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TRANSPORTATION OF COAL BY HYDRAULIC CONTAINER PIPELINE (HCP)—A FEASIBILITY STUDY

Project Completion Report for Period June 1, 1978–April 30, 1979

By
Henry Liu
M. Assadollahbaik
J. C. Yang

May 1979

Work Performed Under Contract No. EM-78-S-02-4935

University of Missouri—Columbia
Department of Civil Engineering
Columbia, Missouri

U. S. DEPARTMENT OF ENERGY

Division of Transportation Energy Conservation

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FORWORD

In June 1978, the University of Missouri-Columbia received a research contract (EM-78-5-02-4935) from the U.S. Department of Energy to investigate the feasibility of HCP (Hydraulic Container Pipeline)* as a viable means of freight transport that conserves energy. HCP is a particular type of freight pipeline which transports cargoes in containers moving through pipelines filled with liquid--usually water. It is a new concept of freight transport originated in Canada in the 1960's. Potential advantages of this new mode of transport include (1) energy conservation, (2) pollution free, (3) reduction of highway and railroad accidents, (4) automation, (5) no interruption by adverse weather, and (6) protection of environment.

The four tasks of the contracted research are: (1) assessment of the energy conservation value of HCP as compared to other modes of freight transport such as truck, railroad, and slurry pipeline, (2) assessment of the market of HCP for coal transportation, (3) development of design concepts on HCP for transporting coal, and (4) design and construction of a small HCP system for the demonstration of the concept of HCP transportation. This report deals with the second and the third tasks. An earlier report entitled "Energy Conservation Value of Hydraulic Container Pipeline (HCP)" deals with the first task.

This research was funded through the Non-Highway Program, Division of Transportation Energy Conservation, Office of Conservation and Solar Applications, U.S. Department of Energy. Encouragement and guidance provided by Mr. Richard Alpaugh of the funding agency is greatly appreciated. The research reported herein was performed by M. Assadollahbaik and J.C. Yang--the two research assistants of the project.

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*Hydraulic container pipeline is usually referred to as "hydraulic capsule pipeline" or simply "capsule pipeline." In this report, the terms "capsule" and "container" will be used as synonyms.

ABSTRACT

The purpose of this sponsored research is to assess the feasibility and the potential value of HCP (Hydraulic Container Pipeline) as a new mode of freight transport. The tasks of the study involve (1) assessment of the energy conservation value of HCP as compared to other modes of freight transport such as truck, rail and slurry pipeline, (2) assessment of the market of HCP for coal transportation, (3) development of design concepts on HCP system for transporting coal, and (4) design and construction of a small HCP system for the demonstration of the concept of HCP transportation.

To date, the first three of the four aforementioned tasks have been completed; task 4 has just begun. This report deals with tasks 2 and 3. Another report, entitled "Energy Conservation Value of Hydraulic Container Pipeline (HCP)," deals with task 1.

It is shown in this report that a large market exists for HCP to transport coal. Not only is HCP the most environmentally and socially acceptable way to transport coal, it can also compete effectively with truck, train and even slurry pipeline on economic grounds.

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I. INTRODUCTION

The most versatile and sophisticated mode of pipeline transportation is container (capsule) pipelines. In this new mode of freight transport, cargo laden capsules (containers) of large size are forced through pipeline by the fluid flowing in the pipe. When the fluid is liquid (usually water), the pipeline is called hydraulic capsule pipeline (HCP); when the fluid is gas (usually air), the pipeline is termed pneumatic capsule pipeline (PCP).

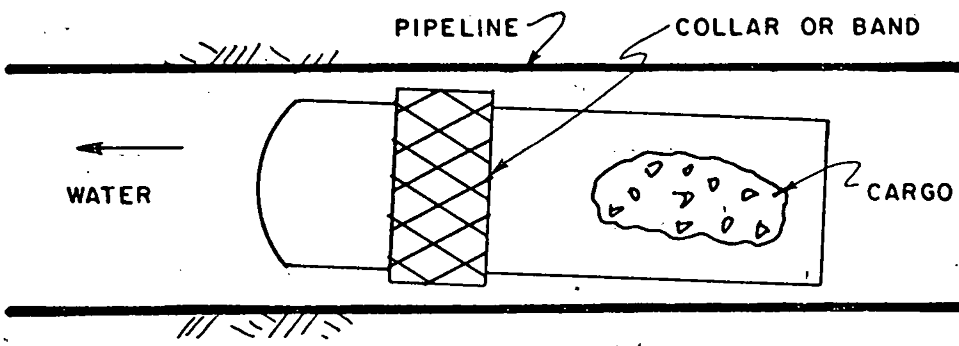
In the case of PCP, because the fluid is air which is too light to generate significant bouyancy, capsules that contain heavy cargo must be suspended on wheels rolling inside the pipeline. On the other hand, because HCP uses water which is a thousand times heavier than air, the capsules in HCP need no wheels. They are suspended by the bouyancy and the lift of the water moving through the pipe. How lift is generated in HCP was clarified by Liu in 1977 [1].* Fig. 1(a) and (b) give the configurations of HCP and PCP, respectively. In certain instances, a band (collar) may be placed near the front of a capsule of HCP, as shown in Fig. 1(a), to increase the hydrodynamic lift and to reduce frictional loss.

As analyzed in [2], while PCP seems to be more suitable than HCP for short distance transportation, the opposite is true for long distances. Therefore, PCP and HCP are suited respectively for urban and intercity freight transports. They do not compete for the same market.

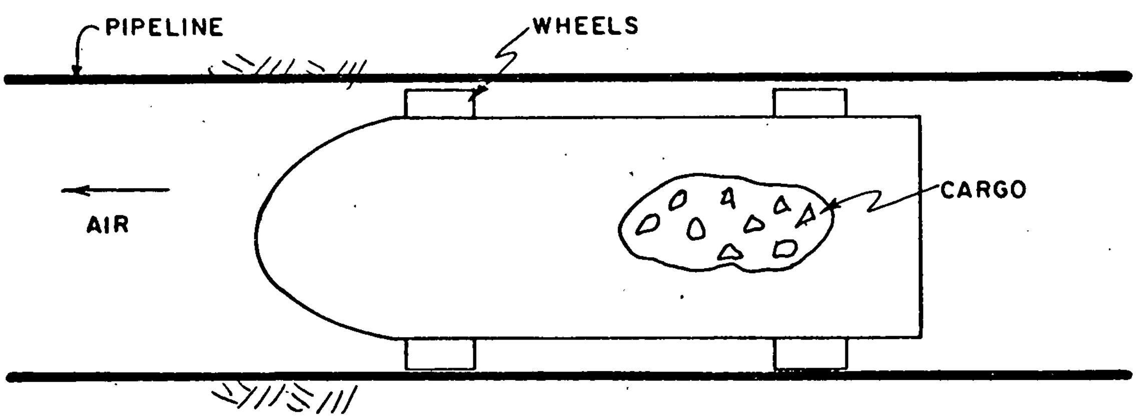
There are many potential applications of HCP for long-distance freight transport other than hauling coal.** In fact, coal may not even be the most important application of HCP. However, because the nation desperately needs coal

* Numerals in [ ] refer to corresponding items in APPENDIX 1 - REFERENCES.

**A discussion of various applications of HCP is given in [3]. A special application is grain transportation discussed in the newspaper clipping in APPENDIX 2 - RELATED DOCUMENTS.



a) HYDRAULIC CAPSULE PIPELINE (HCP)



b) PNEUMATIC CAPSULE PIPELINE (PCP)

Fig. 1 THE TWO TYPES OF CONTAINER (CAPSULE) PIPELINES and needs energy-conserving and environmentally acceptable ways to transport large quantities of coal, an assessment of HCP for coal transportation is much needed. Another reason for choosing to study HCP for coal transportation is that HCP is a new technology not yet fully developed. All new technology must start from a simple form, and then gradually increase sophistication as more and more about the technology is learned. Coal transportation seems to offer an opportunity to develop the simplest type of HCP conceivable. The system is simple for five reasons: (1) only a single cargo is involved. This makes capsule preparation and handling an easy task. (2) Accidental leakage of water into capsules has no serious consequences. (3) The bulk density of coal is such that when capsules are filled with coal, the capsule density becomes only slightly greater than water density. This minimizes contact between capsules and pipe, and optimizes energy consumption. It also makes start-up an easy task. (4) Unlike the transport of perishable commodities which require speedy delivery, speed is not needed at all for transporting coal; what counts in this case is the throughput. Even at very low speed HCP can produce an amazingly large throughput of coal (see Table 1). This offers an opportunity to run the flow at rather low speed to conserve energy. At low speed the injection and handling of capsules also become easier. (5) The piping consists of only two parallel pipes (a delivery

TABLE 1 - Variation of Coal Throughput of HCP with Pipeline Diameter

(Assumptions: Capsule velocity = 6 ft/sec, diameter ratio = 0.9, linefill rate = 0.9, bulk specific gravity of coal = 0.83, etc.)

Pipeline Diameter (ft)	Coal Throughput (million tons per year)
1	2.8
1.5	6.2
2	11
3	25

and a return line) connecting between a coal mine and a large power plant. No branching or telescoping of pipes are involved.

II. PURPOSE OF STUDY

The purpose of the study is to assess the feasibility and desirability of transporting coal by HCP. The feasibility of any engineering project depends on (1) engineering or technical feasibility, (2) environmental and social feasibility, and (3) economic feasibility. All three criteria must be met before a project can be considered feasible and desirable. Therefore, the feasibility and desirability of HCP for coal transport will be examined in light of these three criteria.

III. SUMMARY OF FINDINGS

It was found that HCP is technically feasible although much remains to be researched and developed before an efficient and trouble-free system of HCP can be built. A small crash R&D program costing five to ten million dollars and lasting five to ten years is required for the successful development of HCP for coal transportation.

On the environmental/social side, the study found that HCP is clearly the most environmentally and socially acceptable way to transport large quantities of coal. The method saves energy, reduces U.S. dependence on oil, does not cause air, water and noise pollutions, saves lives, reduces traffic and accidents on highways and railroads, and consumes little water.

As far as economics is concerned, it was found that in many circumstances it is more economical to transport coal by HCP than by slurry pipeline or unit train. It is always economical to transport coal by HCP than by truck, even for distances as short as about 20 miles. Therefore, HCP can compete economically with slurry pipeline, unit train and, especially, trucks. HCP could play an important role in coal transportation in the future.

IV. FEASIBILITY/DESIRABILITY ASSESSMENT OF USING HCP TO TRANSPORT COAL

A. Technical (Engineering) Feasibility

1. General Technical Feasibility Assessment

Two decades of extensive study of HCP at the Alberta Research Council in Canada [4-6] has generated a wealth of knowledge in capsule hydrodynamics and in how to design and operate HCP systems. The Council's study included extensive experimentation with pipes up to ten inches in diameter. The Council's researchers also carried out a special test in which a cylindrical capsule of 16 inch diameter weighing 514 lbs was injected into a 20 inch diameter crude oil pipeline at Edmonton, Canada. The capsule traveled a hilly countryside of 109 miles before it was picked up. No difficulty was encountered in the movement of the capsule in the experiment. A recent account of this test is given by Ellis [7].

From the Canadian experience alone, one can conclude that HCP is technically feasible. However, the Canadian study so far has been concentrating on the hydrodynamics of HCP; it has not explored the system hardware with equal eagerness. Much about the hardware of HCP remains to be researched before an efficient and reliable HCP can be built. Thus, for early development of HCP, future research in the field should be focused on hardware.

The hardware components which require greatest attention from researchers are (1) injectors to inject capsules into the pipe, (2) ejectors which eject or retrieve capsules from pipe, and (3) capsule pumps. Handling of capsules, such as filling capsules with coal, sealing the capsules, and transporting capsules to (from) injector (ejector), also requires some attention. However, the main task there is design based on existing technology. Special valves that do not block capsule passage can also be built within current technology of the valve manufacturers. A slight modification of the design of ball valves will make the valve suitable for HCP. The pipe and the construction technique for HCP will be little different from that for regular pipelines, except sharp bends must be avoided at all costs, and pipe joints should be as smooth as practical.

2. Injectors

Several schemes to inject capsules into pipeline have been investigated in Canada by the Alberta Research Council. Fig. 2 illustrates the lock-type injector. The operation of the system involves two steps: First, open valves 1, 4 and 5 and close valves 2 and 3; the suction pump draws capsules into the lock as shown, and the main pump drives water into the downstream pipeline. In the second step, valves 2 and 3 are opened, whereas valves 1, 4 and 5 are closed. The flow through the main pump now drives the capsule train out of the lock and into the downstream pipeline.

Although the lock-type injector produces densely spaced capsules within each train, the linefill of the entire pipeline is low due to the large distances separating trains. The system is not suited for commercial operation when high degree of linefill* is required for economical reasons. Although several lock-type injectors placed in parallel may be used to increase the linefill, the operation of a system with parallel locks becomes rather complex. The main advantage of the lock-type injector is that the pumps used for such a system

*Linefill is the length of the pipe occupied by capsules divided by the total length of the pipe.

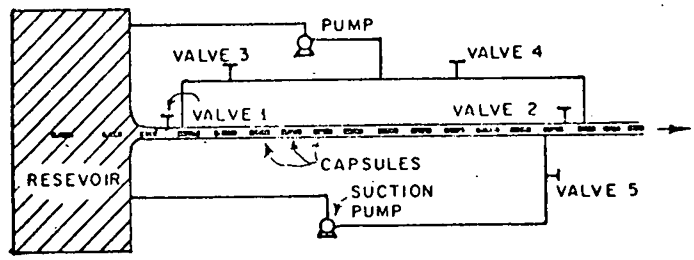


Fig. 2 THE LOCK-TYPE INJECTOR

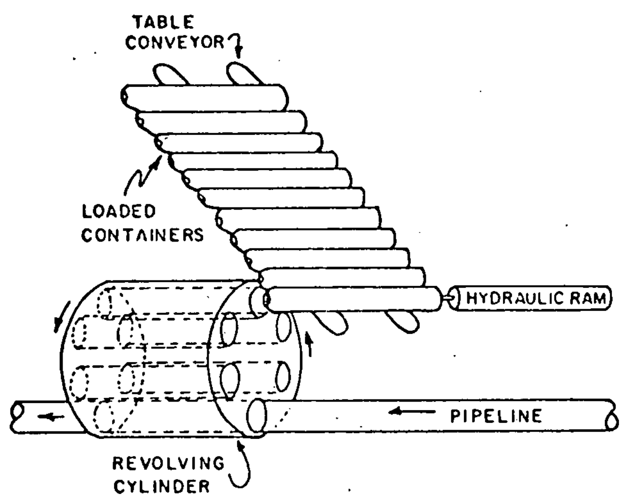


Fig. 3 THE REVOLVER-TYPE INJECTOR

(both the main pump and the suction pump in Fig. 2) are ordinary centrifugal pumps. If the line is so short that booster pumps are not required, the entire HCP system can be powered by ordinary centrifugal pumps. No capsule pumps (i.e., special pumps which allow passage of capsule through the pumps) are needed.

Another type of injector studied in Canada is the multi-barrel revolver shown in Fig. 3. Each time the injector revolves to a new position, a capsule is injected into the pipeline. The force that causes the capsule to accelerate out of the barrel is the water-hammer force generated by pressure surges. For this type of injector to work, it must be mounted on the suction side of capsule pumps where the line pressure is low, and it must be immersed in a reservoir. Otherwise, there would be serious leakage problems. Other shortcomings of the revolver injector are the difficulty in loading capsules into the revolver at a fast rate, and problems associated with the high pressure surges (the water - hammer effect). The problems are expected to be especially hard to overcome in large pipelines.

Two new ways to inject capsules have been explored in this study. The first is the multi-tube launcher as shown in Fig. 4. The system consists of a set of parallel launching tubes mounted on a wide conveyor belt which can cause the tubes to move laterally one step at a time. Capsules are fed into several tubes (say four as in the figure)* simultaneously at a slow rate. Each time when a tube in position 1 through 4 moves one step laterally, an additional capsule is fed into the tube. Thus, when the tube comes to position 4, it will have accumulated in it 4 capsules. As the tube moves to position 5, a water jet (hydraulic catapult) accelerates the capsules. Finally, when the tube reaches

*In commercial application, it is believed that five to ten tubes are needed.

