UMR-MEC Conference on Energy / UMR-DNR Conference on Energy

13 Oct 1977

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Henry Liu

Donald L. Gibson

Recommended Citation

Liu, Henry and Gibson, Donald L., "Conserving Energy and Protecting Environment by Using Freight Pipelines -- A Technology Assessment" (1977). *UMR-MEC Conference on Energy / UMR-DNR Conference on Energy*. 271.
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CONSERVING ENERGY AND PROTECTING ENVIRONMENT BY USING FREIGHT PIPELINES-- A TECHNOLOGY ASSESSMENT

Henry Liu and Donald L. Gibson
College of Engineering
University of Missouri-Columbia

Abstract

Freight pipeline is not just a possibility but a reality. It is an emerging new mode of transportation which has many advantages such as energy conservation and environment protection. The paper discusses the state-of-the-art of this new technology.

1. INTRODUCTION

Pipelines can be classified in many different ways, one of which is according to the types of material transported--whether they are gas, liquid, solid-gas mixture, liquid-solid mixture, or freight inside containers. Fig. 1 gives a chart of this classification. In the broadest sense of the term, "freight pipeline" represents all pipelines, since all materials moved through a pipeline may be regarded as freight. On the other hand, in a narrow sense, "freight pipeline" represents only pipelines which are able to carry a large variety of cargoes; this limits it to container pipelines. It is the latter sense of the term which will be used in this paper.

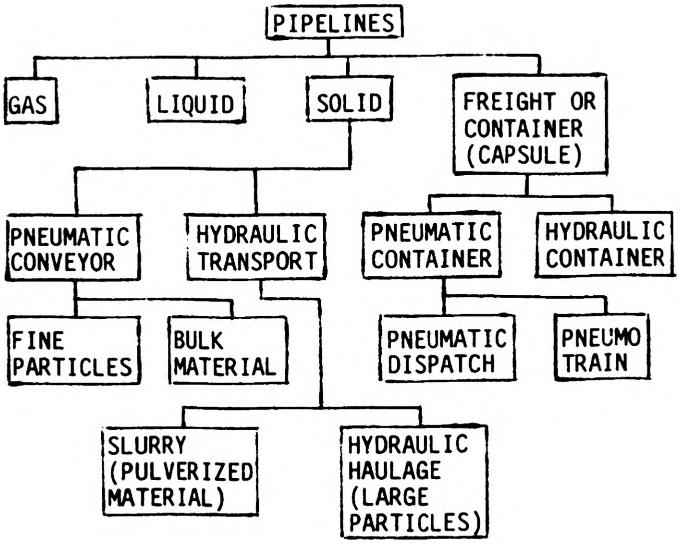

Figure 1. Classification of Pipelines

2. DESCRIPTION OF FREIGHT PIPELINES

As illustrated in Fig. 1, there are two general categories of freight or container pipelines: the pneumatic container pipeline (PCP) which uses air as the carrier, and the hydraulic container pipeline (HCP) which uses liquid--generally water--as the carrier fluid.

Pneumatic container pipelines, sometimes called "pneumatic capsule pipelines", can be further divided into two groups: the pneumatic dispatch system, and the pneumo train.

According to Vivian(15), pneumatic dispatch is an old concept that appeared first in the literature in 1667 in a paper by French physicist Denis Papin. Since then, the method has been used throughout the world for transporting light-weight cargoes such as cash, documents, mails, telegrams, etc. As reported by Zandi and Kim(16), the British Postal

Department operates more than six hundred miles of pneumatic dispatch pipelines for transporting telegrams, and in Germany, Berlin alone has about 30 miles of telegram pipelines.

In the U.S., the first pneumatic dispatch system to transport mail was built in Philadelphia in 1892. Later, four other cities--New York, Boston, Chicago, and St. Louis--built similar systems. All the U.S. pneumatic dispatch systems to carry mail were closed down later because it was felt that trucks could move faster. At present, many industrial plants, banks, stores, etc. in the U.S. still use pneumatic dispatch systems. The Library of Congress has four oval shaped pipelines for carrying books.

