for visual inspection. Special "p are also sent through pipelines to detect possible flaw the pipeline walls and signs of corrosion. Highly corr pipes are replaced before a leak develops. Often referr as "smart pigs," these carry instruments that detect cr and corrosion of pipeline interiors. (H

## Urban mass transportation

Urban mass transportation is the movement of pe within urban areas using group travel technologies suc buses and trains. The essential feature of mass transp tion is that many people are carried in the same ve (*e.g.*, buses) or collection of attached vehicles (trains). makes it possible to move people in the same travel c dor with greater efficiency, which can lead to lower to carry each person or—because the costs are share many people—the opportunity to spend more mone provide better service, or both.

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

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

Travelers make rational choices of the modes they each choosing the one that serves him or her best though best may be viewed differently by each trav Transportation services in a city define the alterna from which travelers must choose, the activities avai to them, and the places to which they can go. The t portation available to an individual is the collective r of government policies, the overall demand for trav the region, competition among different modes, and resources available to each individual to buy serv Urban transportation services directly affect the char and quality of urban life, which can differ among ind uals who have access to different kinds and amoun transportation services.

### EVOLUTION OF URBAN MASS TRANSPORTATION

**Growth in the 19th century.** The history of urban transportation is first a story of the evolution of tech ogy, from walking, to riding animals, to riding in gr on vehicles pulled by animals, and eventually to c cars, larger-capacity steam-powered trains, electric tr and motor buses powered by internal-combustion eng It is a story of gradually increasing speed, vehicle capa and range of travel that has shaped cities and struct the lives of those who live in them.

Attachment 9: Governor Carnihan's Budget Request for Center

# DEPARTMENT OF ECONOMIC DEVELOPMENT

## POLICY SUMMARY (Continued)

**TECHNOLOGY DEVELOPMENT FOR COMMERCIAL USES:** Missouri's three Centers for Advanced Technology (CATs), supported in part by the Department of Economic Development, actively assist in the development of marketable technology processes and products. The Centers are supported through the cooperation of academic, government, and business interests. To increase the development and sharing of technology, the Governor recommends an additional:

- $250,000 for expansion of the CAT program through conversion of the two-year-old Capsule Pipeline Research Center into a CAT. In addition to research, the Center will develop a strategy to transfer capsule pipeline technology to the private sector.

**STIMULATING FOREIGN TRADE:** In a steadily growing global economy, state economic development efforts increasingly depend on the economic stimulus provided by foreign trade. Foreign trade has become particularly vital to state economic development with passage of the North American Free Trade Agreement (NAFTA) and ratification of the General Agreement on Tariffs and Trade (GATT). The Department of Economic Development seeks to stimulate foreign trade through the operation of foreign offices and a local staff of export development professionals. These offices assist Missouri businesses by developing markets for Missouri goods in foreign countries and providing expertise in the areas of operations and financing. To increase the volume of foreign trade undertaken by Missouri businesses, the Governor recommends an additional:

- $70,000 to establish a foreign trade presence in China and for increasing trade activity in Korea.

**RECOVERING FROM THE FLOOD OF 1993:** Across the state, efforts to recover from the recent flooding continue. To improve flood recovery services offered by the Department of Economic Development, the Governor recommends an additional:

- $132,734 for flood recovery staff who will provide economic recovery planning assistance to counties lacking active Regional Planning Commissions.
- $42,000 for two staff with the Missouri Housing Development Commission to provide housing assistance to flood victims.

**BUSINESS REGULATION AND PROFESSIONAL LICENSING:** In addition to promoting economic development, the department is responsible for regulation of certain businesses and the licensing of professionals. The Governor recommends an additional $936,060 for regulatory agencies in the Department of Economic Development, including:

- $60,865 for a light rail safety specialist in the Division of Transportation to oversee the safety plan of the Bi-State Metro Link Light Rail Transit System. Federal law requires Bi-State to have a safety plan in place and requires the state to designate an agency to oversee implementation of the plan.
- $97,000 to develop a national hazardous materials training curriculum by the Division of Transportation, which has been selected by the Federal Highway Administration as the lead agency and recipient of federal funds through Fiscal Year 1996. The curriculum will be used by all federal, state, and local enforcement, regulatory, and educational and training agencies.
- $104,006 for the Public Service Commission for two manufactured housing inspectors to decrease the number of defective manufactured homes reaching consumers.
- $674,189 for the Professional Registration Boards, including support staff for the Dental Board to administer a continuing education requirement, a part-time examiner and clerk for the Real Estate Commission for regulation of escrow agents, and an inspector for the Board of Pharmacy to improve the quality and quantity of pharmacy inspections.

# DEPARTMENT OF ECONOMIC DEVELOPMENT

**Centers for Advanced Technology**
The State of Missouri, in conjunction with academic, government, and business interests, supports three Centers for Adva Technology (CATs), cooperative efforts between universities and private corporations for the development of advanced techno The partnership combines the research abilities of the universities to develop new advanced technology processes or products the ability of the corporations to develop advanced technology businesses by marketing products which use the technology. CATs currently in operation are the Center for Plant Science and Biotechnology at Washington University and the Universi Missouri-Columbia, the Center for Telecomputing Research at the University of Missouri-Kansas City, and the Manufact Research and Training Center at the University of Missouri-Rolla. For Fiscal Year 1995, the Governor has recommended a f CAT at the University of Missouri-Columbia, the Capsule Pipeline Research Center.

**Capsule Pipeline Research Center**
The Capsule Pipeline Research Center at the University of Missouri-Columbia is developing a coal log pipeline system, with ultimate goal of transferring the technology to the private sector. The cooperative research center is supported by the Sta Missouri, the National Science Foundation, the United States Department of Energy, the University of Missouri Colleg Engineering, the Electric Power Research Institute, and several utility, pipeline, and mining companies.

**Small Business Incubators**
The Small Business Incubator Program assists new and existing industry to succeed in the marketplace by providing fina consulting, marketing, and management assistance services to tenants housed in incubators. Local sponsors for incubators provided with loans, loan guarantees, and grants. The program is similar to the Innovation Center program, except that busine need not be involved in development of technology-based enterprises.

