

# Pneumatic Capsule Pipeline – Basic Concept, Practical Considerations, and Current Research

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Pneumatic capsule pipeline (PCP) uses air blown through a pipeline to propel capsules (wheeled vehicles carrying cargoes) through the pipeline. It is a modern and large version of the century-old technology of “tube transport” used rather widely and successfully in the first half of the 20th century in major European and U.S. cities for transporting mail, parcels, telegraphs, documents, cash, and other lightweight materials. Modern PCP systems, such as those used in Japan for transporting limestone to a cement plant, use large wheeled capsules moving heavy cargoes through pipes of 3-ft diameter, approximately. Each capsule can carry almost two tons of cargo. The system is driven by blowers located near the beginning of the pipeline, and it is highly automated (by computers and programmable logic controllers). The system is being used very successfully in Japan, with a high reliability record. Yet, only limited use exists today due to its high unit freight transportation cost in \$/ton as compared to that by truck. The unit cost is high due to low system throughput (freight capacity). Major improvement in throughput can be made by replacing the pumping mechanism from blowers (which are used currently), to electromagnetic pumps (for the future systems), and using off-line loading/unloading. Research in such improvements of PCP is currently underway at the Capsule Pipeline Research Center at the University of Missouri-Columbia. Key words: capsule pipeline, PCP, pneumatic capsule pipeline, tube freight, underground freight transport.

## INTRODUCTION

Capsule pipeline is the transport of freight by capsules moving through a pipeline propelled by fluid—either gas or liquid. When the fluid involved is liquid (usually water), it is called hydraulic capsule pipeline (HCP), and when the fluid is gas (usually air), it is called pneumatic capsule pipeline (PCP). Both HCP and PCP have distinct characteristics and respective advantages and disadvantages. Therefore, they are best suited for different applications—having their different niches.

Because the fluid used in HCP (water) is much denser than the fluid used in PCP (air), the capsules in HCP can be suspended by the fluid and hence they don't need wheels to move through the pipe. In contrast, PCP capsules need wheels in order to carry heavy cargo. On the other hand, PCP capsules move much faster in the pipe than HCP capsules—15 to 20 m/s for PCP and only 2 to 3 m/s for HCP. Due to these and other differences, HCP is more suitable for transporting low-cost bulk materials such as coal and other minerals, grain and other agricultural products,

and solid wastes. Speed of transportation is not a crucial factor in transporting these commodities. In contrast, PCP is more suitable for transporting higher valued products that must be delivered speedily, such as mail and parcels, fruits and vegetables, and many other commercial products. Details about HCP and PCP and their expected applications can be found in a 1998 publication of the Task Committee on Freight Pipelines, American Society of Civil Engineers (1).

The advantages of using PCP to transport freight are not difficult to see. When PCP is used to transport a significant portion of freight in the future, it will reduce the number of trucks on highways and streets, resulting in reduced traffic jams, accidents, air and noise pollution, and damage to pavement and bridges, that would otherwise be caused by trucks. Consequently, PCP can make a significant contribution to the U.S. highway system in the future.

The purpose of this paper is to discuss the basic concept, practical considerations, and current research on PCP, especially with respect to its potential future use as a means of underground freight transport between major cities.

## BASIC CONCEPT

All contemporary PCP systems, such as those used in the former Soviet Union for transporting rock (2) and those used in Japan for transporting limestone and other products (3), use wheeled capsules rolling through a pipeline. For capsule stability inside a circular conduit (pipe), it is not permissible to mount wheels on the bottom of capsules. Instead, two sets of wheels are mounted on the two ends of each capsule as shown in Figure 1. Each wheel set consists of a minimum of five small wheels placed in symmetric position around the pipe interior in contact with the pipe wall. The wheels are connected to the central axis of the capsule and free to rotate around the pipe in a manner similar to gimbals. In so doing, the capsule will always remain in a stable equilibrium position without spilling the cargo. For PCPs that use square or rectangular conduits, as used in Japan for tunnel construction (4), the gimbals-type wheels are no longer needed. Such PCPs use capsules with wheels mounted on capsule bottom, as in the case of ordinary vehicles that run on flat horizontal surface. Most current systems use rubber tires to minimize noise and prevent wear of the pipeline.