Pneumo train is different from pneumatic dispatch in that the trains are suspended by wheels inside the pipe. As it is so, pneumo trains can carry heavy cargoes. In 1971, the Russians built an experimental pneumo train system 40 inches in diameter and 1.5 miles long. The trains move inside the pipe at a speed of 22 m.p.h.(9). In the U.S., the Tubexpress System, Inc., Houston, Texas, has built a 16-inch diameter pneumo train and is marketing the product(1).

Hydraulic container pipelining (HCP)--more often referred to in the literature as "hydraulic capsule pipelining" or simply "capsule pipelining"--was invented in Canada in 1961, growing out of observations of two-phase flow of oil and water in pipe(4). Hodgson and Bolt(6), in 1962, and Ellis, Redberger, and Bolt(3), in 1963, discussed the potential applications of HCP. In 1963, in the first of a series of articles on the subject, Hodgson and Charles(7) referred to HCP as "the third generation pipelining," with the first and the second generations to be respectively liquid pipelines and slurry pipelines.

Most studies of HCP were conducted in Canada, under the auspices of the Research Council of Alberta, and the Canadian Federal Ministry of Transport. The largest test loop of HCP is a 10-inch diameter pipeline built and tested in Alberta, Canada(8). To date, no HCP system has yet been built for commercial purpose; the technique is still in a research and development stage.

The two types of freight pipelines which appear most important are the pneumo train and HCP, since both have the ability to transport heavy cargoes. While pneumo train has several advantages over HCP such as it runs faster and does not use water which is more costly and troublesome than air, pneumo train is unsuitable for long distances because of possible damage to wheels and a higher energy consumption rate than HCP. Therefore, it is believed that pneumo trains are better than HCP for short-distance transportation, whereas the opposite is true at long distance. This paper will only deal with HCP--the newest and least developed type of pipelines.

3. POTENTIAL APPLICATION OF HCP

A potential application of HCP is transporting coal over long distances. At present, the most economical way for distant transport of coal is via slurry pipelines. For instance, a coal slurry pipeline from Wyoming to Arkansas has been proposed. This proposed pipeline has caused grave concern by the public in Wyoming and in the neighboring state South Dakota because it taxes heavily on the scarce water resources of the two states. Compared with slurry pipelining, the principal drawbacks of HCP are the cost associated with loading and unloading of capsules, and a higher initial investment due to the need for containers and a separate return pipeline. The initial economic disadvantage of HCP may be offset by the following advantages: (1) HCP is more versatile than slurry pipelining; containers can carry a large variety of cargoes. (2) Coal or other minerals do not have to be pulverized; they can be transported in the form mined. (3) Because of the returning pipeline, water recirculates in the system and is not lost. This eliminates water consumption and, hence, avoids detrimental environmental impacts such as that feared by the public in Wyoming and South Dakota. (4) No pollution is caused in transporting coal or anything else by HCP. In contrast, the water coming out of the coal slurry at pipeline terminals must be treated to prevent serious surface water pollution if discharged into streams and ground water contamination if infiltrated into soil. (5) With HCP systems built for transporting coal from mines to power plants, the return pipeline can be utilized to carry fly ash and solid waste for disposal in mine pits. This not only solves a waste disposal problem, but also restores coal mines to their original contour--a matter of increasing interest to the nation.

Another potential application of HCP is transporting grains and other agricultural products. The export of U.S. agricultural products plays a vital role in balancing the trade of the nation, and in feeding the hungry of the world. Therefore, it is expected that in the future the production level of U.S. agriculture will be increased, and the export of agricultural products will be expanded. This requires a transportation capacity larger than the existing network of deteriorating railroads can handle. Instead of building new railroads, it may be much cheaper to build pipelines. HCP may make an important contribution in this case.

There are many other potential applications of HCP, such as transporting minerals over mountainous areas, transporting construction materials to large construction sites, transporting hazardous materials such as nuclear fuels or waste for safety not economic reasons, etc.