**Chillicothe and Hannibal Small Business Development Center Satellites**
The Small Business Development Center Satellites located in Hannibal and Chillicothe were funded in Fiscal Year 1994 to pro northern Missouri counties with adequate access to Small Business Development Center services. Eighteen SBDCs are curre operated by the University of Missouri Extension Service, usually in conjunction with a state college or university. The state fun provides a 50% match for federal funds from the Small Business Administration. Services offered include preparation of busi plans, marketing and promotion information, referral to organizations and agencies which provide specialized business services technical assistance, and information on many management and marketing topics needed to compete in a global economy.

**COMMUNITY DEVELOPMENT BLOCK GRANTS**
The goal of the CDBG section is to improve living conditions of Missouri's citizens by assisting localities with projects which prim benefit low and moderate income persons. Assistance is mainly provided for housing, infrastructure, and employment needs. unit administers the CDBG program by distributing funds and monitoring recipients.

**RURAL DEVELOPMENT PROGRAM**
The Rural Development Program, which includes the Rural Development Council and Rural Development Grants, provides techn assistance and grants to communities with populations below 15,000. The grants are for job creation and retention, busin attraction, and resource recovery.

## ECONOMIC DEVELOPMENT ACTIVITIES

**Fiscal Year 1995 Governor's Recommendations**

- $587,124 for 9.25 staff to implement HB 566.
- $250,000 for expansion of Centers for Advanced Technology (CATs) through conversion of the Capsule Pipeline Resea program into a CAT.
- $140,188 for three staff for the transfer of the Missouri Film Office from the Division of Tourism.
- $139,543 for two staff transferred to the Minority Business and Procurement Assistance Office from the Office of Administrat including $69,543 general revenue.
- $132,734 federal funds for four staff for flood recovery planning.
- $65,000 for a senior policy analyst.
- $40,000 to establish a foreign trade presence in China.
- $32,618 for a community development staff member to address expanding program needs.
- $30,000 for the Korea foreign office to address an increased volume of trade.
- $102,656 for pay plan, including $78,221 general revenue.
- ($3,540) transferred for lease costs to the new consolidated leasing budget.
- ($35,030) for one-time expenditures, including $12,130 general revenue.

SUPPLEMENTAL APPROPRIATIONS
DEPARTMENT OF ECONOMIC DEVELOPMENT
ECONOMIC DEVELOPMENT PROGRAMS
CAPSULE PIPELINE

| H.B. Sec. 14.150 | GOVERNOR'S ORIGINAL RECOMMENDATION | ORIGINAL APPROPRIATION | CURRENT REQUEST | GOVERNOR RECOMMENDS |
|---|---|---|---|---|
| PROGRAM SPECIFIC DISTRIBUTION | | | | |
| General Revenue Fund | $ 200,000 | $ 25,000 | $ 200,000 | $ 200,000 |

The Governor recommends $200,000 to provide the state match for a National Science Foundation grant.

DEPARTMENT OF ECONOMIC DEVELOPMENT
ECONOMIC DEVELOPMENT PROGRAMS
INTERNATIONAL BUSINESS DEVELOPMENT

| H.B. Sec. 14.155 | GOVERNOR'S ORIGINAL RECOMMENDATION | ORIGINAL APPROPRIATION | CURRENT REQUEST | GOVERNOR RECOMMENDS |
|---|---|---|---|---|
| EXPENSE AND EQUIPMENT | | | | |
| General Revenue Fund | $ 212,800 | $ 205,352 | $ 65,495 | $ 65,495 |

The Governor recommends $65,495 for one-time costs of relocating the Missouri Korea office to the Korean World Trade Center in Seoul.

DEPARTMENT OF ECONOMIC DEVELOPMENT
ECONOMIC DEVELOPMENT PROGRAMS
RESEARCH AND SUPPORT

| H.B. Sec. 14.160 | GOVERNOR'S ORIGINAL RECOMMENDATION | ORIGINAL APPROPRIATION | CURRENT REQUEST | GOVERNOR RECOMMENDS |
|---|---|---|---|---|
| PERSONAL SERVICE | $ 684,729 | $ 688,264 | $ 31,500 | $ 31,500 |
| General Revenue Fund | 112,244 | 112,244 | 0 | 0 |
| Federal Funds | 23,500 | 23,500 | 0 | 0 |
| Department of Economic Development Administrative Fund | | | | |
| EXPENSE AND EQUIPMENT | 174,799 | 163,341 | 53,000 | 53,000 |
| General Revenue Fund | 38,000 | 38,000 | 0 | 0 |
| Federal Funds | 14,600 | 14,600 | 0 | 0 |
| Department of Economic Development Administrative Fund | | | | |
| TOTAL | $ 1,047,872 | $ 1,039,949 | $ 84,500 | $ 84,500 |
| General Revenue Fund | 859,528 | 851,605 | 84,500 | 84,500 |
| Federal Funds | 150,244 | 150,244 | 0 | 0 |
| Department of Economic Development Administrative Fund | 38,100 | 38,100 | 0 | 0 |

he Governor recommends $54,500 for a senior policy analyst and $30,000 for the Commission on Informational Technology created y HB 566 (1933) for consultants to assist in developing a state telecommunications strategy.

# Attachment 10: Latest IAB Meeting Minutes

**CLP CONSORTIUM/NSF CAPSULE PIPELINE CENTER**

Joint Advisory Board Meeting

October 5, 1993

**1.** The meeting began at 8:00 a.m. in Room 208C in the Donald W. Reynolds Alumni Center. A list of participants is given in Appendix 1.

**2.** Dr. Liu gave a presentation focusing on the next two years research plans. Each principal investigator gave a technical presentation of the research they are responsible for. A list of the topics of presentations are included in Appendix 2.

**3.** At the end of the morning session, a tour of the pipeline facilities was conducted for the participants.

**4.** The afternoon session resumed at 1:00 pm beginning with a brief presentation by Dr. Yuyi Lin, on coal log fabrication machine design.

**5.** Dr. Jim Baldwin, Interim Dean, College of Engineering, gave a brief speech welcoming participants to the UMC Campus. He mentioned the good research being conducted by the Center.