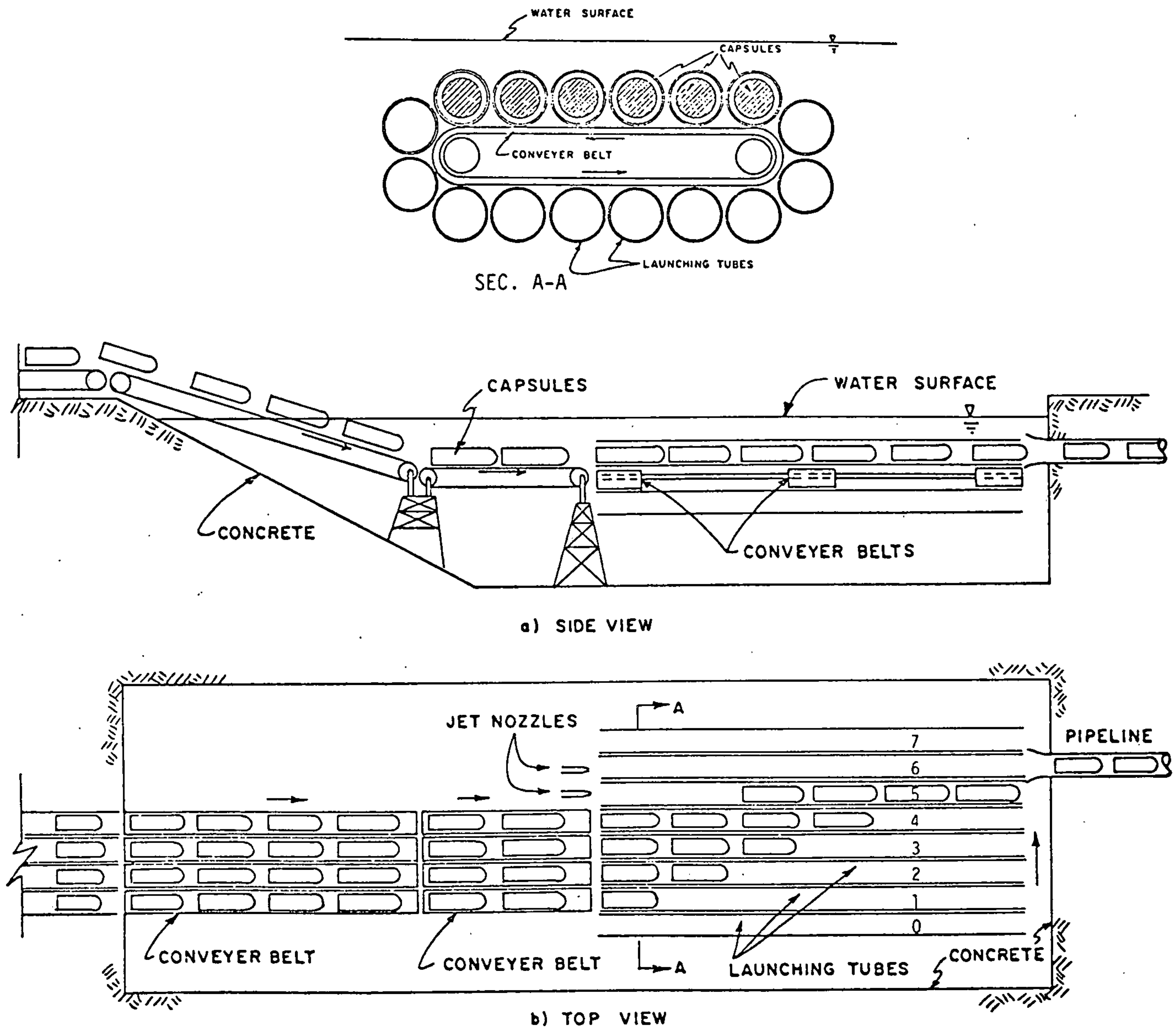


Fig. 4 THE MULTI-TUBE LAUNCHER

position 6, another jet pushes the entire train of capsules into the pipe.

Note that by using the multi-tube launching system described above, densely spaced capsules can be accelerated before they enter the pipe. This makes rapid injection and high degree of linefill possible for any size of pipelines. It is anticipated that this system should be able to produce linefill greater than 80%. The main shortcomings of the multi-tube launching system are the bulkiness of the systems and the need for precise control. In spite of these shortcomings, the system is the only known practical means that can produce high linefill by continuous feeding at pipeline inlet. The system is not intended either for intermittent operations, or for pipelines with more than one capsule feeding stations along the pipe.

Another new method to inject capsules, first revealed in this report, is the <u>gravity feeders or injectors</u> shown in Fig. 5(a) and (b). The feeder is somewhat similar to the vending machine that releases bottles of soft drinks by gravity. While Fig. 5(a) shows the gravity feeder for use at pipeline inlet, 5(b) gives the type used at intermediate stations along the pipe. The <u>intermediate feeder</u> is different from the <u>inlet feeder</u> in that the former must allow capsules coming from upstream to pass through the bottom of the feeder. Unlike the capsules in the inlet feeder being free to drop into the pipe at a steady rate, the capsules in the intermediate feeders are restrained by supporting pins. They cannot drop into the pipe unless the pins under them are activated. The pins are activated electrically when sensors upstream do not detect any capsule approaching the intermediate feeder.

The gravity feeders are designed for injecting capsules at more than one location along any pipeline. Although each gravity feeder does not produce high degree of linefill, when several of them are used in series in a given

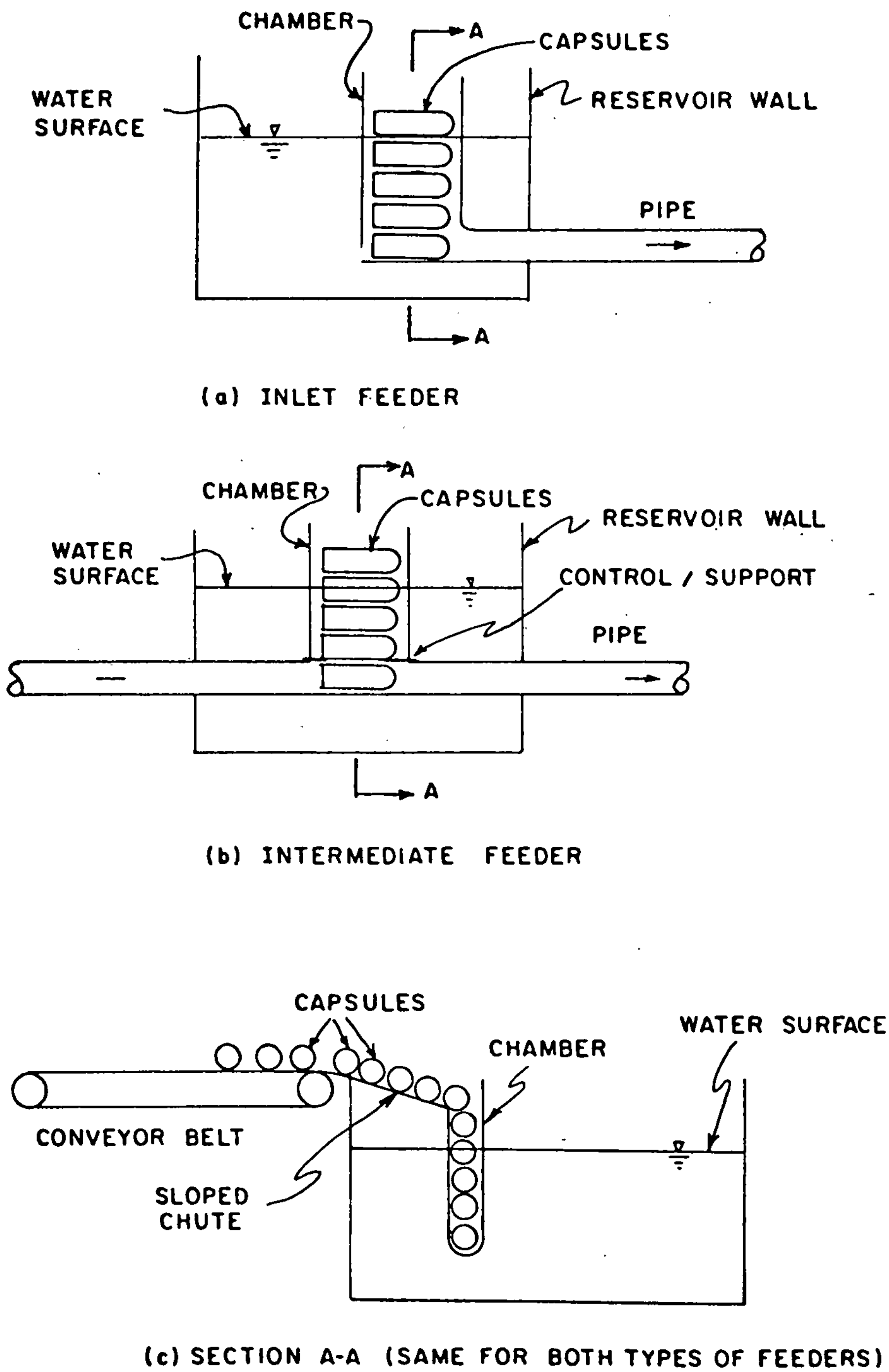


Fig. 5 GRAVITY FEEDER OR INJECTOR

pipeline, they can produce high linefill. They are particularly suited for cargoes (such as grain or coal) that must be picked up from several nearby locations for transport to a distant location. Note that both the inlet and the intermediate gravity feeders must be placed inside a reservoir. Due to the existence of free surface, the feeders must be placed on the suction side of the pump.

3. Ejectors

At the exit of HCP, capsules come out of the pipe with the fluid (water) in a natural manner; no special effort is needed to eject them. Nonetheless, an automatic system is needed to collect the capsules and to convey them to terminal buildings where the capsules are emptied of their content, cleaned, and then either stored temporarily or sent back through the return pipeline with or without another cargo. A proposed conveyor system to collect capsules at pipeline exit for transport to terminal buildings is shown in Fig. 6. The conveyor belt that receives the capsules coming out of the pipes should be moving at the same speed as the capsule velocity in the pipe.

Ejection of capsules from pipeline at intermediate stations is more difficult. Although various schemes are possible, one which seems most practical is the one shown in Fig. 7, first disclosed in this report. The system consists of a carefully shaped bifurcation near the entrance of the intermediate station. A LIM (i.e., linear induction motor) will be placed on each side of the bifurcation. The LIM produces two components of force: one is a thrust on the capsules in the direction of the flow, and the other is an attractive force toward the LIM. Thus, when LIM #1 is turned on and #2 turned off, capsules will pass through the intermediate injector and remain in the pipeline. On the other hand, when LIM #2 is turned on and #1 turned off, the capsules will be

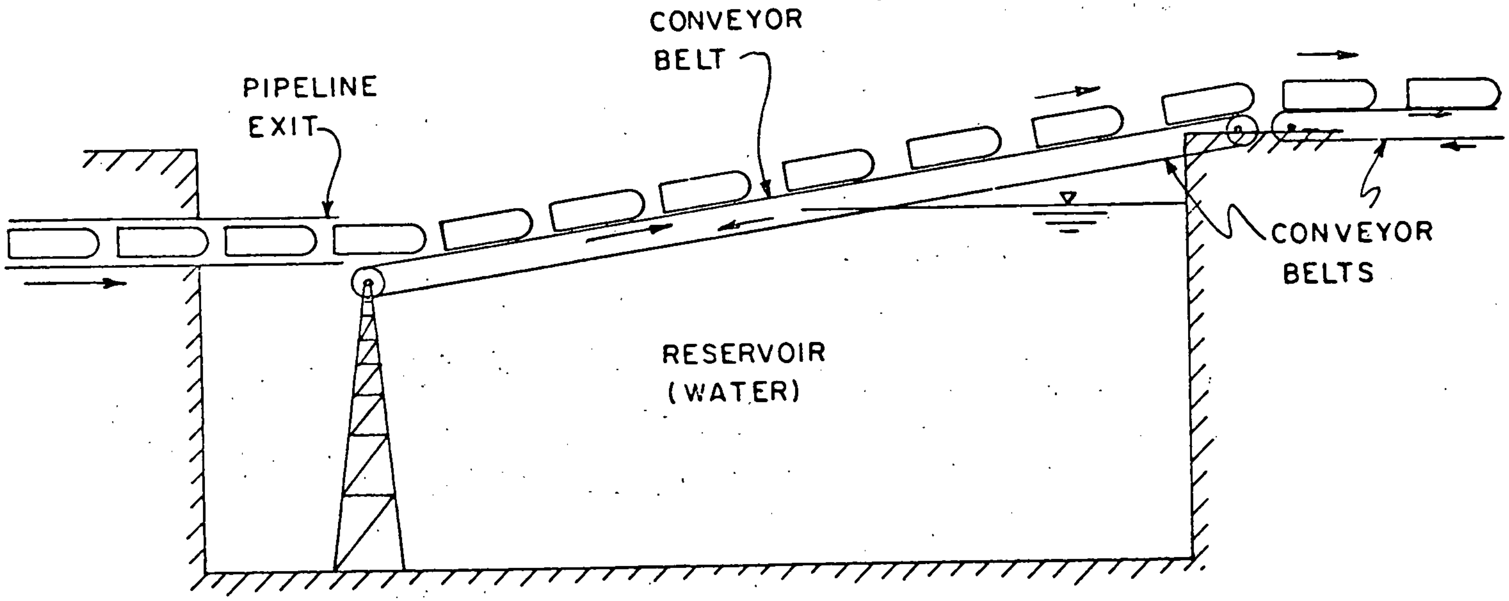


Fig. 6 RETRIEVAL OF CAPSULES AT PIPELINE EXIT (VERTICAL PROFILE)

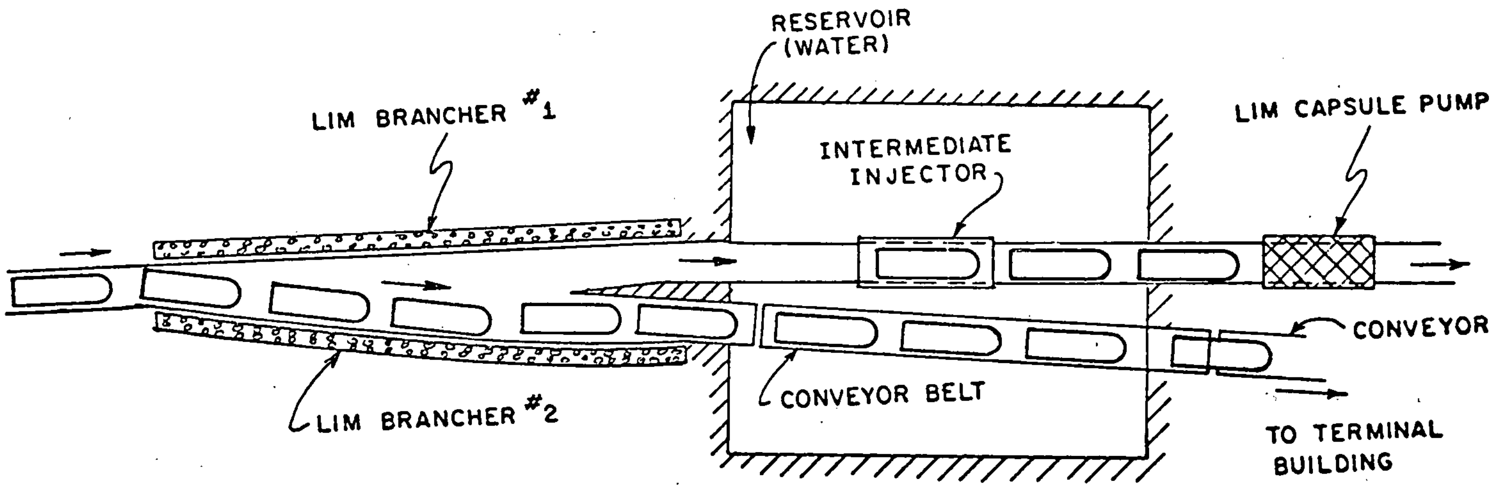


Fig. 7 EJECTION OF CAPSULES AT INTERMEDIATE STATION (TOP VIEW)

sucked into the exit branch and then retrieved by a moving conveyor belt in the same manner as at regular pipeline exit shown in Fig. 6.

4. Pumps

Two types of capsule pumps were studied by researchers at the Alberta Research Center in Canada: the vortex pump and the rotary-vane pump. The vortex pump is based on the same principle as conventional jet pumps, except the jet nozzle does not protrude into the pipe, and there is no change in pipe diameter at the pump. The energy transferred to the flow and the capsules comes from a set of wall jets injected into the pipe, as shown in Fig. 8. Capsules can pass through the pump completely unhindered. The main advantage of the vortex pump is its simplicity. The main shortcomings are low efficiency and low head. The developers of the vortex pump in Canada were only able to get 15% efficiency for their small-scale test model [6]. It is believed that a well designed large vortex pump should have much higher efficiency, although no efficiency as high as those for ordinary centrifugal pumps is anticipated. Modern ordinary water jet pumps have efficiency in the neighborhood of 40% only. Theoretical analysis shows that the vortex pump develops low head at best efficiency. Although vortex pumps can be put in stages to produce high head, the economics of multi-stage vortex pumps may not be favorable.

A sketch of the rotary-vane pump developed in Canada is shown in Fig. 9. To date, only small-scale models of the pump have been tested. The main drawback of this pump is its bulkiness. For instance, to pass cylindrical capsules of a length of 15 feet, the diameter of the rotary pump will have to be about 40 feet. This could cause economical as well as technical problems, for the water in the pump will be under high pressure.