The PCP capsules normally have a diameter approximately 85% of the pipe diameter, and a capsule length about five times the capsule diameter. This means the capsule length-to-diameter ratio, called the

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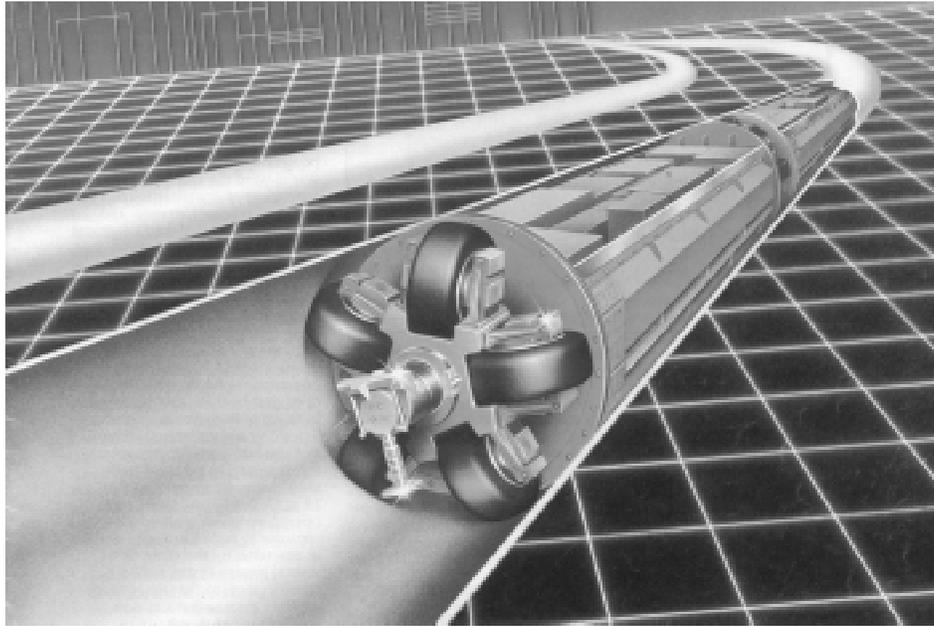


FIGURE 1 A PCP capsule used in Japan (3)

“aspect ratio,” is about 5. Both ends of the capsule are mounted with an end disk made of steel having a rubber rim. The end disks minimize air leakage through the capsule, increase capsule drag, and make the capsule to move almost as fast as the air moving in the spacing between capsules. In ordinary commercial PCPs, the end-disk diameter is about 97% of the pipe inner diameter. This creates a drag coefficient in the neighborhood of 1,000, and a capsule velocity within 1 m/s of that of the fluid (air) velocity.

Normally, five or more capsules are linked together to form a capsule train moving through the pipe. Double pipe is used—one for delivering the cargo, and the other for bringing empty capsules back to the intake. The capsule train is first loaded with cargo at the loading station. Then, air is directed behind the capsules to push them through the pipeline. As the capsule train reaches the end of the pipe, the capsule bottom opens up, and the cargo is dropped by gravity. Then the air is directed behind the empty capsules to push them back to the pipe inlet. The entire system is shown in Figure 2.

## PRACTICAL CONSIDERATION

The current commercial systems of PCP, as used in Japan, have demonstrated their high reliability—over 98% of availability when needed. The system is highly automated, and the operation cost is low. In spite of that, the system has not been widely used even in Japan due to the following reasons.

The current PCP systems have very low linefill rate (3%). This means only 3% of the pipe length is occupied by capsules; 97% is empty. As a result of this low linefill rate, large diameter pipe is required to transport relatively small quantity of cargo—the throughput is low! Note that unit freight transportation cost in \$/ton is directly proportional to the total system cost and inversely proportional to the linefill rate or throughput. Therefore, a five-fold increase in linefill from 3% to 15% would cut the unit cost by half even if the total system cost is increased 2.5 times due to increased throughput—more capsules, more handling facility, and higher operation costs.