**6.** Dr. Win Aung, Program Director, National Science Foundation, discussed partnership among NSF, states and industry, coming year (3rd-year) evaluation, and funding. He mentioned that the 3rd-year review site visit team will consist of two persons selected by the State and additional two or more by NSF. The state appointed members will focus on technology transfer. More details are contained in the document in Appendix 3. Criteria for the 3rd-year review are being completed and will be sent out when done.

**7.** The site visit for the CPRC was tentatively scheduled for May 19 & 20, 1994. The IAB meeting will be May 19--the first day of the site visit. Everyone in attendance agreed to these dates. Dr. Aung mentioned that it is desirable to have as many industry members as possible to be present on May 19.

**8.** Tom Barry gave his presentation and said that the Governor's Office had agreed to a Supplementary Appropriation request for $250,000 of State matching fund for the Center for the current year. He mentioned that the CPRC will be designated as a State center under the CAT (Center for Advanced Technology) Program administered by his office. This designation will make it easier to deal with budget-wise in the future. Statutory requirements for this change will be worked out soon. He said the Capsule Pipeline Research Center (PRC) is in pretty good shape in getting the State's support.

**9.** Connie Armentrout mentioned that the CPRC had submitted two preliminary invention disclosures required by Federal sponsorship of the Center. Filing of patent applications will be done later when the merits (practical value) of those inventions can better be judged. She will work closely with CPRC researchers in filing patent applications.

**10.** Armentrout said that because most Consortium members have already paid four of the five years of the Consortium fee, they will be eligible for a license, (U.S. Patent No. 4946317 entitled "Coal Log Pipeline System and Method of Operation"), in a year after they have made the fifth payment. Meanwhile, the University Patent & Licensing will prepare a draft licensing agreement on this for Consortium Members' perusal and comments prior to the next Board meeting. (Note: This license of a pre-existing patent is for Principals and Members only, not for Small Business Participants, as specified in the original Agreement signed with the University.)

**11.** Dr. Liu then discussed a summary of the budget for this and two previous years:

| | |
|---|---|
| 1st year:<br>(9/1/91-8/31/92) | $175,000 from NSF (Received)<br>$175,000 from State (Received)<br>$215,905 from Industry (Received) |
| 2nd year:<br>(9/1/92-8/31/93) | $200,000 from NSF (Received)<br>$200,000 from State (Received)<br>$205,000 from Industry (Received) |
| 3rd year:<br>(9/1/93-8/31/94) | $250,000 from NSF (Received)<br>$250,000 from State (delay approved by NSF. State approval expected to be in March 1994).<br>$160,000 From Industry (as of Oct. 5, 1993) |

Dr. Liu mentioned that due to recent dropout of two Consortium members (KCPL and Coal Services), the industry matching fund for this year has fallen to $160,000 which is $90,000 below the minimum required by NSF and the State. He said that he, Dr. Marrero and Dr. Wilson are working very hard (contacting industry) to recruit new members. Two large utilities are on the verge of joining. If any of the two joined, it would bring in $100,000 per year for the next three years, which will solve the industry matching fund problem. Meanwhile, he is not taking chances and is actively recruiting other new members. Mr. Bill Weber of EPRI is helping the Center to encourage electric utilities (EPRI members) to engage in an EPRI-TC (Tailored Collaboration) project in CLP, making participation in CLP development more attractive to utilities. He and Marrero are also contacting a number of small companies to join as "Small Business Participants". He says that with all these actions underway, he is confident that the Center will have sufficient industry matching funds by the end of the current fiscal year, hopefully much sooner. He also announced that Erie Press, a company in Erie, Pennsylvania, that specializes in making large extruders for carbon electrodes, had joined the Center as a "Small Business Participant." The Erie Press will advise the Center in coal log machine design, and has judged the design contest.

**12.** The afternoon session was chaired by Doug Lee of the MAPCO Company, who is the elected Vice Chairman of the CLP Consortium. The chairman, Rick Smith, could not be at the meeting due to serious illness of a family member. Mr. Charles Henderson represented UE at the meeting. Doug Lee thanked the participants for being there. He briefly discussed the planned test of large (5.3" diameter) logs in a 6-inch MAPCO Pipeline in Conway, Kansas. He said that single logs could be tested through this pipeline without having to modify the line. It can be done as soon as the University researchers have made 5.3" logs. On behalf of the IAB, he suggested holding a two day **"work session"** in which industry members will be on campus to interact with the Center's faculty and research assistants, and spend time in the lab and in a meeting to discuss R & D in CLP. Dr. Liu welcomed the suggestion and said it was a good idea. The two dates selected for the session are January 11th and 12th, 1994.

**13.** The IAB members gave Dr. Liu four other suggestions that he gladly accepted. (1) To prepare a Gantt chart showing the various R&D tasks, their schedule and inter-relationship. Dr. Marrero offered to help Dr. Liu to prepare the chart. (2) To ask Dr. Yuyi Lin to revise and refine the coal log compaction machine design by taking into account the judge's (Erie Press') comments and suggestions. Mr. Jim Ramer was also to be encouraged to complete his design as soon as possible and submit the design to Dr. Liu for him to forward to Erie Press for evaluation and comments. The IAB members hope that two good designs will result from such a process. Dr. Liu mentioned that recent work conducted by Dr. Wilson and Dr. Ding at UMR revealed that with as little as 2% asphalt as binder, durable coal logs can be produced at temperature less than 80°C and compression pressure less than 10,000 psi. This could simplify the machine design considerably. (3) To define the performance criteria of coal logs, i.e., the accepted hardness, attrition rate, etc. Dr. Liu mentioned that he would try to define the criteria, but it is expected to differ for different pipeline lengths and other conditions. (4) To develop the outline for the coal log design and operation manual for review by IAB members and others.

The meeting was adjourned at approximately 4:30.