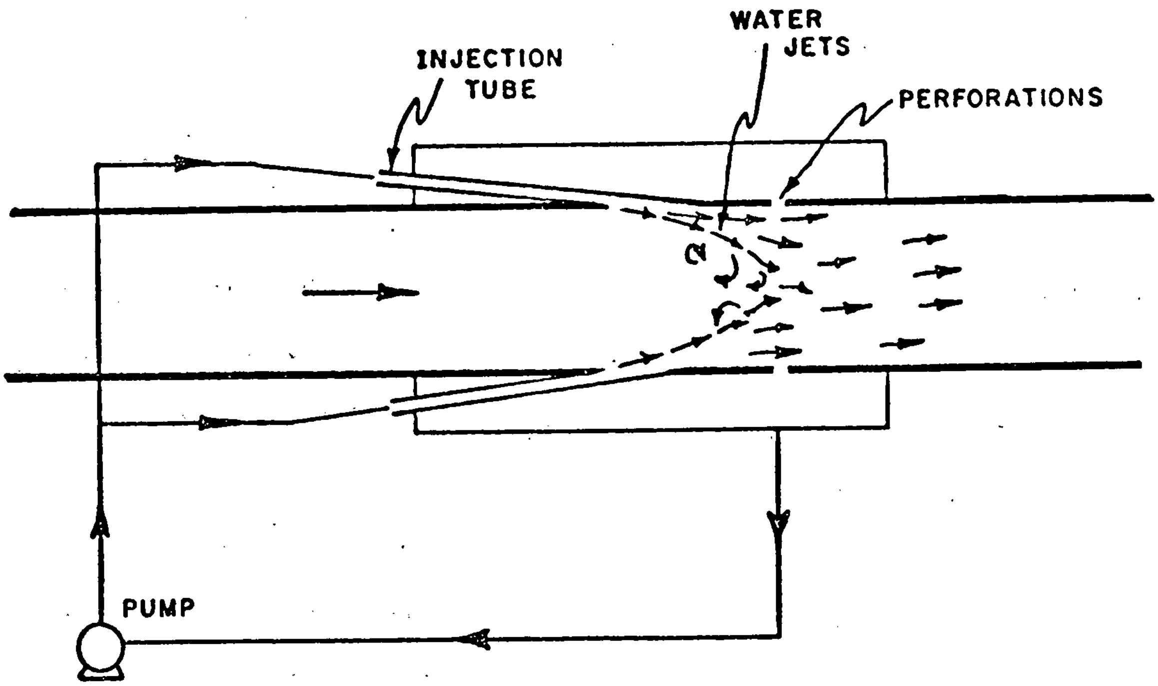


Fig. 8 THE VORTEX PUMP

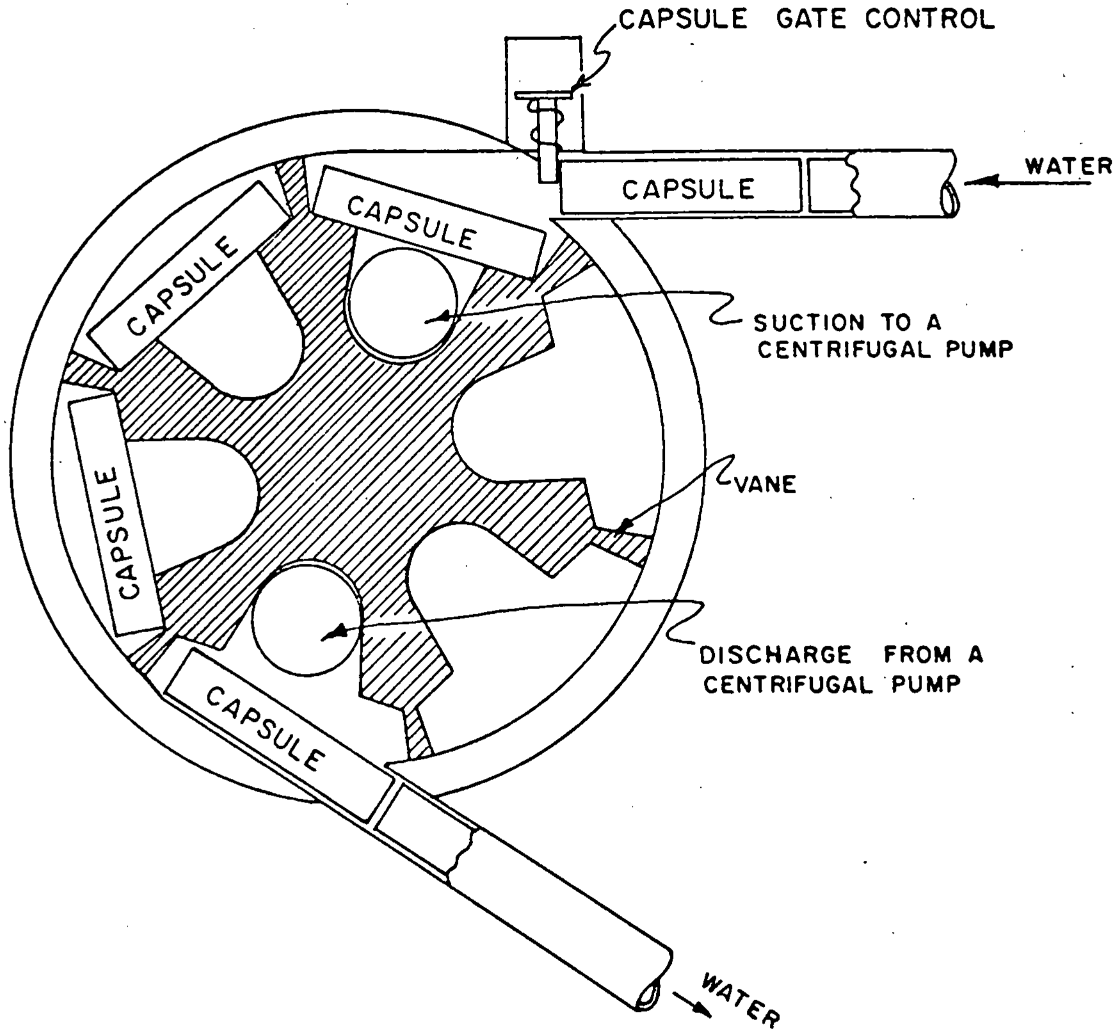


Fig. 9 THE ROTARY-VANE PUMP

Several schemes to cause capsules to bypass ordinary pumps have been studied in Canada; one is illustrated in Fig. 10. This scheme, involving the closing and opening of valves according to the sequence shown in Fig. 10, allows the capsules to bypass the pump.

The advantage of the bypass scheme is that when it is used in association with the lock-type injector, only ordinary pumps (centrifugal pumps) are needed for the entire HCP system. No special pumps that can pass capsules need to be developed. In spite of this advantage, some serious disadvantages exist with the bypass scheme. One disadvantage is the high pressure surges (the water hammer effect) generated from rapid closure or opening of valves. If valves are not closed and opened rapidly, the efficiency and the linefill of the system will be low. Another disadvantage is the complexity of the operation involved. Due to the above, the bypassing scheme is not considered a practical means for HCP systems that must operate at high linefill rate. However, in circumstances in which only a low degree of linefill is needed*, the bypassing scheme may be a good solution.

All of the aforementioned pumping systems for HCP require the use of mechanical pumps in one way or another. Engineers at the University of Missouri-Columbia have investigated two alternative methods to pump capsules without having to use mechanical pumps. These new methods, involving a direct transfer of electromagnetic energy to capsules, are described as follows:

The first method uses a special form of linear induction motor (LIM). Induction motors operate on the principle that a moving magnetic field induces a current and a force on a conductor (the 'rotor') exposed to the magnetic field. The force on the 'rotor' of a LIM is linear and hence causes the 'rotor' to

*Such a system exists when the primary cargo to be transported is the fluid rather than the capsules, such as the Canadian proposal of using existing oil pipelines to ship grain [8].

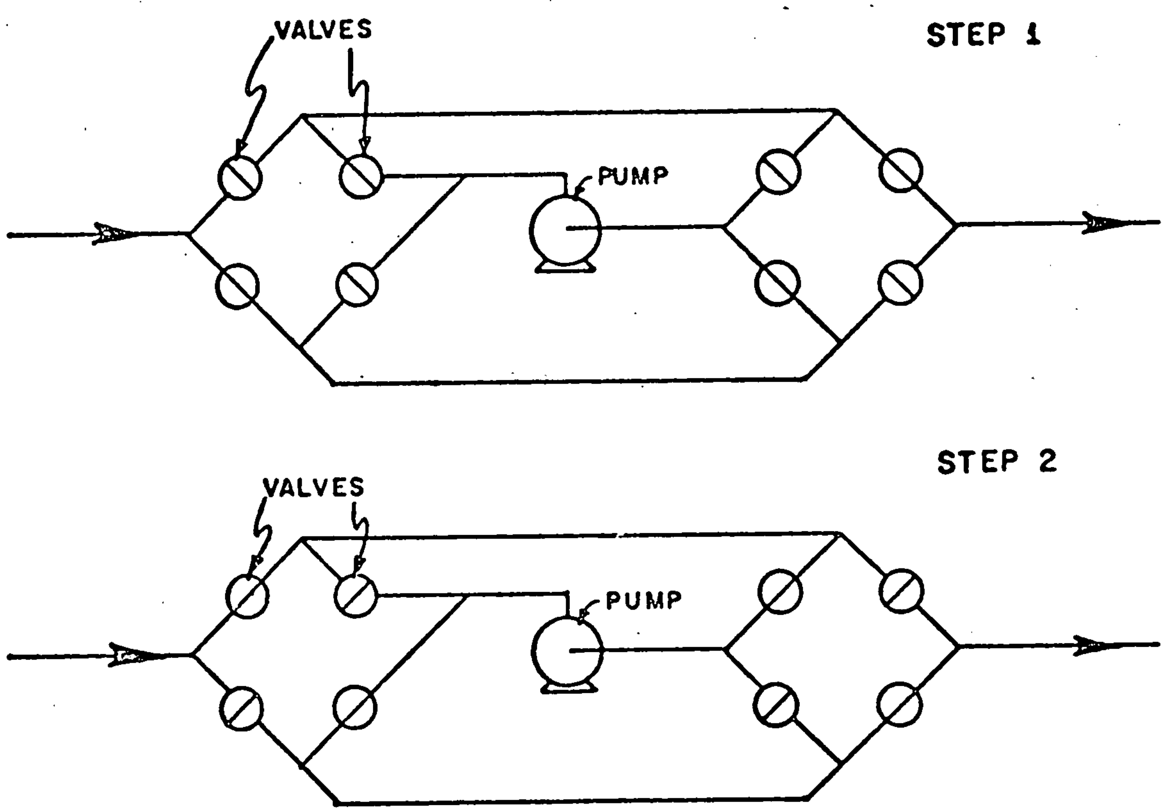


Fig. 10 PUMP BYPASS SCHEME

move in a straight path. LIM devices have proved to be useful in many unusual applications; they have received wide attention in recent years. A recent review of the LIM was given by Laithwaite and Nasar [9].

The LIM has been investigated thoroughly in recent years for the propulsion of high speed trains, as described in an article by Kolm and Thornton [10]. The high-speed train uses no wheel and hence must be levitated either pneumatically or magnetically. LIM has also been investigated for low speed mass transit application, as discussed by Caudill in 1976 [11]. In HCP, the capsules are levitated by the lift force generated by water [1]; no magnetic or other energy is needed for levitation. The only magnetic force needed in HCP is the force of propulsion in the direction of flow. The use of the LIM for HCP is further simplified due to the fact the system does not require a magnetic field along the entire length of the pipe. As long as there is a continuous train of densely-spaced capsules in the pipe, the magnetic field needed to push the capsules can be concentrated at pumping stations along the pipeline. The capsules which are pushed by the magnetic field in turn push other capsules and/or the water in the pipe, causing a continuous movement of capsules and water through the pipe.

The LIM device used for HCP is called a <u>LIM capsule pump</u>. It is a tubular motor with special windings around the pipe through which capsules pass. The capsules to be used with the LIM capsule pump should have a ferromagnetic wall (such as steel) covered by a good conductor (such as aluminum). A LIM capsule pump is shown in Fig. 11.

Another way to pump capsules electromagnetically involves the use of capsules with ferromagnetic walls but without aluminum cover. With a set of solenoids placed around a short segment of the pipe, ferromagnetic capsules can be pumped through the pipe by electric pulses. The action is similar to attracting an iron or a steel bar to a solenoid when a switch is closed, except in HCP a set of

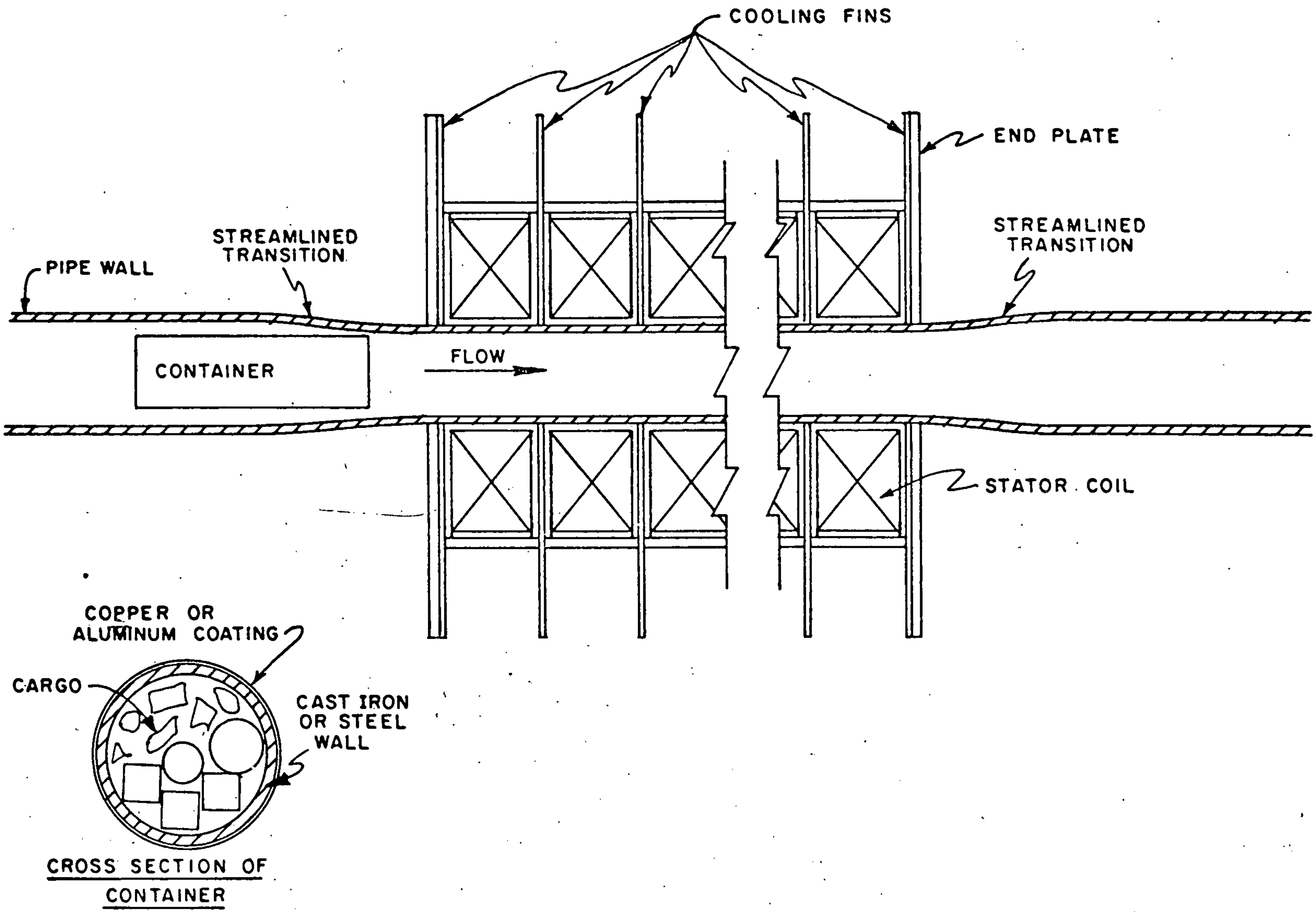


Fig. 11 THE LIM CAPSULE PUMP

solenoids operating in succession are needed to cause the continuous motion of capsules. This can be seen as follows:

Referring to Fig. 12, $S_1,\ldots S_5$ are a set of five solenoids around a pipe. When a ferromagnetic capsule approaches S_1 as shown in the sketch, S_1 is switched on. This causes a magnetic force on the capsule, forcing the capsule to move to the right. As soon as half of the capsule has entered S_1, the solenoid is switched off while S_2 is switched on, causing the capsule to move further to the right. Continuing this process until the capsule has entered the last solenoid S_5, the capsule will be moved a distance L along the pipe.

The above scheme to move capsules through pipe does not work when the pipe is filled with ferromagnetic capsules at a high degree of linefill. In such a situation, each solenoid attracts capsules on both sides at equal strength, causing no net movement of the entire capsule train. However, by placing at least one non-ferromagnetic capsule between any two ferromagnetic capsules, or by making a segment of each capsule non-ferromagnetic, trains of capsules can be made to pass through the solenoids continuously. Such a device is called a <u>solenoid capsule pump</u> or a <u>magnetic capsule pump</u>.