All of the aforementioned applications deal with specific cargoes. Since HCP can be used to transport any cargo that can be fitted into a container, there is no need to limit the type of cargo. An underground network of HCP between large cities can be used to transport various cargoes in much the same manner as railroads or trucks are used. When different containers carry different cargoes, each container should be identified by a number and a tag, with the number identifying the customer and content, and the tag indicating the destination. Highly automated systems to handle capsule transport is of course a necessity.

It is possible that in the future some major pipelines built for transporting commodities such as natural gas, oil or slurry will be abandoned for lack of commodity to be transported. When that happens, these pipelines may be converted to capsule pipelines at minimal costs for general transportation use. This could effect great savings for pipeline companies.

4. ADVANTAGES OF HCP

The advantages of HCP over slurry pipelines have already been discussed. The following is a comparison between HCP and trucks for freight transportation:

According to a study by Hirst(5), the average values of the energy intensiveness (EI)* for ordinary pipelines and trucks are respectively 450 and 2,300 Btu/ton-mile. Since the EI for HCP, estimated by Liu(13), is approximately three times that of an ordinary (liquid) pipeline of the same size and velocity, it may be deduced then that the average value of EI for commercial HCP should be in the neighborhood of 450x3 = 1,350 Btu/ton-mile which is only about one half the average value of EI for trucks. This shows that HCP systems are expected to use much less energy than trucks for transporting the same quantity of cargo over the same distance, or in short, HCP conserves energy.

Another advantage of HCP over trucks is that the former uses electrical energy which need not be generated from oil which has become

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*Energy intensiveness (EI) is the energy consumed in transporting a unit weight of cargo over unit distance. A common unit for EI is Btu/ton-mile.

increasingly scarce; trucks, on the other hand, use petroleum. In addition, HCP causes less damage to the environment and less air pollution, and reduces traffic jams and highway accidents caused by trucks. So, HCP has many advantages over trucks and should be developed to replace trucks for long-distance freight transport, whenever possible.

5. STATE-OF-THE-ART OF HCP

Due to vigorous research by many individuals in the past fifteen years, the hydrodynamics of HCP is now fairly well understood. For instance, it is now known that best results can be produced with capsules (containers) having an outer diameter 5 to 10% smaller than the inner diameter of the pipe. It is also known that capsules travel in the pipe in a nose-up position as shown in Fig. 2. Contrary to what one may expect, streamlining capsules has little effect on drag reduction. On the other hand, fitting a collar (band) on the front of a capsule, as shown in Fig. 2, may drastically increase the hydrodynamic lift on the capsule and reduces contact friction. This may result in a large reduction in drag and energy loss. How lift is generated on capsules has been clarified recently by Liu(12).

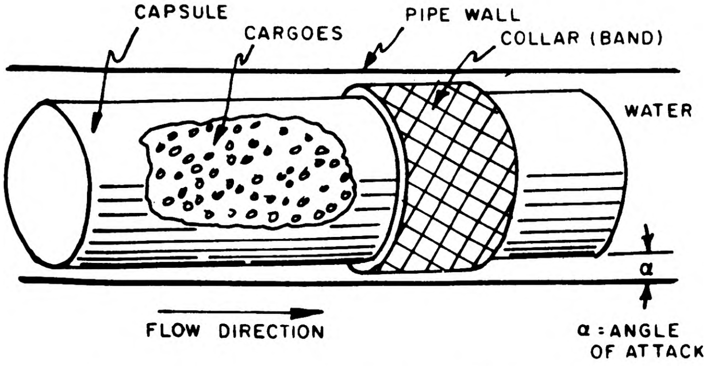

Figure 2. Capsules Moving Through Pipe

In spite of the abundant current information on the hydrodynamics of HCP, many technical problems remain to be studied before efficient utilization of HCP is possible. The state-of-the-art of HCP is still in an infant stage.

A major area of HCP which needs more studies is pumping. Capsules simply cannot pass through ordinary pumps; they must either bypass the pump, or a special pump that can pass capsules must be used. Both alternatives have been investigated recently.