# CLP/NSF Capsule Pipeline Center
# Joint Advisory Board Meeting

Columbia, Missouri, October 5, 1993

ATTENDANCE LIST

| Name/Title | Affiliation | Phone |
|---|---|---|
| **INDUSTRY REPRESENTATIVES** | | |
| Mr. Henry Brolick | Williams Technologies, Inc. | (918) 582-5811 |
| Mr. Charles Henderson | Union Electric Co. | (314) 554-3529 |
| Mr. Ted Jaenke, President | Pro-Mark Systems | (314)878-6450 |
| Mr. Douglas Lee | MAPCO Transportation | (918) 581-1814 |
| Mr. Dennis Turner | Williams Pipe Line Co. | (918) 588-3375 |
| **NSF SPONSOR** | | |
| Dr. Win Aung, Program Director | NSF | (202) 786-9532 |
| **STATE SPONSOR** | | |
| Mr. Tom Barry, Program Director | MO Dept. of Economic Dev. | (314) 751-3906 |
| **GUEST** | | |
| Mr. Walter Vanderlicht | MO Dept. of Hway & Transportation | (314) 751-3692 |
| **UNIVERSITY REPRESENTATIVES** | | |
| Ms. Connie Armentrout | UMC Patents & Licensing | (314) 882-2821 |
| Dr. Jim Baldwin | UMC Engineering Deans' Office | (314) 882-4378 |
| 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. Frank Seibert | Small Business Center | (314) 882-7096 |
| Mr. Robert Zuniga | UMC Industrial Engineering | (314) 882-1505 |

Attachment 11: University Policy Committee and Latest Meeting Minutes

# 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 (1994 Update)

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

Dr. James W. Baldwin, Chairman, 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. John McCormick, Vice Provost for Research (Committee Chairman) (882-9500)

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

Dr. Lee Saperstein, Dean, School of Mines and Metallurgy (UMR) (341-4153)

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 Engr. (882-2785)

# Annual Meeting of the CPRC University Policy Committee
## March 11, 1994
## Room W1054, Engineering Building East

**List of Attendees**

Connie Armentrout, Coordinator, Patents & Licensing

Dr. James W. Baldwin, Jr., Interim Dean, College of Engineering

Dr. Jay B. McGarraugh, Interim Chairman, Dept. of Civil Engineering

Dr. Charles (Don) Miles, Associate Dean, Graduate School

Deborah Robison, Assistant Vice Provost for Extension

Dr. David Retzloff, Dept. of Chemical Engineering

Dr. John Wilson, Chairman, Mining Engineering Dept. UMR

Dr. Henry Liu, Director, Capsule Pipeline Research Center

Dr. Tom R. Marrero, Assoc. Director, Capsule Pipeline Research Center

Voronica I. Bonaparte, Sr. Secretary, Capsule Pipeline Research Center

**CPRC University Policy Committee**
**Annual Meeting**
**March 11, 1994**

1. The meeting began at 3:37 p.m. in room W1054 in the Engineering Deans Conference Room. A list of the participants is given in Appendix 1.

2. Dr. Liu gave a presentation focusing on the Center's function for the past three years and the next five years pending renewal of NSF and other sources of supports. His presentation included the following topics:

   - NSF Centers
   - Organizational Charts
   - Center's Mission
   - Strategic Plan
   - University Participants
   - Accomplishments last 3 years
   - 3rd Year Annual Review
   - Activities Planned to Commercialize CLP
   - Pending Proposals

3. Dr. Liu mentioned that he is preparing a Year-3 report which must be submitted to NSF by April 1. In this report, he needs to document to NSF the University supports for the Center, both from the College and the Campus.

4. Ms. Connie Armentrout discussed patent applications and publications disclosures. A meeting will be scheduled next week between her and Dr. Liu to discuss more details.

6. Dr. Liu mentioned that due to expansion in the Center's program in the last 2½ years, the Center has no space to accommodate additional graduate students. The Departments in which each student is enrolled needs to provide such space for the student. He thanked the various chairmen whose faculty and students participate in the Center's research, and said it is mutually beneficial for centers and departments to work together.

7. Dr. Warder commended the Center for involving young faculty members in the Center's research program. Dr. Liu mentioned that the strength of the Center lies in the high-quality faculty and students working for the Center.

8. Dr. James Baldwin discussed the College of Engineering support which included director's salary, visiting professor, graduate student support, equipment and expenses, totaling $190,000 for the current year. College salary support for the Center is higher than last year but equipment support will be less than last year due to a reduction in the College's special equipment fund.

9. Dr. Liu briefly reviewed the status of the state matching fund, and the fact that the Governor had recommended to the Legislature to include CPRC as a CAT (Center for Advanced Technology) Center.

10. Dr. Liu praised Dr. John Wilson (UMR) for his cooperation and contribution to the success of the Center. He regrets, however, that Dr. Wilson had not been paid for his work in the last 8 months due to failure to receive the state matching fund. Dr. Wilson asked whether the Columbia Campus can help him by transferring some money soon as he is running out of support for graduate students working on coal logs. Dr. Baldwin said he would consider it and talk to Rolla campus administrators.

11. Dr. Liu thanked all those who attended the meeting for their support.

12. Meeting adjourned at approximately 5:00 p.m.

Attachment 12

# WORK SESSION ON CONTROL

## University of Missouri, Columbia, Missouri, 4 March 1994

### MINUTES

1. The meeting was held in Room E2423, Capsule Pipeline Research Center, College c Engineering. Those present included Mr. Aubrey Zey from Novatech, Inc., Kansas City ; Prof Henry Liu, Satish Nair, Charles Lenau, and Yuyi Lin ; Richard Oberto, senior electronic technician, and graduate students J. Wu and H. Du.

2. Presentations : The overall issues were discussed in the morning session. Dr. Nair mentione that the session, after a brief introduction, would be unstructured to provide for inputs of all type He gave an overview of the progress in control research and plan for the design of a control syste for commercial operation of CLP. He reported that two MS students recently completed reports o (i) mechanical subsystem design for control and (ii) software and interface design, both pertainin primarily to the small scale prototype system in the hydraulics laboratory from which considerab insights have been developed for the design of a commercial scale system. The mechanic subsystem design research is being continued currently by H. Du who is focusing on the trai separator and emergency stopper design. H. Du then gave a presentation of the proposed trai separator design and the associated calculations. The injection and pump bypass subsyste requirements have been investigated in detail as part of his Ph.D. dissertation by J. Wu. H presented his findings and guidelines for designing those subsystems to the group.