In both the LIM and the magnetic capsule pumps, electromagnetic energy is transferred directly to capsules which in turn push the liquid and the other capsules forward. In such a case, a high pump head or pressure can be generated only if the gap between the capsule surface and the inner surface of the pipe is small. This means the segment of the pipe going through an electromagnetic pump or the short reach immediately downstream must have an inner diameter smaller than the inner diameter of the rest of the pipeline. A smooth transition at the inlet of the narrow section is, of course, required. More details about the LIM and the magnetic capsule pumps are given by Liu and Rathke in 1976 [12].

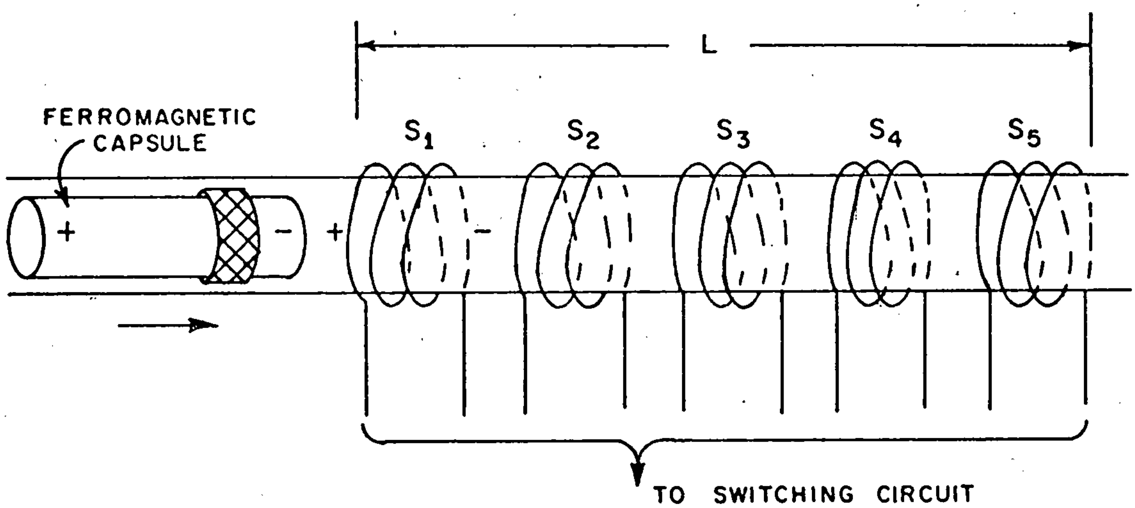


Fig. 12 SCHEMATIC REPRESENTATION OF THE SOLENOID CAPSULE PUMP

The greatest advantage of electromagnetic pumping is its simplicity. The pump has no moving or rotating parts, and it requires only a short segment of pipe wrapped with wires. The electrical energy in the wires is transmitted to the walls of the capsules. The capsules in turn push other capsules and the liquid through the pipe. The greatest limitation of electromagnetic pumping is that the pump does not work unless there are capsules passing through the pump. Therefore, the pump is not suitable for systems having low linefill rates. Even at high linefill, an auxilliary pump such as a vortex pump may be needed to start the system and to keep the flow going during periods when no capsule is passing through the pump.

Of the two types of electromagnetic capsule pumps discussed, the LIM type seems more practical than the solenoid type. It should be the type investigated for coal transportation. From a recent preliminary investigation [13] conducted by E. R. Laithwaite who is the world's foremost authority on linear motors, the efficiency that can be expected from a well-designed LIM capsule pump should be around 50%. Although this efficiency is less than the peak efficiency of ordinary rotating motors, it should be considered as satisfactory for HCP application. As revealed in a previous report [14], even at 50% efficiency HCP still uses much less energy than slurry pipeline, trucks, and trains under most conditions.

5. HCP System for Transporting Coal

The overall process of transporting coal by HCP is illustrated in Fig. 13. The first step is coal preparation (crushing and cleaning) which is required regardless of how coal is transported (by HCP or other transportation modes). With HCP, coal does not have to be pulverized as with slurry pipeline transportation.

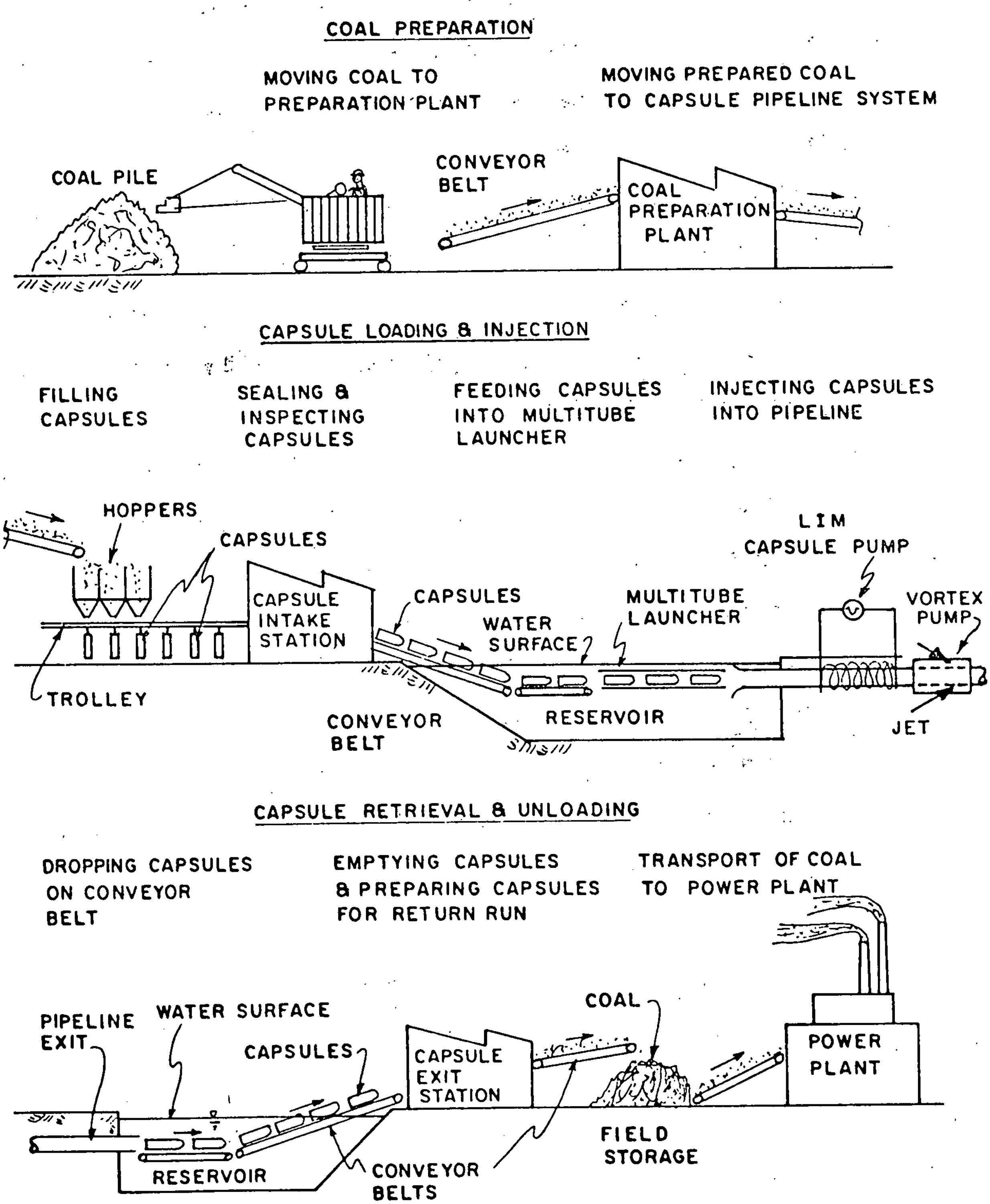


Fig. 13 CONCEPT ON HYDRAULIC-CAPSULE-PIPELINE (HCP) TRANSPORT OF COAL

As shown in Fig. 13, after the coal has been prepared, it can be transported either by conveyor belts or by pneumatic pipelines to the capsule filling station where the coal is fed into capsules through automatic hoppers and trolleys. The hoppers can be controlled by the weight of the coal fed into each capsule. Each time after a certain weight of coal has entered a capsule, the hopper stops feeding and the filled capsule is moved by the trolley into the capsule preparation station where the capsule is sealed and inspected for the sealing. The sealed capsules are then carried by conveyor belts for direct feeding into the capsule injection system.

In cases where all the coal to be transported by an HCP system comes from a single large coal mine, the multi-tube launcher discussed on page 8 should be used to inject capsules. On the other hand, when the coal to be transported comes from several mines, the gravity feeders discussed on page 10 are more appropriate.

As shown in Fig. 13, a LIM capsule pump should be placed near the pipeline intake to maintain proper water level in the reservoir housing the inlet injector or feeder. The LIM pump should be followed by a vortex pump used as an auxilliary device. The vortex pump is needed only during start-up and at times when there is no capsule going through the LIM. In cases where more than one injection stations are needed, a LIM and a vortex pump are needed at each station. In addition, every 10 to 100 miles of the pipe should have a booster pump which is a LIM. The optimum distance between booster pumps cannot be determined until more is learned about the characteristics of the LIM capsule pump.

Finally, after the capsules have reached the exit end of the pipeline, they will be carried by conveyor belts to a handling station where the capsules are emptied of their content, cleaned, and either stored temporarily or refilled with another cargo or water. Then they will be shipped back through the return pipeline in a similar manner.

It can be concluded that HCP is technically feasible although much remains to be researched and developed before an efficient and trouble-free system of HCP can be built. It is estimated that a mini crash problem of R&D costing five to ten million dollars and lasting five to ten years is required for successful development of this new technology for transporting coal.

B. Environmental/Social Feasibility

The environmental/social feasibility of HCP is most easy to demonstrate. As will be shown shortly, HCP has vast environmental and social values. It is the most environmentally and socially acceptable way to transport freight--especially coal.

An important social value of HCP is energy conservation. According to the finding of this research project reported earlier [14], HCP uses far less energy than slurry pipeline and trucks under most situations. Large systems of HCP also use less energy than rail and waterways. Thus, the development of HCP for commercial use can produce great saving of energy (trillions of Btu's per year) and oil (billions of gallons per year), resulting primarily from penetration into the markets of trucks and trains for intercity transport.

Even in the penetration of the market of coal slurry pipelines, the saving of energy is substantial. For instance, as computed in [14], if instead of building a slurry pipeline 2 feet in diameter 100 miles long, one uses an HCP of the same diameter and length, the saving of energy accomplished by this single pipeline system alone will be approximately $3x10^{12}$ Btu per year, which is equivalent to the saving of 100 thousand tons of coal per year, or 20 million gallons of oil per year. The saving of money from fuel cost for this pipeline in 40 years--the expected life span of the system--is more than 100 million dollars.

In addition to the fact that HCP uses less energy than trucks, it also has the advantage that the energy used by HCP is electricity which can be generated from hydro, nuclear, or coal-powered plants. Therefore, substituting a significant portion of trucks by HCP means a significant reduction in our nation's reliance on oil--a matter of great importance to the nation.

Another important social benefit of HCP is in lifesaving. According to the statistics compiled by the U.S. Department of Transportation [15], truck accidents in 1975 resulted in 2,232 fatalities, 26,375 injuries, and $158,200,000 property damages. Even if in the future HCP can replace only 10% of the freight carried by trucks, it still means the saving of more than two hundred lives and two thousand injuries per year. This alone will be a great contribution to society. The assumed 10% penetration of truck market by HCP is believed to be a conservative estimate, in view of the findings of a freight pipeline demand study conducted recently by Zandi [16].

An important environmental value of HCP is reducing air and noise pollution resulting from reduced usage of trucks and trains. Because HCP uses electricity, it does not pollute the air. Even if one considers the fact that the electricity used is generated by coal-fired power plants which emit pollutants, a recent study by Zandi [17] shows that far smaller quantities of pollutants are emitted from these power plants than from trucks for producing the energy needed to transport the same cargo over the same distance. Besides, the pollution generated by power plants is concentrated at fewer locations and hence can be more easily controlled. The fact that HCP creates much less noise than trucks and trains is easy to see and needs no elaboration.

Another environmental or social value of HCP, stemming from the fact that HCP is underground, is that it does not interrupt traffic. For instance, Zandi has shown that [17] if instead of building the proposed Wyoming-to-Arkansas coal slurry pipeline*, the coal were transported by rail, it would require one unit train of 100 cars every hour and forty minutes. This means every town and every railroad crossing along the more than one thousand miles of the railroad between Wyoming and Arkansas will be interrupted by a train every hour and forty minutes. The use of HCP or other pipeline systems will not cause any such disruption.

Another important contribution of HCP is the system is best suited for the transport of hazardous chemicals or nuclear wastes. The chance of an accident involving a capsule traveling in an HCP is practically nil. The only accident that might happen in HCP is at pipeline terminals where the cargoes are loaded and unloaded. Thus, HCP not only reduces the chance of spill of hazardous chemicals that must be transported over long distances, it also confines accidents to special locations where the equipment to combat spill can be stored and made readily available in the event of a spill. In fact, if in the future the U.S. will have an underground network of HCP, the government should require that all hazardous chemicals and nuclear wastes be transported by HCP, whenever possible.

All of the aforementioned environmental and social benefits of HCP resulted from substituting the use of a portion of trucks and trains by HCP. Benefits may also be derived by substituting HCP for some slurry pipelines. Although slurry pipeline has all the aforementioned advantages of HCP, it has some

*The pipeline, designed by the Energy Transportation System, Inc. (ETSI), is to deliver 25 million tons of coal per year. Due to law suits involved, the construction of this slurry pipeline has not yet started to date.

environmental problems HCP does not have. For instance, as mentioned in a U.S. congressional report [18], "Slurry pipelines consume large quantities of water, and, owing to the geographic location of coal, most of the pipelines originate in somewhat arid regions." For instance, great controversy surrounds the proposed ETSI slurry pipeline from Wyoming to Arkansas. The main concern by the people in Wyoming and South Dakota is how this pipeline will affect the existing water users (such as the farmers) and the ground water table of the Madison Formation. This concern has been analyzed in great detail in [18], in association with congressional considerations of granting the right of eminent domain to coal slurry pipelines. On the other hand, the water in HCP is recirculated through the return pipeline which transports emptied capsules to coal mines. Once an HCP system is filled with water, it needs little replenishment.

Another problem of coal slurry pipeline is water pollution. Coal slurry must be dewatered at the exit terminal of the pipeline. The water released from the slurry may contain high concentration of pollutants [18]. If discharged into the environment without treatment, it could cause serious pollution problems to surface and ground waters. Because the water in an HCP system is recirculated and not in contact with coal, there is no water pollution problem with HCP. Coal slurry pipeline also consumes a great amount of energy in the process of dewatering. Thus, using HCP instead of slurry pipeline conserves energy. This is true especially for shorter systems [14].

The above shows the positive impacts of HCP. The only significant negative impact happens during construction, when both the environment and the people's lives will be disrupted temporarily. However, this disruption is no more serious than the disruption caused by the construction of slurry pipeline or highway. It is a price that must be paid for increased utilization of coal and conservation of energy.

Concerns have been raised that with the introduction of HCP, truckers may lose their jobs in the future. The fear is unwarranted not only because HCP can replace only a small portion of truck business but also because the replacement can take place only gradually. It will take decades before enough HCP's can be built to cut into truck market substantially. What this means is that with the development of HCP, in the future fewer people will enter into truck-driving jobs; the jobs of existing truck drivers will not be eliminated. Besides, new jobs will be generated by HCP which may be more comfortable and secure than trucking jobs. It should be realized that whenever any improved technology is introduced, it always replaces some old jobs with new jobs. Such a change represents progress; it is needed if the nation is to remain technologically strong and continue to enjoy the highest living standard in the world.

It can be concluded from the foregoing analysis that enormous social and environmental benefits can be reaped by using HCP to transport coal and other cargoes.

C. Economic Feasibility

1. General Comments

Great difficulties exist in assessing the economic feasibility of HCP. The difficulties are due mainly to the fact that HCP is still a not-yet-fully-developed technology. Notwithstanding two decades of research in HCP conducted mainly in Canada, more R&D works are required before commercial utilization is possible. The economic assessment of any undeveloped and unproven new technology is bound to be conditional and uncertain; it should not be taken without reservation. Nonetheless, it is important to give some considerations to the economics of any new technology before it is developed. Such considerations are of value not only to the policy maker who must decide whether to support the development of a new technology, but also to the researchers themselves who must make a choice among several alternatives about the best way to accomplish the same goal.