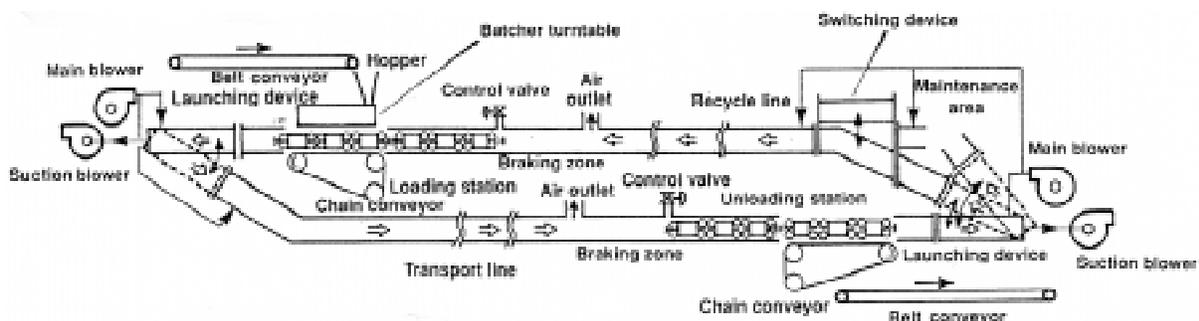


FIGURE 2 A PCP system used in Japan (3)

There are two reasons for the low linefill and low throughput. The first is the use of blowers (fans) which block the passage of the capsules. Capsules must stop before they reach any blower, and then must be routed through a bypass line in order to proceed down the pipeline without going through the blower. This greatly impedes the capsule traffic, and limits the linefill rate. Another reason for the low linefill is in-line loading/unloading. Instead of taking the capsules out of the pipe for loading/unloading, the current system has the capsules loaded and unloaded while they are inside the pipe. Flow is stopped while loading/unloading is taking place. This again greatly impedes the traffic and reduces the linefill rate.

Therefore, in order to improve the current PCP system and increase its linefill, two things must be done. First, a non-intrusive type of pump must be used in lieu of blowers which impede capsule motion. Secondly, loading and unloading of capsules must be done outside the pipeline—i.e., off-line loading/unloading. With such improvements, it is believed that a fivefold increase in the linefill of PCP from the current 3%, to 15%, is possible.

The most promising non-intrusive pump for PCP is electromagnetic capsule pump such as linear induction motor (LIM), the same technology used for advanced roller coaster systems and magnetic propulsion and levitation of high-speed train (5). As capsules of metallic wall enter the LIM, an electromagnetic thrust is generated on the capsules to accelerate and to push the fluid forward. The capsule wall will be made of steel with an outer layer of aluminum. An “eddy current” is induced in the aluminum wall which generates the electromagnetic force (thrust) needed to push the capsules forward. By having the inner diameter of the LIM made slightly smaller than the inner diameter of the pipe, the capsules going through the LIM behave like a piston pump, causing the fluid in the pipe to be pushed forward (6). See Figure 3 for such a pump.

Note that LIMs can be used not only for pumping capsules, but also for capsule injection/ejection, climbing steep slopes, capsule speed control, and capsule breaking. They need not be placed along

the entire pipeline. On the contrary, they need only to be placed at strategic locations along a PCP. Furthermore, single-sided LIMs can be used to control the direction of motion of capsules at pipeline branching points (see Figure 4). By turning on the LIM on one side of the branch instead of the other, a lateral electromagnetic force is generated to direct the capsule into the desired branch. This means that the LIM can also be used for system control purpose.

All PCP systems must be automatically controlled. This requires the detection of capsules at many strategic locations along the pipe. Capsules can be detected and identified by placing bar codes on them and using a special bar-code scanner to detect and identify them.

For transporting bulk materials such as minerals or solid wastes, cylindrical capsules in cylindrical pipe are preferred. In contrast, for transporting packaged commodities, capsules of square or rectangular cross sections traveling inside a square or rectangular conduit will be the choice. A 1.5 m wide rectangular section will allow cargoes to be transported on pallets, and a 2 m wide rectangular section will allow large crates to be transported. Rectangular conduits can be used for PCP due to the relatively low internal pressure in the system—usually not more than one or two atmospheric pressure. Such conduits can be made of reinforced concrete.

## CURRENT RESEARCH

Only limited research is currently taking place in PCP to improve the system. Four current or recent research projects are known. One is a project completed recently at the University of Minnesota, sponsored by the Minnesota Department of Transportation (7). This study investigated the possible use of large conduits or tunnels of diameter greater than 3 m placed under a highway. The capsules are self-propelled vehicles carrying their own electric motors. Such a system is more of the nature of underground electric trains rather than PCP,