3. Discussion on Overall Issues : (i) A discussion on several issues pertaining to control followe with Mr. Zey explaining the typical problems faced by oil and gas pipelines companies (e.g. 18 inc diameter, @ 8-10 ft/sec) and how Novatech solves some of those. (ii) Drawing on his experienc he mentioned that a 2 sec valve closure time was too optimistic since high torques would b required. The valve maintenance requirements also go up in inverse relation to the closure tim Oil and gas pipelines have a closure time of 1 minute, typically. Dr. Lenau mentioned that the valu used in simulation was to check for a worst case type scenario and ensure that the pressu transients are within bounds even for such a case. The final design will have slower closure rate (iii) Oil and gas pipelines typically operate in the 300-400 psi pressure range. The operatin pressures which the CLP team uses (~ 2000 psi assuming 50 mile spacing between pumpin stations) is somewhat high according to him since this would cause problems with pump seals et

Dr. Liu later clarified that slurry pumps and seals would be used and not ordinary ones so that the problem with pump and valve seals would not be of concern. (iv) The startup problems faced using positive displacement pumps should be considered. Usage of centrifugal pumps would require multi-staging. (v) Mr. Zey felt that spacing between capsules within a train and between trains themselves would not be difficult to control without active intervention. A train separator design is essential for proper functioning of the CLP system. For the proposed design, he felt that the capsules should not be stopped since they have such a large momentum. This is being considered in the separator design which creates spacing with only a few capsules possibly coming to rest. (v) Redundancy in system design would be important. Mr. Zey mentioned that pipeline companies typically use the 'three 50% capacity units' strategy rather than a 'two 100% capacity units' one.

The group had lunch at the Alumni Center at noon.

4. Discussion on Specific Issues : The afternoon session focused on specifics. Dr. Nair listed the following items as starting points for discussion : Sensors, Pigs, SCADA software, Distributed control architecture, and Control design for the proposed Thomas Hill project.

(i) Sensors : Several sensors were discussed including optics with lasers, radioactive, and pig themselves. Considering the medium the sensor would have to operate in/around, optics may pose a problem. Optics requires a different transparent section of pipe, the medium being 'murky' laser intensity and focusing may be a problem, the transparent section may become 'coated' and may require periodic cleaning. Some solutions to overcome these problems were discussed and it was suggested that it be looked into in more detail. Radioactive sensors which measure mass density were another choice and they would be able to distinguish between water and coal logs. These are attractive since they probably would involve less maintenance, and it was decided that they be pursued further.

(ii) Pigs : Much literature and information have been gathered on pigs by Richard Oberto and Dr. Liu. *While it was felt that pigs were definitely required for 'cleaning' and possibly weld* monitoring, etc., using them in a control application may be expensive and unnecessary.

(iii) SCADA Software : Novatech has extensive experience with such software and Mr. Zey felt that focusing on this issue was a full-time project in itself. It is better to buy software from reliable vendors rather than the CPRC develop it in-house. Several suggestions as to possible MMI candidates were provided by him. Either Windows or OS/2 operating system can be used.

(iv) Distributed Control Architecture : Again, Novatech has extensive experience with such systems. They, in fact, have their own RTUs. Mr. Zey mentioned that PLCs are becoming more sophisticated without easier programming interfaces. Current PLC speeds allow for sampling of 3 or 4 times per second. A PLC or RTU would be needed at each site, i.e. at the injection system, at the pump bypass system, and the ejection system, to perform the local functions autonomously (sub-master) with a link to a master located centrally. Such a master could be a personal computer such as a 486 for which MMI interfaces are available easily. For communication betwen th submaster and the master, Mr. Zey suggested using either Modbus (Modicon) protocol or BNC (Harris) protocol. A 4-wire or leased line would cost approximately $200/month and can suppo 9600 baud transmission rates. Distance is not an important criterion. He also felt that studying th different tasks for the sub-master and master control stations including alarm and safety issues an coordinating their activities (e.g during startup, shutdown and other occassions such as durin surges, component malfunction, and other emergencies) was complex and required careful attentio The submasters could would also monitor maintenance data of various types. Several catalog pertaining to PLCs and SCADA software were provided by Novatech.

(v) Other : Mr. Zey suggested that pressure servo control be used for relevant valves at th injection and pump bypass subsystems to ensure that surges were reliably kept under control. Th would supplement the valve-stroking strategies developed by CPRC. Ball valves have problem with seals and usage of slurry valves such as plug valves or pinch valves should be investigate Novatech had received the writeup about the proposed Thomas Hill project sent by CPRC. Issue concerning the project are similar and Dr. Liu mentioned that CPRC was waiting to hear about th proposal outcome.

The participants felt that the meeting was very productive, particularly the informative inp from Novatech, Inc. The meeting was adjourned at 3:50 p.m.

Attachment - Schedule

# CONTROL WORK SESSION

**NSF Capsule Pipeline Research Center**
**University of Missouri - Columbia**
**4 March 1994**

| | | |
|---|---|---|
| Participants : | Sponsor : | Aubrey Zey, Novatech, Inc. |
| | Faculty : | Satish Nair, Henry Liu and Charles Lenau (and others interested) |
| | Staff : | Richard Oberto |
| | Students : | Jianping Wu, Hongliu Du, Majed El-Bayya (and others interested) |

Purpose : To review progress in CLP control research, to plan for future research, and to design a control system for commercial operation of CLP.

Schedule :

9:00 Overview -- Satish S. Nair

9:30 Injection and Pump bypass subsystem requirements -- Jianping Wu

9:45 Train separator design -- Hongliu Du

10:00 - 12:00 Discussion : Overall Definition and Strategies

1. Mechanical subsystem functions and design problems
2. Control system objectives
3. Control implementation
4. Current and future research, e.g. separator design

12:00 - 1:00 Lunch at the Alumni Center

1:00 - 4:00 Discussion : Specific Issues

1. Sensors
2. Pigs
3. SCADA software
4. Distributed control architecture - communication protocols etc
5. Control design for the proposed Thomas Hill full-scale demo test facility (pipe diameter 8 inches, length 12 miles)
6. Recommendations for future studies

Attachment 13: Pipeline Courses Offered

**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

## Appendix 3: References

1. Boettcher, R.A. (1971). "Pipeline Transportation of Solid Waste," Paper presented at the 64th Annual Meeting of AIChE, San Francisco, California, 17 pages.