As is well-known by transportation experts, the cost of any ground transportation system depends on many important variables such as river crossings (the number of crossings and the size of the rivers), topography (whether the route crosses mountains or whether the land is hilly or not), land value (urban or rural setting), climate (cold or warm, wet or dry), availability of construction materials, etc. Different transportation modes depend on each of these factors in a different manner. For instance, because railroads cannot have large slopes, they are very expensive to built in hilly areas. The same does not hold for pipelines which can have much greater slopes without any adverse effect. Therefore, it is impossible to compare the costs of two transportation modes in general. One mode may be more economical under one set of conditions, whereas the opposite may be true under a different set of conditions. This is clearly illustrated in the economic comparison of slurry pipeline with rail as given in the congressional report on slurry-pipeline mentioned before [18]. Of the four cases studied in the said report, two cases (the Wyoming-to-Texas, and the Tennessee-to-Florida lines) turned out in favor of slurry pipeline, whereas the other two cases (the Montana-to-Minnesota, and the Utah-to-California lines) turned out in favor of railroad. Note that in all the four cases, the cost of building railroads was not considered. It was assumed that existing railroads can be used. To build new railroads merely for transporting coal would be clearly uneconomical in most situations.

In spite of the aforementioned great difficulties in comparing different modes, a comparison may sometimes offer an insight, as will be shown next.

Generally, pipelines provide one of the most economic ways to transport materials. For example, according to Hirst [19], the price for inter-city freight transport by ordinary (liquid) pipelines in 1970 was 0.27¢ per ton-mile. The corresponding figures for railroad and truck were respectively 1.4 and 7.5¢. This means transportation of freight by rail and trucks are respectively 5 and 28 times more expensive than by ordinary pipelines. Although the transport of solids by HCP is bound to be more expensive than the transport of liquid by pipelines, it is likely that under favorable conditions HCP transportation cost will not be more than 28 times or even 5 times the transport cost of ordinary pipeline. This means it is likely that under favorable conditions coal transportation by HCP will turn out cheaper than by truck and railroad.

In the ensuing discussion, an economic comparison will be made first between coal slurry pipeline and HCP. Then, HCP will be compared with truck and train for hauling coal.

In general, slurry pipelines require large investment on the facility for slurry preparation at the pipeline intake, and even a larger investment on the dewatering facility at pipeline exit. In addition, large costs are encountered for the power required for slurry preparation and dewatering, and for the purchase of flocculants used in the dewatering process. All these expenses are independent of the length of the pipeline. On the other hand, two major items of HCP which cost more than slurry pipeline are pipeline cost (due to the need for a return pipeline) and container cost - an item which does not exist for slurry pipeline. The costs for these two items are directly proportional to pipeline length. Because what makes slurry pipeline more costly is independent of pipeline length whereas what makes HCP more costly depends on length, it is expected that slurry pipeline will be more economical than HCP when transportation distance is long, whereas the opposite may hold for short-distance transportation. Of course, the distance of HCP cannot be too short or it may lose competitiveness to trains or trucks.

2. Cost Comparison between HCP and Slurry Pipeline*

a. Capital Cost for Terminal Facilities

The cost of the terminal facilities (i.e., the facilities at the two ends of HCP) depends on the total coal throughput and the kind of capsule injection system used. Whether one uses the multi-tube launcher or the gravity feeders makes a difference.

First, consider the cost of HCP terminal facilities using a multi-tube launcher that can produce as high as 90% linefill. Use the throughputs of the systems given in Table 1 on page 3, and use the design given in Fig. 13 on page 25. The costs for the terminal facilities are itemized in Table 2 on the next page.

Note that the terminal building cost listed in Table 2 is based on 30 dollars per square foot. The area of the building is calculated from

$$A = B \times L$$

where B = width = 60', L = length = 88 D + 20', and D = pipe diameter in ft.

The reservoir cost is based on 15 dollars per square foot. The area of the reservoir is determined from

$$A = B \times L = (20\ D) \times (100\ D) = 2{,}000\ D^2$$

where D is in ft.

The land cost is based on $1,000 per acre. The total area occupied by each terminus, including recreational and landscape areas, is assumed to be 100 acres.

The above computations assume the facilities with multi-tube launchers which are needed when all the coal transported by the pipeline comes from a single

*The cost figures for slurry pipeline used herein are those obtained from [18]. It was found that they are slightly more conservative than figures given in a GRC (General Research Corporation) report [20].

TABLE 2 - Capital Costs of HCP Terminal Facilities With Multi-Tube Launchers (Million Dollars)

Items and Quantity	Throughput (Million Tons Per Year)			
	2.8	6.2	11	25
22 conveyors (from coal storage to hoppers)	0.20	0.30	0.40	0.60
22 hoppers	0.04	0.06	0.08	0.12
44 trolleys for filled capsule	0.18	0.26	0.35	0.53
Terminal Building	0.19	0.27	0.35	0.51
8 conveyors (from trolleys to multi-tube launcher)	0.08	0.12	0.14	0.20
1 special conveyer system for the multi-tube launcher	0.02	0.03	0.04	0.05
1 reservoir	0.03	0.07	0.12	0.27
1 conveyor system for capsule retrieval	0.02	0.03	0.04	0.05
44 trolleys for emptied capsules	0.18	0.26	0.35	0.53
100 acres of land	0.10	0.10	0.10	0.10
Control equipment	1.00	1.00	1.00	1.00
Total Above	2.04	2.59	2.97	3.96
18% of total (for engineering, inspection and contingencies)	0.37	0.45	0.53	0.71
Total for One Terminus	2.41	2.95	3.50	4.67
Total for the Two Termini of an HCP System	4.82	5.90	7.00	9.34

large mine. When the coal to be transported comes from several adjacent mines, the gravity feeders (injectors) are to be used. The capital cost for the terminal facilities of HCP system with gravity feeders is to be considered next.

When only one intermediate feeder is used, the inlet and the intermediate feeders may inject respectively, say, 50% and 40% capsules; together they produce 90% linefill. The costs of terminal facilities for this case are shown in Table 3. Note that while the cost of the inlet station is obtained by summing up the costs of each component of the inlet station, the cost of the intermediate station is assumed to be the same as that of the inlet station. The outlet station cost (i.e., the cost of the terminal facilities at the exit end of the pipeline) should be the same as that for each terminus given in Table 2 because gravity feeders are not suitable for use at the exit end of the pipe to inject empty capsules back to the coal mines.

Comparison of the results in Table 2 with those given in Table 3 shows that it costs more to build gravity feeder stations than multi-tube launcher type stations. The reason for the higher cost for gravity feeders is that this type of feeder requires intermediate injection stations. It should be clear that the more intermediate stations are required in a given pipeline, the higher the cost will be.

To compare HCP with a slurry pipeline having only one injection station, the HCP also should have only one injection station. This means it is inappropriate to compare a gravity feeders type HCP with a slurry pipeline having only one injection station. For this reason, only the multi-tube launcher type HCP will be used in the ensuing comparison.

Table 4 gives a comparison between slurry pipeline and HCP regarding the costs for terminal facilities. The costs for HCP are obtained from Table 2,

TABLE 3 - Capital Costs of HCP Terminal Facilities Having An Intermediate Feeder Station (Million Dollars)

Items and Quantity	Throughput (Million Tons Per Year)			
	2.8	6.2	11	25
Inlet Station:	1.37	1.64	1.96	2.47
12 conveyors (from coal storage to hoppers)	0.11	0.16	0.22	0.33
12 hoppers	0.02	0.03	0.04	0.07
48 trolleys (for emptied and filled capsules)	0.20	0.28	0.38	0.60
Terminal Building	0.10	0.20	0.30	0.40
1 conveyor (from trolleys to inlet feeder)	0.04	0.06	0.07	0.10
1 inlet feeder	0.01	0.01	0.02	0.02
1 reservoir	0.01	0.01	0.02	0.03
1 capsule exit tube	0.01	0.01	0.02	0.02
1 conveyor system for capsule retrieval	0.02	0.03	0.04	0.05
50 acres of land	0.05	0.05	0.05	0.05
Control equipment	0.80	0.80	0.80	0.80
Intermediate Station	1.37	1.64	1.96	2.47
Outlet Station	2.04	2.50	2.97	3.96
Total for the 3 Stations	4.78	5.78	6.89	8.90
18% of total (for engineering, inspection and contingencies	0.86	1.04	1.24	1.60
Total for an HCP System	5.64	6.82	8.13	10.50

TABLE 4 - Comparison of HCP with Slurry Pipeline About Costs of Terminal Facilities (Million Dollars)

Item	Throughput (Million Tons Per Year)			
	2.8	6.2	11	25
Slurry Pipeline Termini:	16	37	62	118
Dewatering Facility	10	23	41	78
Slurry-Preparation Facility	6	14	21	40
HCP Termini	4.8	5.9	7.0	9.3

whereas the costs for slurry pipeline are those determined from throughputs by using Fig. 10 of [18]. It is clear from Table 4 that the cost of terminal facilities is much less for HCP than for slurry pipeline, especially when the throughput is large.

b. Operational/Maintenance Cost for Terminal Facilities

It is expected that due to the need for loading and unloading of capsules, HCP is more labor intensive than slurry pipeline. This means the labor cost for HCP is expected to be higher than that for slurry pipeline. Counter-balancing the higher labor costs is the lower cost for power consumption at HCP termini than at slurry pipeline termini. Because the ultimate degree of automation of HCP cannot be predicted with accuracy at this stage, the labor cost of HCP used in this analysis is based on three levels or degrees of automation: low (1,000 workers), medium (200 workers) and high (50 workers). The labor costs listed in Table 5 are based on the assumption that each worker costs the company $20,000 a year. (This includes salary, fringe benefits, social security, etc.) The energy costs of HCP termini are those based on the energy consumptions listed in Table 4 of [14], assuming the price of electricity to be 2.6¢ per kwhr--the same as assumed in [18] for computing the power cost for slurry pipeline. Energy used at HCP termini is for transporting capsules within each terminus, heating, air conditioning, lighting, etc. Energy used in pumping will be considered separately later. Note that the large consumption of power at slurry pipeline termini is mainly the result of pulverizing coal at the slurry intake terminus and dewatering coal at the exit terminus. Both the power cost and the cost of flocculants for slurry pipeline are those found from Figs. 13 and 14 of [18]. The costs of slurry water listed in Table 5 are

TABLE 5 - Comparison of HCP with Slurry Pipeline About Costs for Operation/Maintenance of Termini (Million Dollars Per Year)

Item	Throughput (Million Tons Per Year)			
	2.8	6.2	11	25
HCP Labor Cost:				
Low Automation	20	20	20	20
Medium Automation	4.0	4.0	4.0	4.0
High Automation	1.0	1.0	1.0	1.0
Slurry Pipeline Labor Cost:	1.2	1.8	2.7	4.7
Dewatering Facility	0.6	0.9	1.4	2.5
Slurry Preparation Facility	0.6	0.9	1.3	2.2
HCP Termini Energy Cost	0.03	0.03	0.04	0.07
Slurry Termini Energy Cost:	2.0	3.5	5.7	11.2
Dewatering Facility	1.1	1.9	3.0	6.0
Slurry Preparation Facility	0.9	1.6	2.7	5.2
Slurry Flocculants Cost	0.6	1.4	2.6	5.7
Slurry Water Cost	0.6	1.5	2.1	5.4
General Administration Cost (Same for HCP and Slurry Pipeline)	0.6	0.8	1.0	1.4
Maintenance Materials and Supplies (same for HCP and Slurry Pipeline)	0.8	1.6	2.6	5.4
Total for HCP:				
Low Automation	21.4	22.4	23.6	26.8
Medium Automation	5.4	6.4	7.6	10.8
High Automation	2.4	3.4	4.6	7.8
Total for Slurry Pipeline	5.8	10.6	16.7	33.8

obtained from Fig. 20 of [18] using a rate of 70¢ per 100 cubic feet of water. It is assumed that little water is consumed by HCP.

c. Costs for Operation/Maintenance of Pumps

The cost values listed in Tables 4 and 5 are those independent of pipeline length. Cost values that depend on the length of the pipe include the costs for pipeline, capsules, pumps, pumping stations, pumping power, etc.; they are listed in Tables 6 and 7.

From Table 7 of [14], the power dissipated through internal friction of fluid along one-mile reach of a coal slurry pipeline is approximately 34, 46, 56 and 78 Btu/sec., respectively for 1', 1.5', 2' and 3' pipelines. Assuming the efficiency of slurry pumps to be 70%, the corresponding power consumptions by the pumps over 100 miles of the pipeline is 5110, 6930, 8430 and 11700 Kw. Assuming as before each kw-hr of electrical energy costs 2.6¢, the costs for running the slurry pumps over a one year period are 1.2, 1.6, 1.9 and 2.7 million dollars, respectively for 1', 1.5', 2' and 3' pipelines. This result is listed in Table 6.

From [14], the pressure gradient along a well-designed HCP system is only about 0.6 times that of an equivalent slurry pipeline system. However, while slurry pumps have efficiencies in the neighborhood of 70%, the efficiency of HCP pumps (LIM capsule pumps) are expected to be only 50%. Due to this fact, and due to the fact that HCP requires pumping in both the delivery and the return pipelines, it is expected that the power consumed in HCP pumping will be about $0.6 \times \frac{70}{50} \times 2 = 1.7$ times the power consumed by slurry pumps in an equivalent system. Thus, the pump power costs for HCP listed in Table 6 are obtained by multiplying the corresponding figures for slurry pipeline by 1.7.

TABLE 6 - Comparison of HCP with Slurry Pipeline about Annual Costs for Operation/Maintenance of Pumps (Million Dollars Per 100 Miles)

Item	Throughput (Million Tons Per Year)			
	2.8	6.2	11	25
Pump Power Cost Per Year:				
Slurry Pipeline	1.2	1.6	1.9	2.7
HCP	2.0	2.7	3.2	4.6
Maintenance Materials and Supplies:				
Slurry Pipeline	0.2	0.3	0.3	0.4
HCP	0.1	0.1	0.2	0.2
Labor and General Administration:				
Slurry Pipeline	0.1	0.1	0.1	0.2
HCP	0.1	0.1	0.1	0.1
Total Above				
Slurry Pipeline	1.5	2.0	2.3	3.3
HCP	2.2	2.9	3.5	4.9

The costs for maintenance materials and supplies, and the costs for labor and administration for pumping stations of slurry pipelines, listed in Table 6, are obtained from Fig. 14 of [18].

d. Costs for Pipeline, Capsules, and Pumping Facilities

Due to the use of dual pipelines in HCP, the pipeline cost of HCP is assumed to double that of slurry pipeline given in Fig. 11 of [18]. This is slightly conservative because the costs for excavation, backfill, and right-of-way should be essentially the same for a dual as for a single pipeline. The cost of capsules depends on capsule diameter and linefill. In this analysis, it is assumed that the cost of capsules for 90 linefill is equal to 3 times the price for pipe steel obtained from Fig. 13 of [18] based on single-pipeline length.

The costs for pumping station facilities for slurry pipeline listed in Table 7 are obtained from Fig. 10 of [18], and from the costs of the Black Mesa slurry pipeline. The costs of HCP pumping facilities are determined in the following manner:

It is believed that large linear induction motors (LIM) for use in HCP should cost about the same as large transformers: approximately $25 per horsepower. To get good pump efficiency, the regular 60-hertz electricity must be changed to a current of much lower frequency. The frequency conversion device (inverter) for use in this case costs in the neighborhood of $50 per horsepower. Thus, the equipment cost for LIM capsule pump is approximately 25 + 50 = 75 $/Hp. Using this figure and knowing the power needed for HCP pumping, the cost for pump equipment (LIM and inverter) is found as listed in Table 7. The cost of shelters for HCP pump listed in Table 7 is believed to be conservative.

Table 7 shows that pipeline cost and capsule cost are the two biggest expenses for long lines of HCP. It is these costs that makes HCP more expensive than slurry pipeline when transportation distance is very long.

TABLE 7 - Comparison of HCP with Slurry Pipeline about Capital Costs for Components Dependent on Pipeline Length (Million Dollars Per 100 Miles)

Item	Throughput (Million Tons Per Year)			
	2.8	6.2	11	25
Pipeline Costs (Including Pipe Steel, Excavation, Welding, Installation, Right-of-Way, etc.):				
Slurry Pipeline	15	22	30	54
HCP	30	44	60	108
Capsule Costs	21	32	45	102
Pumping Facilities:				
Slurry Pipeline	4	5	7	10
HCP:	1.0	1.3	1.6	2.1
LIM and Inverters	0.9	1.2	1.5	2.0
Shelter for HCP Pumps	0.1	0.1	0.1	0.1
Total Above:				
Slurry Pipeline	19	27	37	64
HCP	52	77	107	212

e. Total Capital Cost

The total capital cost for HCP (or for slurry pipeline) is the sum of the capital cost for terminal facilities (figures given in Table 4) and the capital cost for pipelines, capsules and pumping facilities (figures given in Table 7 multiplied by transportation distance). The results are given in Table 8 which shows that HCP is more capital intensive than coal slurry pipeline for distances above approximately 50 miles. The reason HCP has a higher capital cost than slurry pipeline at distances above 50 miles is of course due to the need for capsules and a return pipeline for HCP--two costly items that do not exist for slurry pipeline.

f. Life-Cycle Cost and Unit Cost

The life-cycle cost and the unit cost of HCP are computed assuming the same life span as that of coal slurry pipeline: 30 years. This is believed to be a conservative assumption because the abrasion of pipes caused by capsules with specific gravity close to 1.0 should be less than that by coal slurry. The cost computation for a 500-mile HCP of 25 x 10^6-tons-per-year throughput and of high automation is given in Table 9. An explanation of the method of computation now follows:

Capital Cost: - From Table 8, the capital cost for the system is 1069.3 million dollars. This capital cost represents current or present value; it does not include the interest to be paid on the loans to finance the project.