Two types of capsule pumps were studied by Jensen et al(8) 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. 3. 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 best efficiency obtained so far for the vortex pump is only about 15%. The pump head which yields this efficiency is only a few feet. Although vortex pumps can be put in stages to produce high head, the economics of multi-stage vortex pumps may not be favorable.

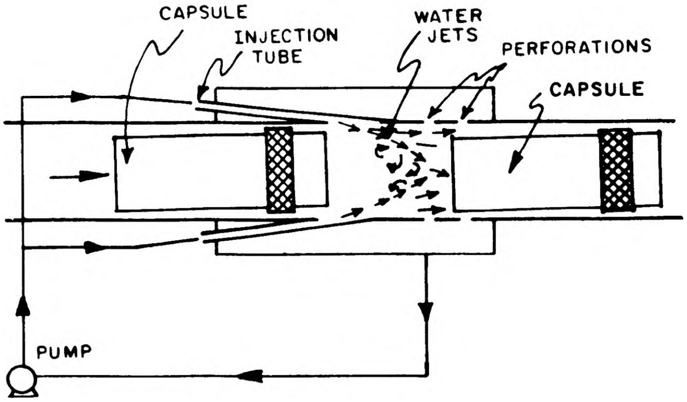

Figure 3. The Vortex Pump

A sketch of the rotary-vane pump developed in Canada is shown in Fig. 4. To date, only small-scale models of the pump have been tested. The main drawback of this pump is its bulkiness.

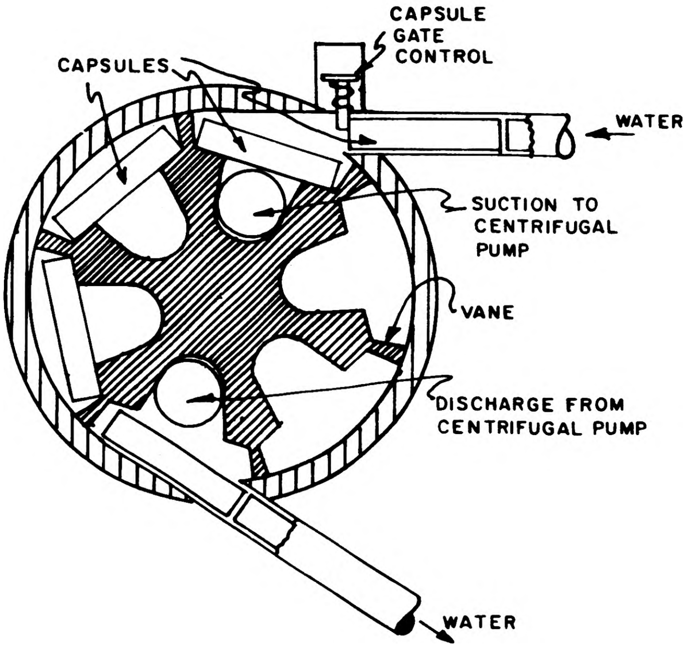

Figure 4. Rotary-Vane Pump Studied in Canada

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.

Several schemes to cause capsules to bypass ordinary pumps have also been studied in Canada; one is illustrated in Fig. 5. This scheme, involving the closing and opening of valves according to the sequence shown in Fig. 5, allows the capsules to bypass the pump.