2. Liu, H. (1993). "Hydraulic Behaviors of Coal Log Flow in Pipe," Freight Pipelines (Editor: G.F. Round), Elsevier Science Publisher, pp. 215-230.

3. Liu, H. and Richards, J.L. (1994). "Hydraulics of Stationary Capsule in Pipe," Journal of Hydraulic Engineering, ASCE, Vol. 120, No. 1, pp. 22-40.

4. Xu, G. (1993). Behavior of Capsules in Slurry Medium in a Pipe, M.S. Thesis, Department of Mechanical & Aerospace Engineering, UMC, 106 pages. (Adviser: James Seaba).

5. Seaba, J.P. and Xu, G. (1994). "Capsule Transport in Coal Slurry Medium," Journal of Fluids Engineering, ASME (submitted on January 2).

6. Huang, X. (1994). Polymer Drag Reduction in Hydraulic Capsule Pipeline (HCP), M.S. Thesis, Department of Civil Engineering, UMC, (Adviser: Henry Liu).

7. Cheng, C.C. (1994). Wear and Damage of Coal Logs in Pipeline, Ph.D Research Progress Report, CPRC, 79 pages.

8. Lenau, C.W. and El-Bayya, M. (1993). "Unsteady Flow in Hydraulic Capsule Pipeline," Journal of Engineering Mechanics, ASCE (submitted).

9. Lenau, C.W. and El-Bayya, M. (1993). "Treatment of Unsteady Flow through Capsule Pipeline: Capsule-Water Interaction," Proc. of the 7th International Sym. on Freight Pipelines, Wollongong, Australia, pp. 215-219.

10. El-Bayya, M. (1994). Unsteady Flow of Capsules in a Hydraulic Pipeline: Theory and Experiment, Ph.D Dissertation, Department of Civil Engineering, UMC (Adviser: Charles W. Lenau).

11. Liang, Z. (1993). Compaction of Binderless Coal for Coal Log Pipelines, M.S. thesis, Department of Civil Engineering, 132 pages, (Adviser: Brett W. Gunnink).

12. Gunnink, B.W. and Liang, Z. (1994). "Compaction of Binderless Coal for

Coal Log Pipelines," (accepted for Fuel Processing Technology), Elsevier, Amsterdam.

13. Lin. Y.Y. and Wang, L.Q. (1993). Binderless Coal Log Extrusion, CPRC Internal Report, 14 pages.

14. Lin, Y.Y. and Liu, H. (1994). Water Assisted Binderless Extrusion of Coal Logs, UMC Invention Disclosure for Patent Application.

15. Marrero, T.R. and Burkett, W.J. (1994). "Coal Log Fabrication: State-of-the-Art for Pipeline Transportation," presented at 11th Annual International Pittsburgh Coal Conference, Pittsburgh, Pennsylvania.

16. Wilson, J.W., Ding, Y, Smith, R.J. and Marrero, T.R. (1994). "Moisture Reduction of Coal in Coal Log Pipeline Technology," presented at Coal Preparation Conference, Lexington, Kentucky.

17. Liu, H. (1994). Analysis of Coal Log Compaction in a Cylindrical Mold, CPRC Internal Report, 18 pages.

18. Smith, R. (1994). "Coal Log Fabrication with the Impregnation of Fine Particles," M.S. Thesis, Chemical Engineering Department, UMC, (Adviser: T.R. Marrero).

19. Carney, D. (1994). "Impregnation of Coal Logs," M.S. Thesis, Chemical Engineering Department, UMC, (Adviser: Richard Luecke).

20. Sun, S.H. (1993). Microwave and Radiation Surface Heat Treatment of Coal Logs. Project Completion Report, CPRC, 20 pages. (Adviser: T. R. Marrero).

21. Lin, Y.Y. and Ji, G. (1993). Coal Log Manufacturing Machine Design Report: Capped Mold Approach, CPRC Report, 23 pages, 5 drawings.

22. Shieh, C.Y. (1993). Computer Control of a Small-Scale Capsule Pipeline System, M.S. Report, Department of Mechanical Engineering, UMC, 120 pages. (Adviser: Satish Nair).

23. Sun, D.X. (1993). Design of Certain Mechanical Subsystems for an Automated Capsule Pipeline, M.S. Report, Department of Mechanical Engineering, UMC, August 1993, 101 pages. (Adviser: Satish Nair).

24. Davis, P.N., Cress, N. and Sullivan, J.P. (1993). "Legal Aspects of Coal Pipelines in the United States—Preliminary Findings," Proc. of the 18th

International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, FL, pp. 735-746.

25. Liu, H., Zuniga, R. and Richards, J.L. (1993). Economic Analysis of Coal Log Pipeline Transportation of Coal, CPRC Report No. 93-1, two volumes, 248 pages.

26. Marrero, T.R. and Wilson, J.W. (1993). Coal Log Fuel Handling and Treatment at Power Plants, EPRI TR-102701s, sponsored by the Electric Power Research Institute, Palo Alto, CA., 1993, 74 pages.

27. Wilson, J.W. (1992). "End-of-Pipeline Requirements for Coal Log Pipeline Technology," Proc. of the 7th International Symposium on Freight Pipelines. Wollongong, Australia, 1992, pp. 207-213.

28. Wilson, J.W. and Marrero, T.R. (1993). "Coal Log Pipeline Concept and Performance Characteristics," Journal of South African Institute of Mining and Metallurgy, Vol. 93, pp. 267-271.

29. Wilson, J.W. and Ding, Y. (1993). "A Technical and Economic Assessment of Coal Log Pipeline Technology at Electric Power Generating Plants," Proc. of the 18rh International Technical Conference on Coal Utilization and Fuel Systems, pp. 759-770.

30. Wu, J.P. (1989). Economic Feasibility of Using Hydraulic Capsule Pipelines to Transport Farm Products of the Midwestern States of the United States, M.S. Thesis, Department of Civil Engineering, UMC, 118 pages.

31. Liu, H. and Wu, J.P. (1992). "Economic Feasibility of Using Hydraulic Capsule Pipeline to Transport Grain in the Midwest of the United States," Freight Pipelines, Proc. of the 6th Int. Symp. on Freight Pipelines, Hemisphere Publishing Corporation, New York, pp. 135-140.