Labor/Energy Cost: - This includes not only the costs of labor and energy but also all the other costs for operating the termini listed in Table 5. For the first year of operation, Table 5 gives a value of 7.8 million dollars which is the first-year value used in Column 2 of Table 9. The labor/energy costs for

TABLE 8 - Comparison of Total Capital Cost of HCP with Slurry Pipeline (Million Dollars)

Type of Pipeline	Transportation Distance (Miles)	Coal Throughput (Million Tons Per Year)			
		2.8	6.2	11	25
Slurry	25	20.75	43.75	71.25	134
	50	25.50	50.50	80.50	150
	75	30.25	57.25	89.75	166
	100	35	64	99	182
	200	54	91	136	246
	500	111	172	247	438
	1,000	206	307	432	758
HCP	25	17.8	25.15	33.75	62.30
	50	30.8	44.40	60.50	115.30
	75	43.8	63.65	87.25	168.30
	100	56.8	82.9	114	221.3
	200	108.8	159.9	221	433.30
	500	264.8	390.90	542	1069.30
	1,000	524.8	775.9	1077	2129.3

TABLE 9 - Computation of Life-Cycle Cost and Unit Cost for Transporting Coal by HCP (High Automation)

LENGTH OF PIPELINE : 500 MILES

THROUGHPUT :25 MILLION TONS PER YEAR

CAPITAL COST : 1069.3 MILLION DOLLARS

INFLATION RATE : 6 PERCENT

INTEREST RATE : 12.5 PERCENT

YEAR	LAB/ENR IN MILLIONS	CP/MAINT IN MILLIONS	TAXES IN MILLIONS	DEPRN IN MILLIONS	RETURN IN MILLIONS	XTOTAL IN MILLIONS	UCST IN $/TM	PXTOTAL IN MILLIONS	PUCST IN $/TM
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	7.80	24.50	20.049	35.643	133.663	221.655	0.0177	197.027	0.0158
2	8.27	25.97	19.381	35.643	129.207	218.469	0.0175	172.618	0.0138
3	8.76	27.53	18.713	35.643	124.752	215.400	0.0172	151.282	0.0121
4	9.29	29.18	18.044	35.643	120.296	212.454	0.0170	132.634	0.0106
5	9.85	30.93	17.376	35.643	115.841	209.638	0.0168	116.334	0.0093
6	10.44	32.79	16.708	35.643	111.385	206.961	0.0166	102.038	0.0082
7	11.06	34.75	16.039	35.643	106.930	204.431	0.0164	89.635	0.0072
8	11.73	36.84	15.371	35.643	102.475	202.056	0.0162	78.750	0.0063
9	12.43	39.05	14.703	35.643	98.019	199.847	0.0160	69.235	0.0055
10	13.18	41.39	14.035	35.643	93.564	197.312	0.0158	60.915	0.0049
11	13.97	43.88	13.366	35.643	89.108	195.962	0.0157	53.641	0.0043
12	14.81	46.51	12.698	35.643	84.653	194.309	0.0155	47.278	0.0038
13	15.70	49.30	12.030	35.643	80.198	192.865	0.0154	41.713	0.0033
14	16.64	52.26	11.361	35.643	75.742	191.641	0.0153	36.843	0.0029
15	17.64	55.39	10.693	35.643	71.287	190.650	0.0153	32.580	0.0026
16	18.69	58.72	10.025	35.643	66.831	189.908	0.0152	28.847	0.0023
17	19.81	62.24	9.356	35.643	62.376	189.429	0.0152	25.577	0.0020
18	21.00	65.97	8.688	35.643	57.920	189.229	0.0151	22.711	0.0018
19	22.26	69.93	8.020	35.643	53.465	189.324	0.0151	20.198	0.0016
20	23.60	74.13	7.351	35.643	49.010	189.732	0.0152	17.992	0.0014
21	25.02	78.58	6.683	35.643	44.554	190.472	0.0152	16.056	0.0013
22	26.52	83.29	6.015	35.643	40.099	191.563	0.0153	14.353	0.0011
23	28.11	88.29	5.347	35.643	35.643	193.028	0.0154	12.856	0.0010
24	29.79	93.58	4.678	35.643	31.188	194.888	0.0156	11.538	0.0009
25	31.58	99.20	4.010	35.643	26.733	197.167	0.0158	10.376	0.0008
26	33.48	105.15	3.342	35.643	22.277	199.890	0.0160	9.350	0.0007
27	35.49	111.46	2.673	35.643	17.822	203.084	0.0162	8.444	0.0007
28	37.61	118.15	2.005	35.643	13.366	206.777	0.0165	7.642	0.0006
29	39.87	125.24	1.337	35.643	8.911	210.999	0.0169	6.932	0.0006
30	42.26	132.75	0.668	35.643	4.455	215.782	0.0173	6.301	0.0005
								1601.745	0.0043

CORE USAGE OBJECT CODE= 4224 BYTES,ARRAY AREA= 2520 BYTES,TOTAL AREA AVAILABLE= 143360 BYTES the subsequent years listed in Column 2 are computed from the first-year value based on a 6% inflation rate using the following formula:

$$F = P(1+i)^N$$

where P is the present cost; F is the future cost after N years; and i is the inflation rate.

Operation/Maintenance Cost: - This includes all the costs listed in Table 6. Since Table 6 lists a total of 4.9 million dollars for 100 miles of HCP, for the 500-mile HCP the operation/maintenance cost should be 4.9 x 5 = 24.5 million dollars which is the first-year value listed in Column 3 of Table 9. For the subsequent years, the cost is again computed based on 6% inflation rate.

Depreciation: - The same amount of capital cost is depreciated every year. The amount depreciated each year is

$$D = \frac{1,069.3}{30} = 35.643 \text{ million dollars}$$

which is listed in Column 5 of Table 9.

Return: - This is a combination of interest on debt financing and return on investment for equity financing. A return rate of 12.5% is assumed. For the N-th year, the return is computed from

$$R = [C - (N-1)D] \times 12.5\%$$

where C is the capital cost. The above formula yields a first-year value of R = 1069.3 x 12.5% = 133.66 million dollars as listed on the top of Column 6.

Taxes: - Taxes are paid on the return from equity. A debt/equity ratio of 40%/60% and a tax rate of 25% are assumed in this study. The taxes are computed from

$$T = R \times (\text{Equity }\%) \times (\text{Tax Rate})$$

For the first year it is 133.66 x 0.6 x 0.25 = 20.049 million dollars which is the first value listed in Column 4.

Annual Cost: - Annual cost for the system is the sum of the annual labor/energy cost, operation/maintenance cost, return, taxes, and depreciation. For the first year, it amounts to

7.80 + 24.50 + 133.66 + 20.05 + 35.64 = 221.65 million dollars.

The annual costs are listed in Column 7 under the heading of 'XTOTAL'.

Unit Cost: - Unit cost is the cost to transport a unit weight of cargo over a unit distance. The unit costs, listed in Column 8, are obtained from

$$\text{Unit Cost} = \frac{\text{Annual Cost}}{(\text{Length of Pipe}) \times (\text{Throughput})}$$

For the HCP system under investigation, this yields a first-year value of 221.65/(500x25) = 0.0177 $/TM as listed in Column 8.

Present Cost: - Both the annual costs given in Column 7 and the unit costs given in Column 8 are those computed at the end of each year. To get their current or present values, the following equation is used:

$$P = \frac{F}{(1+r)^N}$$

where P is the present cost; F is the future cost at the end of the Nth year; and r is the rate of return (assumed to be 12.5%). The present value of the annual cost for each of the 30 years is listed in Column 9 under the heading "PXTOTAL", whereas the present value of the unit cost for each of the 30 years is listed in Column 10 under the heading "PUCST."

Present Life-Cycle Cost: - The present value of the life-cycle cost is computed by summing up all the 30 values of PXTOTAL listed in Column 9. The result is 1,601.75 million dollars which is listed beneath Column 9.

Present Average Unit Cost: - The present value of the average unit cost over the life cycle of 30 years is computed by taking the arithmetic mean of the 30 values of the present unit cost listed in Column 10. The result is 0.0043 \$/TM which is listed beneath Column 10.

Using the same method of cost accounting discussed before, the costs for an equivalent slurry pipeline (500 miles long and 25-million-tons-per-year throughput, etc) can be computed. The results are listed in Table 10. Comparison between the values given in Table 10 and the corresponding values in Table 9 shows that the pipeline life-cycle cost and the unit cost for transporting coal are greater for this 500-mile HCP than for an equivalent slurry pipeline. The HCP is more costly in this case because of the great length of the pipelines involved. As mentioned before, due to the need for capsules and a return pipeline, it is expected that the cost for HCP will be higher than that for an equivalent coal slurry pipeline when the transportation distance is very long.

The foregoing computations have been carried out for HCP and slurry pipeline of four different throughputs (2.8, 6.2, 11.0 and 25.0 million tons per year), seven different lengths of pipes (25, 50, 75, 100, 200, 500 and 1,000 miles), and three different levels of automation for HCP (low, medium and high, corresponding to 1,000, 200 and 50 employees). The present average unit cost for each of these combinations is summarized in Table 11. To facilitate comparison between HCP and slurry pipeline, the results listed in Table 11 are represented graphically in Figures 14, 15 and 16, respectively for low, medium and high degree of automation.

It is clear from Fig. 14 that HCP almost always turns out to be more expensive than slurry pipeline when the degree of automation is low. This shows the importance of automation to HCP rather than the weakness of HCP. It is believed that medium or high degree of automation is feasible for HCP, and no more than 200 workers are needed to operate an HCP system.

TABLE 10 - Computation of Life-Cycle Cost and Unit Cost for Transporting Coal by Slurry Pipeline

LENGTH OF PIPELINE : 500 MILES
THROUGHPUT :25 MILLION TONS PER YEAR
CAPITAL COST : 438. MILLION DOLLARS
INFLATION RATE : 6 PERCENT
INTEREST RATE : 12.5 PERCENT

YEAR	LAB/ENR IN MILLIONS	OP/MAINT IN MILLIONS	TAXES IN MILLIONS	DEPRN IN MILLIONS	RETURN IN MILLIONS	XTOTAL IN MILLIONS	UCST IN $/TM	PXTOTAL IN MILLIONS	PUCST IN $/TM
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	33.80	16.60	8.212	14.600	54.750	127.962	0.0102	113.744	0.0091
2	35.83	17.60	7.939	14.600	52.925	128.888	0.0103	101.837	0.0081
3	37.98	18.65	7.665	14.600	51.100	129.994	0.0104	91.299	0.0073
4	40.26	19.77	7.391	14.600	49.275	131.293	0.0105	81.966	0.0066
5	42.67	20.96	7.117	14.600	47.450	132.796	0.0106	73.693	0.0059
6	45.23	22.21	6.844	14.600	45.625	134.515	0.0108	66.352	0.0053
7	47.95	23.55	6.570	14.600	43.800	136.463	0.0109	59.834	0.0048
8	50.82	24.96	6.296	14.600	41.975	138.654	0.0111	54.040	0.0043
9	53.87	26.46	6.022	14.600	40.150	141.103	0.0113	48.833	0.0039
10	57.10	28.05	5.749	14.600	38.325	143.824	0.0115	44.290	0.0035
11	60.53	29.73	5.475	14.600	36.500	146.834	0.0117	40.193	0.0032
12	64.16	31.51	5.201	14.600	34.675	150.151	0.0120	36.534	0.0029
13	68.01	33.40	4.927	14.600	32.850	153.792	0.0123	33.262	0.0027
14	72.09	35.41	4.654	14.600	31.025	157.779	0.0126	30.333	0.0024
15	76.42	37.53	4.380	14.600	29.200	162.130	0.0130	27.706	0.0022
16	81.00	39.78	4.106	14.600	27.375	166.868	0.0133	25.347	0.0020
17	85.86	42.17	3.832	14.600	25.550	172.017	0.0138	23.226	0.0019
18	91.02	44.70	3.559	14.600	23.725	177.600	0.0142	21.316	0.0017
19	96.48	47.38	3.285	14.600	21.900	183.644	0.0147	19.592	0.0016
20	102.27	50.23	3.011	14.600	20.075	190.177	0.0152	18.035	0.0014
21	108.40	53.24	2.738	14.600	18.250	197.228	0.0158	16.625	0.0013
22	114.91	56.43	2.464	14.600	16.425	204.828	0.0164	15.347	0.0012
23	121.80	59.82	2.190	14.600	14.600	213.009	0.0170	14.187	0.0011
24	129.11	63.41	1.916	14.600	12.775	221.808	0.0177	13.132	0.0011
25	136.85	67.21	1.643	14.600	10.950	231.260	0.0185	12.170	0.0010
26	145.07	71.25	1.369	14.600	9.125	241.405	0.0193	11.292	0.0009
27	153.77	75.52	1.095	14.600	7.300	252.285	0.0202	10.490	0.0008
28	163.00	80.05	0.821	14.600	5.475	263.944	0.0211	9.755	0.0008
29	172.78	84.85	0.548	14.600	3.650	276.428	0.0221	9.082	0.0007
30	183.14	89.95	0.274	14.600	1.825	289.787	0.0232	8.463	0.0007
								1132.021	0.0030

CORE USAGE OBJECT CODE= 4224 BYTES.ARRAY AREA= 2520 BYTES.TOTAL AREA AVAILABLE= 143360 BYTES

TABLE 11 - Average Unit Costs for Transporting Coal by HCP and Slurry Pipeline (1977 Value)

Type of Pipeline	Transportation Distance (Miles)	Coal Throughput (Tons Per Year)			
		2.8	6.2	11	25
Slurry	25	0.0487	0.0410	0.0364	0.0316
	50	0.0267	0.0220	0.0193	0.0165
	75	0.0194	0.0157	0.0136	0.0115
	100	0.0158	0.0125	0.0107	0.0090
	200	0.0103	0.0077	0.0064	0.0053
	500	0.0070	0.0049	0.0038	0.0030
	1,000	0.0059	0.0039	0.0030	0.0023
HCP (Low Automation)	25	0.1433	0.0697	0.0425	0.0228
	50	0.0768	0.0381	0.0237	0.0134
	75	0.0546	0.0276	0.0175	0.0103
	100	0.0435	0.0224	0.0144	0.0087
	200	0.0269	0.0145	0.0097	0.0063
	500	0.0169	0.0097	0.0068	0.0049
	1,000	0.0136	0.0082	0.0059	0.0044
HCP (Medium Automation)	25	0.0457	0.0256	0.0177	0.0119
	50	0.0280	0.0161	0.0113	0.0079
	75	0.0220	0.0129	0.0092	0.0066
	100	0.0191	0.0114	0.0081	0.0060
	200	0.0147	0.0090	0.0066	0.0050
	500	0.0120	0.0075	0.0056	0.0044
	1,000	0.0111	0.0071	0.0053	0.0042
HCP (High Automation)	25	0.0274	0.0174	0.0130	0.0099
	50	0.0188	0.0120	0.0090	0.0069
	75	0.0159	0.0102	0.0076	0.0059
	100	0.0145	0.0093	0.0070	0.0054
	200	0.0124	0.0079	0.0060	0.0047
	500	0.0111	0.0071	0.0054	0.0043
	1,000	0.0107	0.0069	0.0052	0.0041