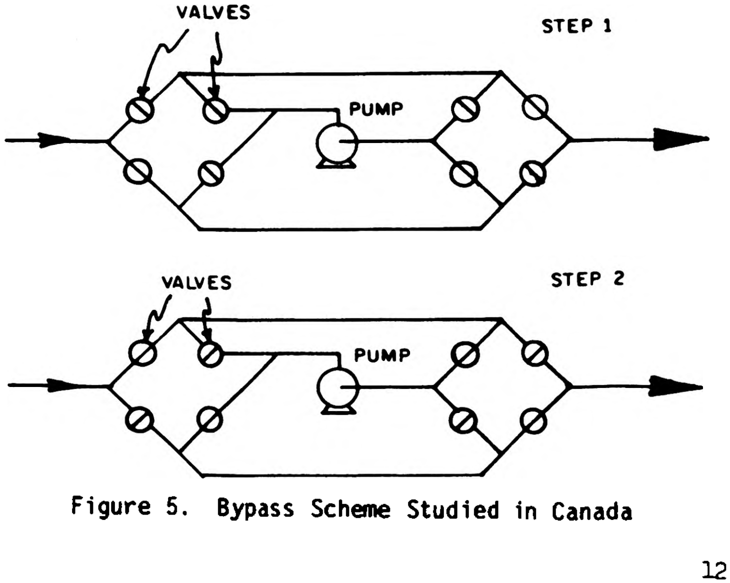

Figure 5. Bypass Scheme Studied in Canada

But, rapid opening and rapid closing of valves in a large pipeline cause large surges of pressure. The problem must be solved before any bypassing scheme can be used in commercial pipelines.

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 are investigating 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 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 review of the LIM was given by Laithwaite and Nasar(11).

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(2). In HCP, the capsules are levitated by the lift force generated by water(12,13). 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 that it does not require a magnetic field along the entire length of the pipe. As long as there is a continuous train of closely-spaced capsules in the pipe, the magnetic field needed to push the capsules can be concentated at pumping stations along the pipeline. The capsule which is pushed by the magnetic field will 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 "LIM capsule pump". 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 wall made of a good conductor. A LIM capsule pump is shown in Fig. 6.

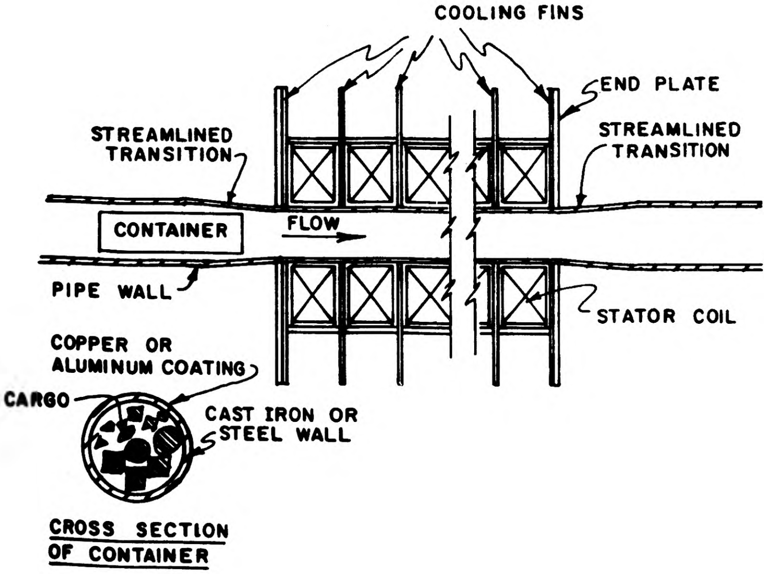

Figure 6. LIM Capsule Pump

Another way to pump capsules electromagnetically involves the use of capsules with ferromagnetic walls. With a set of solenoids wound around 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 solenoids operating in succession are needed to cause the continuous motion of capsules. This can be seen as follows:

Referring to Fig. 7, $S_1, \ldots S_5$ 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.

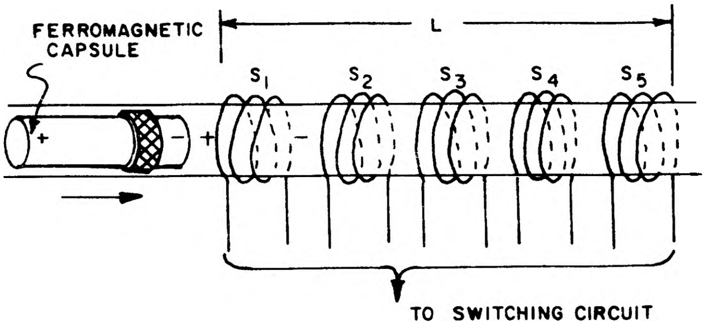

Figure 7. Schematic Representation of the Solenoid Capsule Pump

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 "solenoid capsule pump" or a "magnetic capsule pump".