32. Kosugi, S. (1992). "A Capsule Pipeline System for Limestone Transportation," Proc. of the 7th Inht. Sym. on Freight Pipelines, Wollongong, Australia, pp. 13-17.

33. Jvarsheishvili, A.G. (1992). "Lilo-1 and Lilo-2 Systems for Pneumatic Transportation of Freight in Containers through Pipeline in Georgia," Proc. of the 7th Int. Sym. on Freight Pipelines, Wollongong, Australia, pp. 239-244.

34. Liu, H. et. al. (1984). Pipeline Transportation System (with Electromagnetic Pump), U.S. Patent No. 4,437,799.

35. Assadollahbaik, M. and Liu, H. (1986). "Optimum Design of Electromagnetic Pump for Capsule Pipelines," Journal of Pipelines, No. 5, pp. 157-169.

# Appendix 4: Center Publications
## (First 3 Years: 9/1/91-8/31/94)

## A. Theses/Dissertations and Student Papers:

Berg, D.M., Hot Extrusion of Coal Logs, M.S. Thesis, Department of Chemical Engineering, University of Missouri-Columbia, August 1993, 187 pages. (Adviser: Thomas R. Marrero).

Carney, D., Impregnation of Binderless Coal Logs, M.S. Thesis, Department of Chemical Engineering, University of Missouri-Columbia, May 1994, pages. (Adviser: Richard Luecke)

Chen, F., Advances in Hot Water Dried Coal Log Technology, M.S. Thesis, Department of Civil Engineering, University of Missouri-Columbia, May 1994. (Adviser: Brett W. Gunnink)

Chen, S.H., Effects of Particle Size, Binder Concentration and Compaction Pressure on Selected Properties of Coal Logs, M.S. Thesis, Department of Chemical Engineering, University of Missouri-Columbia, August 1993, 102 pages. (Adviser: Thomas R. Marrero).

Cheng, C.C. Wear and Damage of Coal Logs in Pipeline, Ph.D. Dissertation Proposal, 51 pages May 1994. (Adviser: H. Liu).

El-Bayya, M.M., Unsteady Flow of Capsules in a Hydraulic Pipeline: Theory and Experiment, Ph.D. Dissertation, Department of Civil Engineering, University of Missouri-Columbia, May 1994. (Adviser: Charles W. Lenau).

Holder, M., Methods of Pipeline Joint Improvement in Coal Log Pipeline Systems, CPRC Internal Report, February 1994.

Holder, M., Performance of Coal Logs with Varying Inside Pipe Conditions, CPRC Internal Report, February 1994.

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# Appendix 5: R & D Plan

## COAL LOG PIPELINE RESEARCH & DEVELOPMENT PLANNING FOR THE NEXT 20 MONTHS (1/1/94-8/31/95)

by
Henry Liu
12/1/93

## INTRODUCTION

The Coal Log Pipeline (CLP) Consortium was formed in July 1990, and the NSF Capsule Pipeline Research Center was established in September 1991, to carry out the mission of developing the CLP technology for commercial use. The goal was to ready this emerging technology for commercial use by August 31, 1995, which coincides with the end of the first four-year support from NSF. It was, and still is, hoped that after August 31, 1995, commercial use of the CLP technology can begin with a demonstration project. Then, the mission of the next four years of the NSF Center will shift toward planning and helping industry to carry out a commercial demonstration project of CLP, and broadening the Center's research to cover other types of capsule pipelines for transporting solid wastes (including processed refuse, power-plant ashes and hazardous wastes), grain and other agricultural products, and other commodities.

The purpose of this document is to plan for the remaining 20 months of the first phase of the NSF Center, so that the original goal of readying the CLP technology by August 31, 1995 for commercial use can be accomplished.

In what follows, the remaining works are divided into 21 tasks, each of which is discussed separately. Some of the tasks are new; others are unfinished work that must be completed. The schedule and direct cost of each task are estimated. Based on the cost of each task, the budget for completing all the tasks of the first 8 months (1/1/94-8/31/94) is $553,207, and for the next 12 months (9/1/94-8/31/95) is $495,727. A Gantt chart is prepared separately, summarizing the schedule of work. This document will be reviewed every three months to determine the progress made in each task and the overall progress of the R & D of the CLP technology. It will be an important document for managing the Center's R & D in the coming months, and it must be understood by all those involved in the Center's work, both researchers and sponsors.

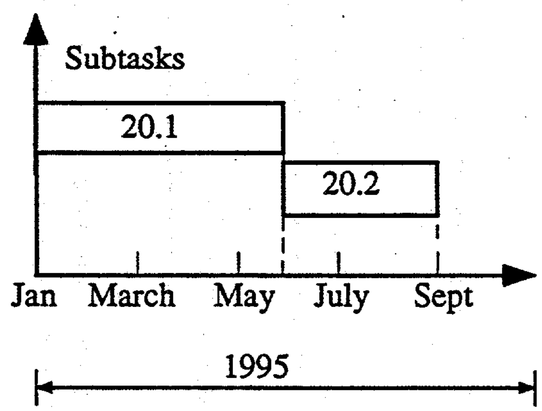
**Task 20:** ***Prepare Manual of Practice and Conduct a Technology Transfer Workshop***

**Subtasks:**

(20.1) Prepare a detailed manual of practice for coal log pipeline.

(20.2) Conduct a 5-day workshop on technology transfer; use completed manual as the text for the workshop.

**Schedule:**




**P.I.:** Dr. Henry Liu, Professor of Civil Engineering

**Budget (1/1/95-8/31/95):** $37,000

| Item | Cost ($) |
| --- | --- |
| P.I. (Liu, 2 months) | 20,000 |
| Fringe Benefit (25% of P.I.) | 5,000 |
| Workshop Management by Engineering Ext. | 10,000 |
| Other Costs (miscellaneous) | 2,000 |
| **Total** | $ 37,000 |

# Coal Log Pipeline (CLP)

## Manual of Practice

**Prepared and published by the**
**Capsule Pipeline Research Center (CPRC)**
**University of Missouri-Columbia**

**July 1, 1995**

# PREFACE

The intent of this Manual of Practice is to provide the essential information needed for the design, construction and operation of coal log pipelines (CLP), a new pipeline technology for transporting coal.