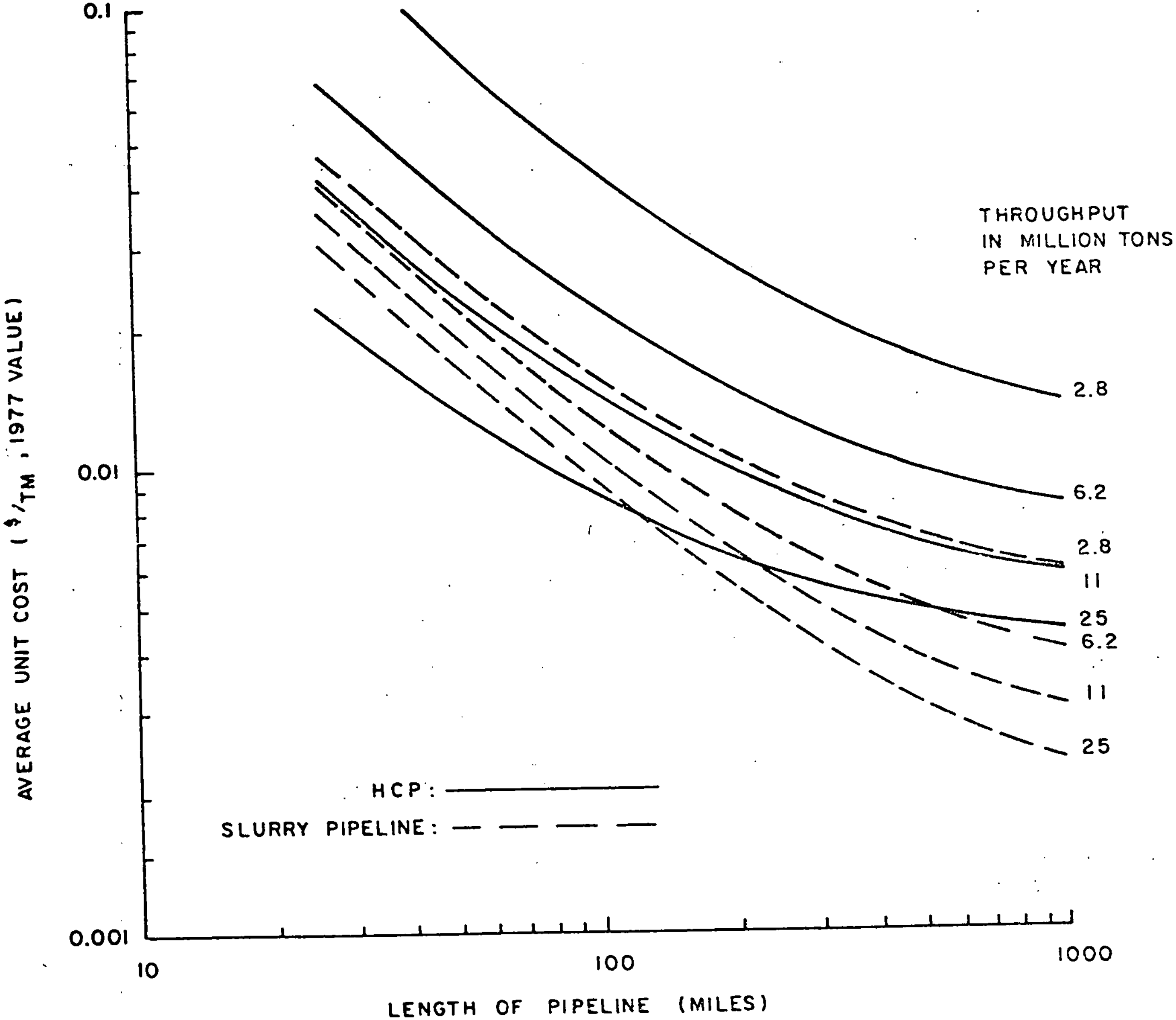


Fig. 14 AVERAGE UNIT COST FOR TRANSPORTING COAL BY HCP AND SLURRY PIPELINE (LOW AUTOMATION)

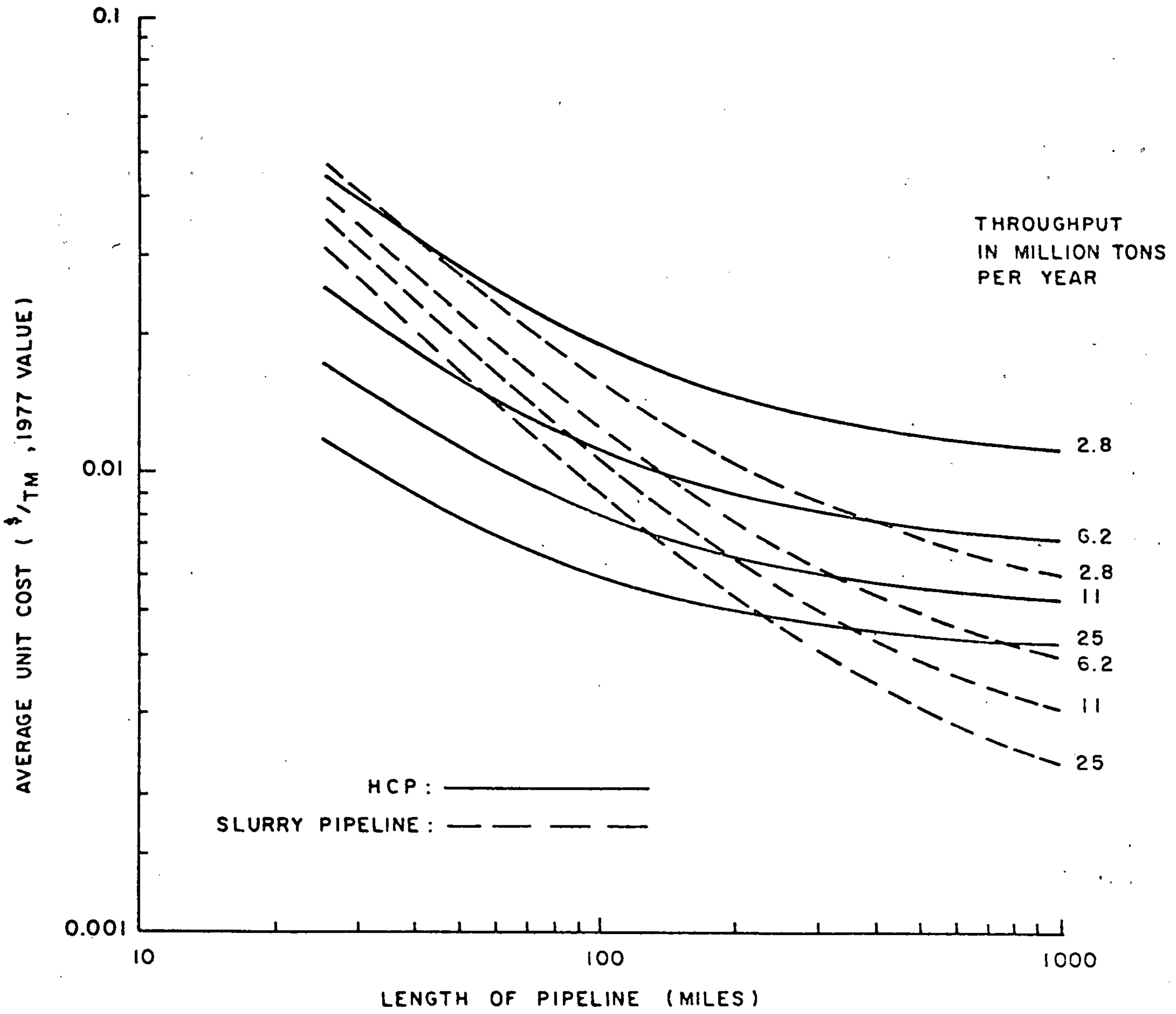


Fig. 15 AVERAGE UNIT COST FOR TRANSPORTING COAL BY HCP AND SLURRY PIPELINE (MEDIUM AUTOMATION)

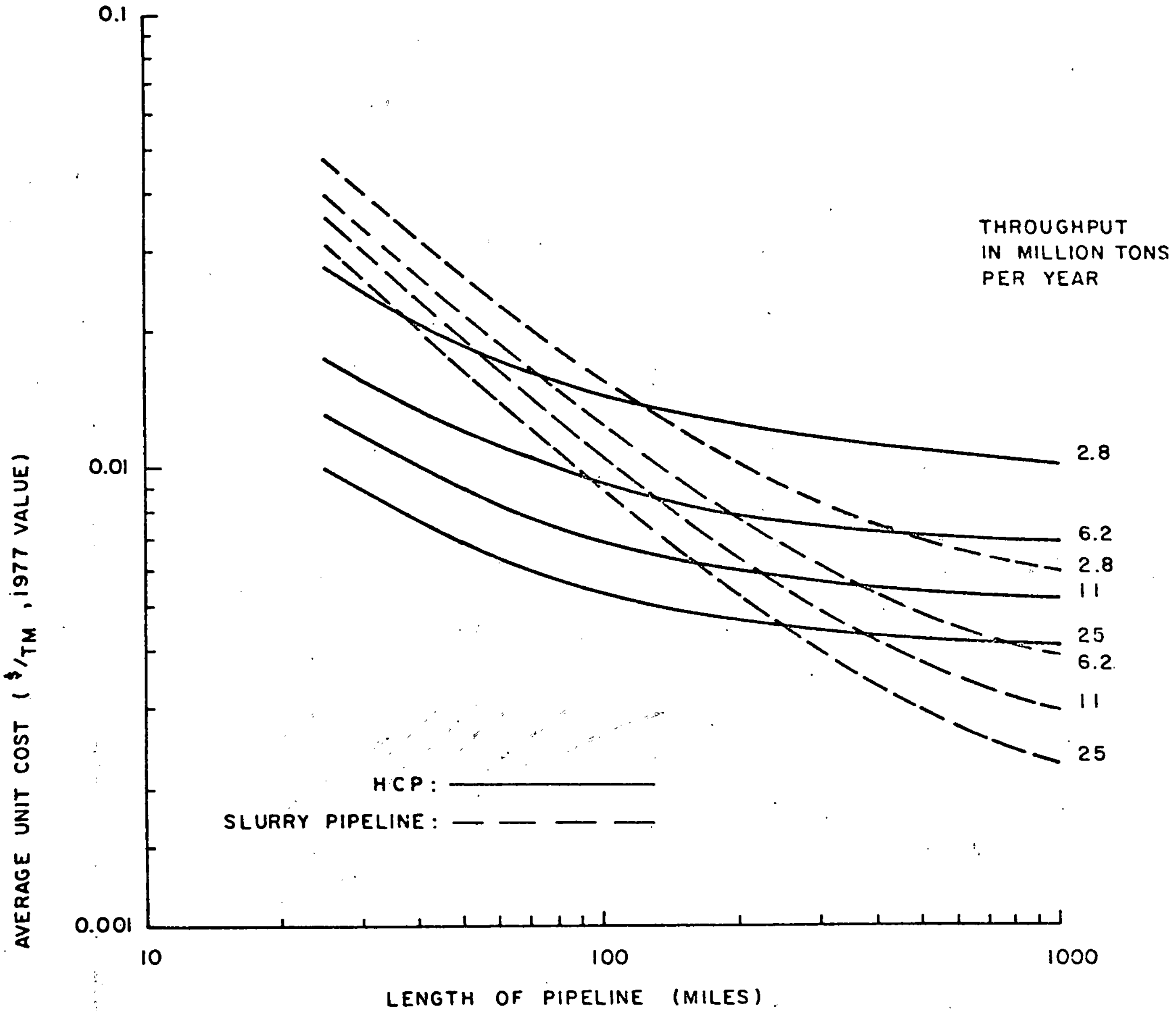


Fig. 16 AVERAGE UNIT COST FOR TRANSPORTING COAL BY HCP AND SLURRY PIPELINE (HIGH AUTOMATION)

Figure 15 shows that at medium level of automation, HCP may be more economical than slurry pipeline when transportation distance is less than about 150 miles and when throughput is greater than about 5 million tons per year. Likewise, Fig. 16 shows that at high level of automation, HCP may be more economical than slurry pipeline when the distance is less than about 250 miles and when throughput is greater than about 10 million tons. It is clear from Figures 15 and 16 that both short distance and large throughput tend to favor HCP over slurry pipeline.

The fact that when transportation distances are short HCP becomes more economical than slurry pipeline is a matter of significance. With increasing emphasis on using regionally available coal*, transportation of coal over short and medium distances will become increasingly important in the future. HCP is ideally suited for such distances.

3. Cost Comparison Between HCP and Truck and Train

a. Costs for Transporting Coal by Truck

Transportation of coal by truck is expensive and it is done usually only over short distances. A recent U.S. Senate document [21] reveals that although coal trucks account for less than 5% of the total ton-miles of coal transported in the U.S. by all transportation modes, about three-fourth of coal produced move some distance over highway. This shows trucking is an important mode of coal transportation, primarily for short distances.

*For instance, Section 125 of the Clean Air Act Amendments of 1977 stipulates that EPA can order major coal users, such as utilities, to buy "regionally available coal". (See Wall Street Journal Article in APPENDIX 2).

Coal trucking may be classified into two kinds: (1) mine-to-tipple trucking which has an average distance of 5 to 10 miles, and (2) mine-to-market trucking which moves an average distance of about 50 miles. Trucking coal over a distance greater than 100 miles is uncommon.

The cost for trucking coal varies greatly with transportation distance and the size of the truck. For instance, a study cited in [21] found that for mine-to-tipple trucking at 5.5 miles, the cost is 22.5 cents per ton for the 65-ton truck, 20.5 cents per ton for an 85-ton truck, 15.5 cents for a 150-ton tractor-trailer, and 14 cents per ton for a 390-ton tractor-trailer. Of course, these heavy trucks are allowed only on private roads owned by coal companies; they are now allowed on public highways.

For mine-to-market trucking, a Kentucky study [22] indicates that the cost of coal transportation by trucks in Kentucky in 1974 lies between 6.5 cents per ton-mile at 50 miles and slightly more than 4 cents per ton-mile at 400 miles. The study concludes that since the majority of coal-hauls in Kentucky are less than 150 miles, truck transport costs average 6 cents per ton-mile there.

An equation to determine trucking cost as a function of transportation distance and cargo density has been proposed by Zandi [23]. The equation is

$$C_s = 23.15 + 0.134L + 0.103L \, \mathrm{EXP}[-0.162(D-7.5)]$$

where C_s is the unit highway cost in cents per hundred weight; L is the transportation distance in miles; and D is the commodity density in pounds per cubic foot. The above formula is for shipment weight greater than 43,700 lbs. Since the formula was derived for general cargoes which are more difficult to handle (load and unload) then coal, it over-estimates the costs for transporting coal when the distance is short. Nonetheless, the formula may be used to determine the upper bound for the cost of trucking coal. Using this as an upper bound and using information contained in [21], the costs for hauling coal by truck at various transportation distances are estimated and listed in Table 12. The values listed in Table 12 will be compared with the unit costs for hauling coal by HCP and the slurry pipeline.

TABLE 12 - Unit Costs for Trucking Coal (Estimated Average for 1977)

Transportation Distance (Miles)	Estimated Unit Cost ($/TM)
25	0.13
50	0.10
75	0.090
100	0.080
200	0.065
500	0.050
1,000	0.040

b. Cost for Transporting Coal by Train

The most common way to transport coal over long distances is by trains--especially the unit train which carry only coal from mines to power plants. Data provided in [21] indicate that rail accounts for more than 70% of the coal shipped over distances greater than 25 miles. Using the values listed in Table III-9 of [21] and assuming an annual rate increase of 6%, the unit costs for transporting coal by trains in 1977 are estimated in Table 13.

c. Comparison of Unit Costs

For comparison purpose, the unit costs for truck given in Table 12 and the unit costs for trains given in Table 13 are represented graphically in Fig. 17. The graph clearly shows that it is much more economical to transport coal by train (especially the unit train) than by truck.

TABLE 13 - Unit Costs for Transporting Coal by Trains
(Estimated Average for 1977)

Transportation Distance (Miles)	Estimated Unit Cost ($/TM) Single Car (No Volume Requirement)	Unit Train (Minimum Volume and Load Requirement)
25	0.11	0.066
50	0.085	0.043
75	0.068	0.034
100	0.057	0.028
200	0.033	0.014
500	0.019	0.0076
1,000	0.012	0.0050

Comparison of Figs. 14-16 with Fig. 17 reveals that it is almost always much more economical to transport coal by HCP than by trucks, even for distances as short as 25 miles. The comparison also shows that HCP is more economical than unit train in most circumstances. Even at low level of automation, HCP is still cheaper than unit train as long as the throughput is greater than 6.2 million tons per year and as long as the distance is no more than a few hundred miles. For instance, for a distance of 500 miles and a throughput of 25 million tons per year, the unit cost for transporting coal by HCP with a low level of automation is 4.8¢/TM. The corresponding cost by unit train is approximately 8¢/TM. The advantage of HCP is even more apparent if high level of automation is possible and if the throughput is large. For instance, for a distance of 100 miles and a throughput of 25 million tons per year, the unit costs for transporting coal by HCP of high automation, slurry pipeline, unit train and truck are respectively

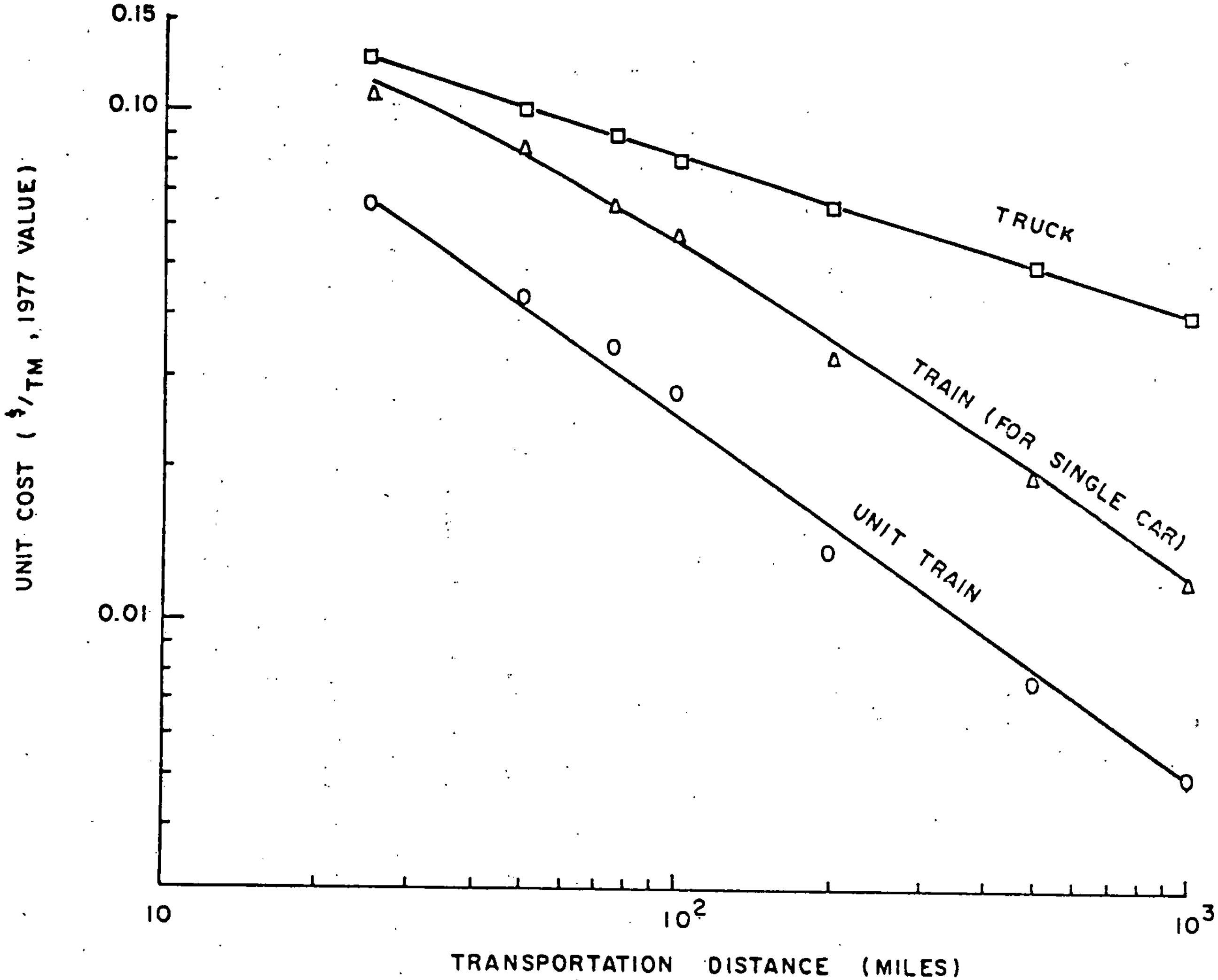


Fig. 17 UNIT COST OF TRANSPORTING COAL BY TRUCK AND TRAIN

0.54, 0.90, 2.5, and 8.0 ¢/TM.