In both the LIM and the magnetic capsule pumps, electromagnetic energy is transferred directly to capsules which in turn push the liquid 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 bore of the pump through which capsules pass must be slightly smaller than the bore of the pipeline. A smooth transition at the inlet of the pump is, of course, required. More details about the LIM and the magnetic capsule pumps are given by Liu and Rathke(14). The University of Missouri has filed a patent application on these pumps.

Another area of HCP which requires further study is capsule injection. The efficiency of any HCP system is directly proportional to the rate of injection of capsules (containers) into the pipe: the higher the injection rate, the better the efficiency of HCP at a given velocity. However, fast injection poses many problems in the field which so far have not been investigated thoroughly.

Several schemes to inject capsules into pipe have been tested in Canada. Fig. 8 illustrates the lock-type injector. The operation of the system involves two steps: First, open valves 1 and 5 and close valve 2; the suction pump draws capsules into the lock as shown. Meanwhile, keep valves 3 closed and 4 open; the other 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. This causes the capsule train to enter the downstream pipeline.

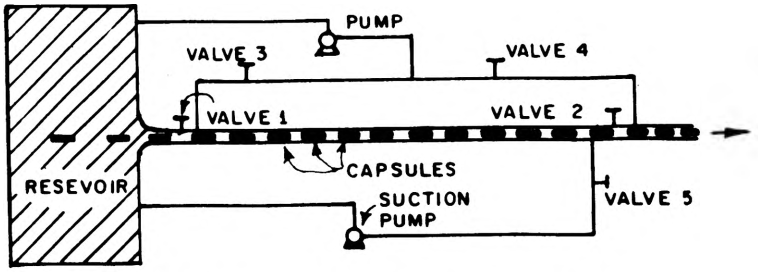

Figure 8. The Lock-Type Injector

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. This renders the injector unsuitable for commercial application which, for economical reasons, must have a high degree of linefill.

Another type of injector studied in Canada is the multi-barrel revolver shown in Fig. 9. 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. The shortcomings of the revolver injector are the difficulty in loading capsules into the revolver at a fast rate, the difficulty in making the injector water-tight, and the problems associated with the high pressure surges. The problems are expected to be especially hard to overcome in large pipelines.

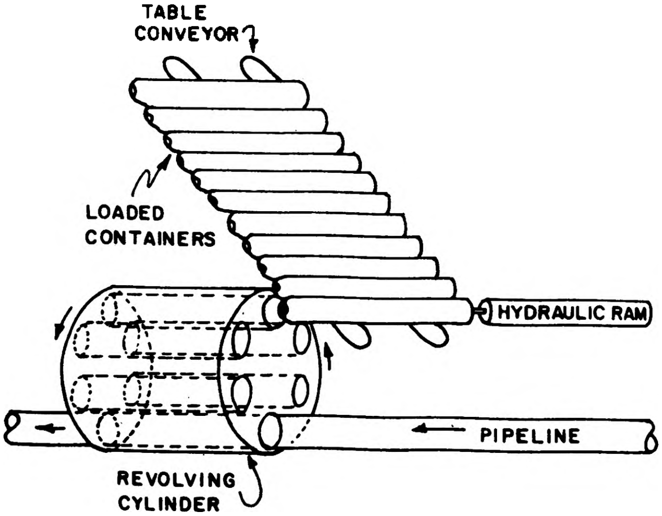

Figure 9. The Revolver-Type Injector

A third way to inject capsules into pipelines, studied in Canada, is to use the rotary-vane pump shown in Fig. 4. For the purpose to inject capsules, the pump functions as a multiple lock system with a single capsule in each lock. The main shortcoming of the system, as mentioned before, is the bulkiness of the pump.