Because CLP is a sophisticated new technology, a Manual of Practice which draws all the essential information on CLP into one volume is needed to facilitate commercial use of this new technology. It goes a long way towards technology transfer and commercialization of CLP.

The Manual is intended for pipeline engineers who already know how to design, construct and operate ordinary liquid pipelines. Since many aspects of the design and construction of CLP are in common with ordinary liquid pipelines, only those aspects different from ordinary pipeline design and construction will be included in this Manual. This is necessary in order to keep the Manual within bound.

Different chapters of this manual will be written by different individuals. Henry Liu will serve as the Editor. The planned authors of each chapter are as follows:

| Chapter | Author(s) |
|---|---|
| 1 | Liu |
| 2 | Liu |
| 3 | Lenau and Wu |
| 4 | Liu andWu |
| 5 | Nair |
| 6.1 | Liu |
| 6.2.1 | Lin |
| 6.2.2 | Marrero |
| 6.2.3 | Gunnink |
| 6.2.4 | Wilson and Ding |
| 6.2.5 | Butler and Lin |
| 6.2.6 | Liu |
| 6.3 | Marrero and Burkett |
| 7 | Banerji, Marrero, Wilson, and Ding |
| 8 | Liu |
| 9 | Liu |
| 10 | Davis |
| 11 | Liu, Noble, and Zuniga |

## SCHEDULE FOR COMPLETING MANUAL OF PRACTICE

| Task Completed | Deadline |
|---|---|
| 1st draft submitted to editor and industry sponsors | 1/15/95 |
| Industry sponsors respond to draft | 2/15/95 |
| Edited draft returned to authors | 3/15/95 |
| 2nd draft submitted to editor | 4/15/95 |
| Edited 2nd draft returned to author | 5/15/95 |
| Final manuscript submitted to editor | 6/15/95 |
| Final editing completed | 7/01/95 |
| Publication of Manual | 7/15/95 |

## CONTENTS

- 8.4. Converting Existing Pipeline to CLP
- 8.5. Freezing Consideration
- 8.6. Earthquake Consideration
- 8.7. Construction Removable Segments to Unclog Coal Log Jams

Chapter 9 Operation Problems Related to CLP

- 9.1. Startup
- 9.2. Shutdown
- 9.3. Restart
- 9.4. Use of Drag Reduction Additives
- 9.5. Maintenance
- 9.6. Jam Prevention
- 9.7. Jam Cure
- 9.8. System Monitoring and Instrumentation
- 9.9. Pigging
- 9.10. Handling of Accidents
- 9.11. Quality Control in Coal Log Manufacturing
- 9.12. Problems Caused by Weather and Other Natural Hazards
- 9.13. Problems Caused by Human (Sabotage, Negligence, Operation Errors, etc.)

Chapter 10 Legal ~~Problems~~ Issues Related to CLP

- 10.1 Eminent Domain Right
- 10.2. Road Crossing
- 10.3. Water Rights
- 10.4. Obtaining Various Permits
- 10.5. Crossing Federal Land and Indian Reservations
- 10.6. Conversion of Decommissioned Existing Pipelines for Coal Log Transport
- 10.7. Environmental Impact Statement (EIS)
- 10.8. Safety Considerations and Regulations

Chapter 11 Project Economics

- 11.1 Economic Models
- 11.2. Comparing Economics of CLP to Other Modes of Coal Transport
- 11.3. Determining Economic Return and Tariff Rate and Structure
- 11.4. Projection of Rail and Truck Tariff Increases

## Appendix 7: Industry Related Visits During First 3 Years (1991-94)

| Dates | Description of Activities |
|---|---|
| 7-28-92 | Dr. Thomas Marrero visited Union Electric Co. in St. Louis with Dr. John Wilson to discuss EPRI projects. |
| 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. |
| 9-21-92 | Dr. Henry Liu went to Tulsa, OK to present a talk to the Pipeliners' Club of Tulsa and visit Williams Technologies, Inc. to discuss economic report. |
| 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. |
| 1-15-93 | Dr. Thomas Marrero and Dr. Henry Liu traveled to TVA in Chattanooga, TN to present CLP to company representatives and to solicit support by encouraging TVA 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. |
| 2-09-93 | Dr. Yuyi Lin visited Mohr Corporation in Detroit, MI to inspect surplus ram extruder for possible purchase. |
| 2-09-93 | Drs. Henry Liu, Thomas Marrero and 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 went to Elizabethton, TN to inspect a surplus extruder for possible purchase from Great Lakes Research Corp. |
| 3-09-93 | Dr. Henry Liu and Dr. Thomas Marrero traveled to Springfield, MO to visit Associated Electric Cooperative on coal log pipeline and presented progress report on project. |
| 4-14-93 | Dr. Henry Liu visited a Williams Pipe Line station in Paola, KS to evaluate an existing dual pipeline as a potential 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. |

**Appendix 7: (Continued)**

| Dates | Description of Activities |
|---|---|
| 7-12-93 | Dr. Marrero traveled to St. Louis, MO to meet with Arch Mineral and Erie Press to discuss Coal Log Manufacturing. |
| 8-03-93 | Dr. Henry Liu traveled to Conway, KS to inspect a site for CLP test. |
| 8-05-93 | Dr. Henry Liu and Dr. Marrero traveled to St. Louis, MO to visit UE and give a presentation to an EPRI group. |
| 8-23-93 | Dr. Liu traveled to Tulsa, OK to visit MAPCO, Wilbros Butler, and Williams Technologies, Inc. |
| 12-07-93 | Drs. Liu, Marrero and Wilson presented a seminar in Atlanta, GA on coal log pipeline to potential sponsors. |
| 1-31-94 | Dr. Marrero visited Associated Industries of Missouri (AIM), Jefferson City, MO, to explore AIM's interest in CLP. |
| 2-03-94 | Dr. Marrero visisted Zellerbach Company in Kansas City, MO, to explore packaging methods that might be used for coal logs or other types of capsules. |
| 3-17-94 | Dr. Liu and Dr. Marrero made a presentation to Burns & McDonnell in Kansas City, MO, inviting the company to participate. |