4. Conclusions and Comments on Cost Comparison

From the foregoing analysis, it can be said that coal can be transported more economically by HCP than by slurry pipeline when transportation distance is not much more than about one hundred miles and when the throughput is at least a few million tons per year. It also can be said that transportation of coal by HCP is cheaper than by unit train except when the distance is very long and when the throughput is low. Finally, it can be concluded that it is almost always much cheaper to transport coal by HCP than by truck, as long as the transportation distance is longer than approximately 20 miles.

It should be realized that in the foregoing economic analysis, it was assumed that each HCP system requires two pipelines (i.e., a pipeline to deliver coal and another to return empty capsules back to coal mines). In contrast, the cost computation on slurry pipeline was based on a single pipeline. Therefore, if in a situation it is possible to utilize the return pipeline of HCP to transport some kind of cargo to mine fields*, the economic comparison between HCP and slurry pipeline will be even more favorably tilted toward HCP. The same holds if slurry pipeline cannot get water from near the mine field and it has to pipe in water from distant locations.

Another point that should be mentioned is that the trucking cost figures used in the foregoing analysis are the costs charged to customers; they do not include the cost to all the taxpayers who must finance the repair of roads damaged by trucks. As mentioned in [21], coal trucks are heavy and they cause

*An example is to use the return line to carry fly ash from power plant to coal mine for filling the mine pits. This would both restore the contours of stripped mine fields and solve a solid waste disposal problem.

severe damage to roads. If the cost for road repair is added to trucking cost, the cost for transporting coal by truck will be even higher than that mentioned earlier.

One should also realize that the cost comparisons made herein are based on 1977 costs. Because oil prices have been rising and will continue to rise at a rate faster than the rate of inflation for electricity, it is expected that the cost for transporting coal by trucks and trains (which use oil) will rise at a pace faster than for HCP (which uses electricity). Therefore, the economic advantage of HCP over truck and train is expected to further increase in the future.

V. APPENDICES

APPENDIX 1 - REFERENCES

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From page 25 of the DENVER POST, Sunday, March 18, 1979 (DOE sponsored project at the University of Missouri-Columbia is mentioned on pages 2 & 3)

Pipelines and grain: a new transportation system

By DICK HANSEN, JR.

Hansen is a Joplin, Mont., wheat farmer who specializes in agricultural journalism. He is agriculture writer for the Great Falls Tribune in Great Falls, Mont.

OUR NATION'S deteriorating rail freight system, coupled with a chronic boxcar shortage and continually soaring freight rates, has American grain producers looking for alternative transport means.

Trucks are seen as about the only other way. But given the huge volumes to be transported, our truck system at best can make only a dent.

There could, though, be a third alternative which has been around for many years—and generally ignored as being too farfetched. This concerns using pipelines to move grain, and in fact, a wide variety of freight and solid products.

Not only is this concept becoming increasingly attractive, most researchers and other authorities agree it is economically feasible.

Also, they point out that with agricultural products in particular, the export of U.S. agricultural commodities plays an increasingly vital role in balancing our trade deficit and feeding the world's expanding hungry population. Therefore, it is expected that in the future the production level of U.S. agriculture will have to be drastically increased and export of agricultural products greatly expanded. Some authorities predict freight transport needs as doubling by the end of this century.

THIS WOULD require a transportation capacity much larger than our present existing, and inadequate, network of railroads can handle.

Instead of building new railroads or trying to upgrade what we have, it could well be cheaper to build pipelines. Also, it is pointed out by both the U.S. Departments of Energy and Transportation that our vast network of existing gas, oil and slurry pipelines could fall into disuse by the year 2000 if new use for them isn't found.

Research tends to lean heavily toward the development of specialized pipelines exclusively for freight.

These lines could be converted easily to freight pipelines at minimal cost. Pipeline operators and manufacturers of related equipment have long been aware of this, as well as the tremendous potential for their systems presented by the grain fields.

Transportation of commodities via pipeline is economical only when these products exist in a somewhat concentrated area and in a relatively large and stable volume. Also, pipelines are expensive to construct.

But when weighed against cost of upgrading our existing rail system or building new railroads to meet greatly expanded future transportation needs, this cost too becomes less significant.

PIPELINES offer huge potential energy savings, since the only energy needed for their operation is electricity, which need not be generated with oil.

Traffic congestion by trucks and trains could be cut dramatically, as well as noise and air pollution. There seems little argument that, once in place, pipelines not only can operate more economically but need far less maintenance than railroads or highways.

The concept of pipelining was first recorded in 1667 by French physicist Denis Papin, who proposed a pneumatic dispatch system. Since then the method has been used throughout the world for transporting light-weight cargoes such as cash, documents, mail or telegrams.

Pneumo trains, different from pneumatic dispatch in that the trains are suspended by wheels inside the pipe, were built experimentally by the Russians a decade or more ago.

In the United States, Tubeexpress System, Inc., of Houston, Tex., has a pneumo train system currently on the market They are also the only U.S. firm currently making pipeline capsules. This system is known as pneumatic capsule pipeline (PCP), as opposed to hydraulic capsule pipeline (HCP).

PIPELINES in this country and in France and Russia have become firmly established carriers of such minerals and chemicals as nickle-copper concentrates, borax, sulphur, iron, lead, zinc, as well as rock salt, clay, sand, gravel and many other solid commodities

This form of transportation is particularly attractive in areas where rugged terrain restricts or prohibits other means of shipping, such as the 72-mile pipeline used by the American Gilsonite Co. to move solid petroleum product across a summit 3,000 feet above the mine at Bonanza, Utah, to a refinery at Grand Junction, Colo.

In the case of minerals, chemicals and solids, however, movement is usually accomplished by means of reducing them to slurries and pumping them through the line under pressure with water as the transport vehicle. In some cases, minerals such as iron and lead are cast into solid "slugs" and propelled through the lines.

Pipeline engineers also have worked on proposals involving partial processing of some chemicals and minerals while moving through the lines.

Introduction of chemicals, for example, into lines carrying wood chips would partially pulp the chips while they travel to their destination. Another example concerns treatment of pulverized phosphate rock in the line so upon delivery the material is ready for recovering phosphoric acid.

CONVENTIONAL centrifugal or positive displacement pumps are used to help propel solids through the lines, the type depending upon the length of the line and upon pressure requirements.

Theoretically, there is no limit as to the distance solids can be pumped, although in long-distance lines booster pumps usually are installed at 20- to 50-mile spacings.

While such slurry pipelines have carried a wide variety of products with few problems for years, it is obvious that such commodities as grain could not be handled in this manner.

Researchers in this country and Canada turned to their laboratories for the answer during the mid-'60s. One of their first considerations was use of air to move grain and other water-absorbent products. However, the high velocity and resulting damage to grain through abrasion and degradation cast doubt on air as a carrier vehicle.

Research engineers at the U. S. Department of Agriculture Cooperative Seed Processing Laboratory in Corvallis, Ore., finally developed a pneumatic conveying system requiring from 30 to 40 times less velocity than conventional air systems. A test model was built and successfully lowered product damage. But it is presently regarded as feasible mostly for short-distance use.

In 1958, another answer came from the Alberta Research Council of Edmonton, Alberta, Canada. The solution: encapsulation.

THIS CONSISTED of simply sealing grain and similar moisture-absorbent products in "capsules" of water-tight material, which then could be handled with liquid as the transport medium.

Most of the early Canadian research involved using existing oil pipelines, and scientists at Edmonton were successful in sending a capsule weighing several hundred pounds through an oil pipeline for a distance of more than 100 miles.

These and further tests revealed that both power and pumping costs, as compared with that for oil alone, actually decrease as the density of the capsule introduced into the line increases. Also, it was determined a further economic advantage of using existing lines for grain shipment in particular, with a crude oil propellant, was that it would allow for salvage credit of the oil on the receiving end.

CONTINUED research, however, tends to lean heavily toward the development of specialized pipelines exclusively for freight. The general concept is that of using fluid—most likely water, to move the capsules. This is known as hydraulic capsule pipeline (HCP).

At present, most research in progress in the United States involves movement of coal. Coal slurry pipelines have been around for many years. However, they use tremendous amounts of water, and pollution and environmental problems continue to plague the method.

Also, the coal must be reduced to slurry form, then dewatered at destination.

With HCP, the system involves two lines. One to move the capsules, the other to return them. Once the system is charged with water, little or no additional water or other fluid is needed.

About the only work presently under way in the United States is being conducted by Dr. Henry Liu, professor of civil engineering, University of Missouri. Operating under a grant from the U.S. Department of Energy, Dr. Liu and his associates agree that once the

system is perfected for coal it can easily be adapted for grain or other freight.

A RECENT major breakthrough in the technology of HCP is the electromagnetic capsule pump, developed by the University of Missouri research team. The university has applied for a patent, and it is felt by most researchers that the pump has revolutionized the whole technology of HCP by making pumping of capsules through pipe an easy task.

Two related studies also are being conducted there under sponsorship of the U.S. Department of Transportation and Department of Agriculture.

But, as noted, perhaps the greatest push for freight pipelines comes from the energy crisis, as well as environmental and social factors.

According to statistics compiled by the Department of Transportation, some 3,000 fatalities, over 26,000 injuries, and hundreds of millions of dollars in property damage occurs each year from truck accidents alone.

If HCP can replace only 10 percent of the truck freight a significant savings in lives and property damage would result.

Along with this, HCP benefits would include reduced truck traffic and alleviation of much highway congestion, energy conservation, air and noise pollution, and more efficient use of our present rail system for such things as improved passenger service.

SINCE HCP can replace only a small portion of the truck business, and that replacement would take place gradually, proponents see little fear for truckers losing jobs. It would likely be decades before enough HCPs could be built to seriously affect jobs.

As for railroads, they already are demonstrating their inability to cope with current shipping demands and show little concern for preparing for future increased traffic. Thus, HCPs would do little except greatly facilitate coal, grain and other freight at much cheaper rates.

Capsule pipelining of freight and transportation of solids via pipeline is a broad new technology involving a wide range of commodities. Due in part to comparatively simpler problems involved, as well as energy, environmental, pollution and other factors, development of transporting grain and other solids could be the wave of the future.

Dr. Liu thinks perfecting the entire concept and bringing it to market will take another five years.

"Once the system is developed for coal, it can easily be adapted for grain," Dr. Liu said. "In fact, the system appears to be more attractive for grain and other agricultural products than for coal, for the simple reason that for transporting ag products HCP will be competing with trains and trucks rather than slurry pipelines as in the case of coal transport. Transportation costs are generally much higher for trucks and trains than for pipelines, as our studies make clear."

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A spokesman for the Alberta Research Council pointed up another interesting development. "This relates to the common knowledge that rail handling of grain in particular is noticably inefficient. We think we see the possibility of grain pipelining forcing the rail industry, including the rail regulatory bodies, to examine their operations to become substantially more efficient."

So, with all the bright potential, why then did the big push for freight pipelining die on the vine a decade ago?

"Simply because governments at various levels which underwrote much of the research and development, failed to realize that it is not enough to come up with a good idea," said one early researcher.

"The idea has to be explained and sold, and this requires a major educational effort. Very little was done in this area at the time."

From page 4 of the Wall Street Journal, Tuesday, May 8, 1979

U.S. Judge Upholds Antipollution Law Allowing Curbs on Interstate Coal Sales

By a WALL STREET JOURNAL *Staff Reporter*

CATLETTSBURG, Ky.—A federal judge in the eastern district court of Kentucky here upheld the constitutionality of an antipollution law that allows restrictions on interstate coal sales, leaving open the question of whether state boundaries could be the determinants of where coal may be purchased.

The decision is one fragment of a controversy involving the Environmental Protection Agency and major Ohio coal users, especially coal-burning utilities. The EPA wants the utilities to reduce their sulphur dioxide emissions, and the cheapest way for the utilities to do that is to switch from high-sulphur Ohio coal to low-sulphur coal mined elsewhere. The Ohio coal industry is fighting that move.

At issue is Section 125 of the Clean Air Act Amendments of 1977, which stipulates that the EPA can order major coal users, such as utilities, to buy "regionally available coal" and, if necessary, install antipollution equipment to comply with emission standards if "significant local or regional disruption of unemployment" would result from purchases of other than local or regional coal.

The Kentucky case was brought by a subsidiary of General Energy Corp., McCoy Elkhorn Coal Corp., Lexington, Ky. The basic thrust of the challenge to Section 125 by McCoy Elkhorn and Ohio Edison Co., an Akron, Ohio-based utility that acted as an intervening plaintiff, is that the law deprives them of the right to engage in interstate commerce to seek economic gain. That right, they argued, can't be impaired by geographical boundaries.

But the court disagreed: "Congress has the power to define a region about which it is concerned in terms of a state's boundaries or upon any other rational basis regardless of the size of the region. Consequently, there isn't any merit in the argument about the definition of a region or its size." The court didn't attempt to define what "regionally available" means.

In its opinion, the court was careful that it didn't discount the plaintiffs' arguments that Section 125, in effect, favors the high-sulphur Ohio coal producers to preserve jobs. It suggested, though, that the plaintiffs "address themselves to the political process, not to the judiciary, for remedy."

In response to the court's decision, Donald H. Vish, general counsel for McCoy Elkhorn's parent company, said the concern was "disappointed but wasn't discouraged" and is considering appealing the decision. The implication of the ruling, he said, is that it, "in effect, validates a legislative scheme which requires consumers to buy local goods first and thus fosters economic Balkanization and a protectionist economy that isn't in the best interest of national solidarity or national prosperity."

Ohio Edison noted the definition of "regional coal" wasn't spelled out by the court. "If they specify your region and it happens to have strictly high-sulphur coal," Ohio Edison said, "you're then required to install expensive antipollution devices, such as scrubbers. A scrubber recently added to (its Bruce Mansfield) plant in western Pennsylvania is costing about $400 million, or about a third the cost of the plant. A dust collector, used with low-sulphur coal, would be much cheaper," the utility said.

The court said the only basis for challenge to Section 125, which it says is "solely an economic legislative act," is through a "showing of arbitrariness or irrationality" that it couldn't find in either the "narrowness of the act's scope or its lack of uniform geographic application."

In a reference to the meaning of "regionally available," the court said Section 125 makes an "economic distinction and that doesn't constitute a suspect classification subject to special scrutiny."

The Kentucky case is one of two lawsuits in the Ohio coal controversy. The other, filed by Cleveland Electric Illuminating Co. in federal district court in Cleveland, still is pending. The Cleveland suit charges that the EPA's hearings on the Ohio coal situation were a "sham" and that the agency was biased prior to the hearings, according to James M. Friedman, an outside attorney for Cleveland Electric.

Mr. Friedman said the Cleveland Electric suit also questions the constitutionality of Section 125 but the main thrust of it is to challenge the conduct of the EPA.

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