Finally, a new way to inject capsules are being investigated at UMC. The system is shown in Fig. 10. It consists of a set of parallel launching tubes mounted on a wide conveyor belt which can cause the tubes to move laterally. Capsules are fed into the tubes one at a time at a slow rate. As a tube moves to position 10 in Fig. 10, it will be filled with ten cap-

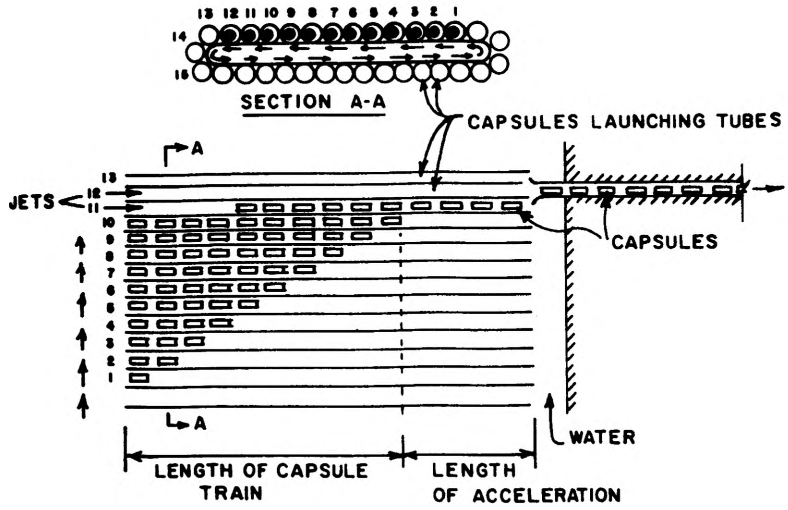

Figure 10. The Multi-Tube Launcher

sules. The train of capsules will then be accelerated by a water jet (hydraulic catapult) as the tube reaches position 11. Finally, when the tube comes to position 12, another jet pushes the entire train of capsules into the pipe.

Note that by using the multi-tube system outlined above, densely spaced capsules are accelerated before they enter the pipe. This makes rapid injection and high degree of line-fill possible for any size of pipelines. This scheme for injecting capsules needs to be evaluated experimentally.

6. REMAINING PROBLEMS

New Transportation technologies usually evolve slowly; HCP is no exception. In spite of a decade of extensive study in Canada, commercial utilization of HCP is still not in sight. At least another five to ten years of extensive R & D are needed before an efficient and trouble-free system of HCP can be developed.

One major problem remaining in HCP is capsule pumping. New ideas such as the LIM capsule pump and the magnetic capsule pump must be tested thoroughly in laboratories before their values can be assessed. Special devices to inject capsules into pipes and to retrieve capsules from pipes must also be tested and perfected. Automation of HCP systems, including the use of electronic eyes and fluidic devices to control the motion of capsules at the branching of pipes, also requires extensive studies.

Finally, continued research is needed to minimize the energy loss in HCP. At least two ways to further reduce the EI of HCP are possible. One is to modify the shape or the center of gravity of capsules in order to increase the lift on them. If capsules with a heavy payload can be lifted off the pipe bottom, much can be gained in reducing the EI. Another potential way to reduce the EI is through the use of high molecular weight polymers. It is known that when a small amount of such polymers are dissolved in water, the energy loss in turbulent flow can be reduced drastically. Since the flow in capsule pipelines of commercial size will be highly turbulent, a reduction of energy loss by high polymers is expected. The crux of the problem is finding a stable form of polymer that will not degenerate under continued action of shear. Polymers used in HCP will not be lost because the water in the pipe will be recirculated.

These remaining problems present a challenge to scientists and engineers in many fields. Only through vigorous research can this potentially useful technique be developed to benefit mankind.

7. REFERENCES

1. Carstens, M.R. and Freeze, B.E., Pneumatic Capsule Pipeline, Publication of Tubexpress System, Inc., Houston, Texas, 1975, 23 pages.

2. Caudill, R.J., Vehicle-Follower Longitudinal Control for Small Automated Transit Vehicles, Ph.D. Thesis, University of Minnesota, December 1976, 265 pages.

3. Ellis, H.S., Redberger, P.J., and Bolt, L.H., "Transporting Solids by Pipeline, Part 2: Capsules and Slugs," Industrial Engineering Chemistry, Vol. 55, No. 9,

1963, pp. 29-34.

4. Govier, G.W. and Aziz, K. The Flow of Complex Mixtures in Pipes (Chap. 12, The Flow of Capsules in Pipes), Van Nostrand Reinhold Company, New York, 1972, 792 pages.

5. Hirst, E., "Energy Intensiveness of Transportation," Transportation Engineering Journal, American Society of Civil Engineers, Vol. 99, No. 1, February 1973, pp. 111-122.

6. Hodgson, G.W. and Bolt, L.H., "The Pipeline Flow of Capsules: Potential Industrial Applications," (Canadian) Engineering Journal, Vol. 45, No. 12, 1962, pp. 25-30.

7. Hodgson, G.W. and Charles, M.E., "The Pipeline Flow of Capsules. Part I: The Concept of Capsule Pipelining," Canadian Journal of Chemical Engineering, Vol. 41, No. 2, April 1963, pp. 43-45.

8. Jensen, E.J. et al., TDA-RCA Capsule Pipeline Project Report, Alberta Research Information Series. No. 63 & 67 January 1975.

9. Kobuliya, G., "The Train Runs in a Tube," Pit & Quarry, July 1972.

10. Kolm, H.H., and Thornton, R.D., "Electromagnetic Flight," Scientific American, Vol. 229, No. 4, 1973, pp. 17-25.

11. Laithwaite, E.R., and Nasar, S.A., "Linear Motion Electrical Machines," Proceedings of IEEE, Vol. 58, April 1970, pp. 531-542.

12. Liu, H., "The Fluid Mechanics of Capsule Pipelining," Proceedings, 2nd Specialty Conference of the Engineering Mechanics Division, ASCE, Raleigh, North Carolina, May 1977, 7 pages.

13. Liu, H. and Gibson, D.L., "Hydraulic Container Pipelining--A Future Transportation System to Conserve Energy," Proceedings, 3rd UMC/MEC Conference on Energy, October 1976, 6 pages.

14. Liu, H. and Rathke, J.E., "Electromagnetic Capsule Pumps," International Symposium on Freight Pipelines, Washington, D.C., December 1976, 20 pages.

15. Vivian, C.H., "Early Pneumatic Tubes," Compressed Air, Vol. 77, No. 1, January 1972.

16. Zandi, I. and Kim, K.S., "Solid Pipeline Conserves Energy," Transportation Research, Vol. 8, No. 4/5, October 1974, pp. 471-480.

8. BIOGRAPHIES

Henry Liu is Professor of Civil Engineering, University of Missouri-Columbia (UMC). Born in Peking, China, in 1936, Liu came to the U.S. from Taiwan in 1961 to pursue his graduate study at Colorado State University where he earned both his M.S. and Ph.D. in fluid mechanics. He joined UMC in Fall 1965, and became a U.S. citizen in 1975.

Liu has published extensively. He is a member of the Committee on Hydromechanics, American Society of Civil Engineers (ASCE). He is also the chairman of the Aerodynamics Committee of ASCE. His biography is listed in AMERICAN MEN AND WOMEN OF SCIENCES, WHO'S WHO IN THE WEST AND MID-WEST, ASIAN WHO? IN AMERICA, NOTABLE AMERICANS OF THE BICENTENIAL ERA, COMMUNITY LEADERS AND NOTABLE AMERICANS, etc.

Donald L. Gibson is an Associate Professor of Mechanical and Aerospace Engineering, UMC. He received his Ph.D. degree from Vanderbilt University in 1971. Dr. Gibson is an expert in Machine Design and Metallurgy, and has extensive teaching, research, and consulting experiences. He is a PE registered in Missouri.