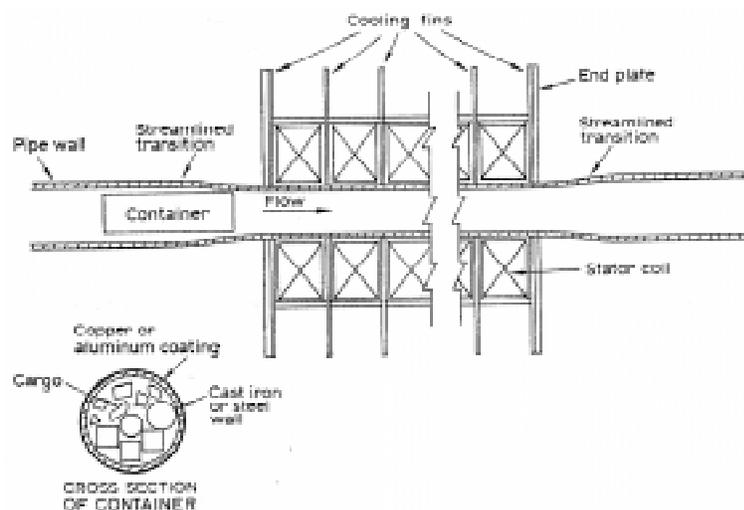
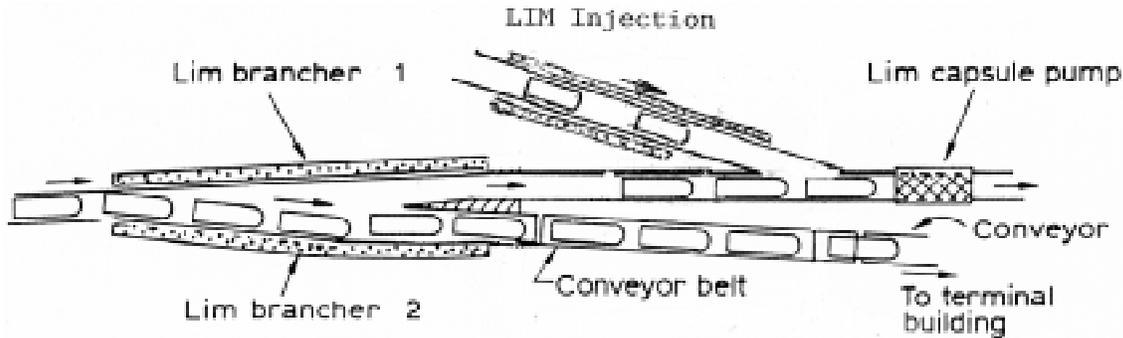


FIGURE 3 LIM capsule pump concept



**FIGURE 4 Use of LIMs for capsule control at terminals—conceptual design**

though many commonalities exist between such a system and PCP. The greatest advantage of this system is it can carry large size cargoes—including standard containers. The drawback of the system is high cost.

A study is taking place currently in Florida for transporting phosphate by using PCP (8). The PCP is to be driven by linear synchronous motors (LSM) instead of linear induction motors (LIM). LSM may have slightly higher efficiency than LIM, but it is difficult to control because the capsule speed and the motor speed must be synchronized. Furthermore, synchronous motors do not self-start. The motor has zero thrust when capsules are in standstill. The rotor (capsules in this case) must be brought to synchronous speed by some other means (a starter) before the LSM can start to work.

A third study is being conducted at Texas Transportation Institute (TTI). In the TEA-21 legislation, TTI was authorized (and funded with \$1.125 million) to conduct a feasibility study of using PCP to transport freight in Texas in order to reduce truck traffic (9). The scope of the study does not include research to improve the current system.

Finally, in 1998, the Mid-America Transportation Center, in collaboration with the Sumitomo Metal Industries, Ltd. in Japan, sponsored a PCP research project at the Capsule Pipeline Research Center (CPRC), University of Missouri-Columbia. The project is focused on studying the use of LIM for PCP. The pertinent electromagnetic and fluid mechanics equations have been derived (10, 11). Currently, preparation is underway to test a special LIM for PCP donated by Force Engineering, Inc. in England (see Figure 5). The test data will be used to verify the equations derived so that these equations can be used with confidence for designing future PCP systems powered by LIMs.

Other much needed research before the improved PCP can be developed and used smoothly in commercial applications includes a study to construct PCPs along highways easement, testing the use of modern bar code scanning systems to detect, identify, and control PCPs, designing a new system for efficient off-line loading/unloading of capsules, and investigation of the economics and market of the new PCP system.

## CONCLUSION

It can be concluded that the use of PCP for underground freight transportation has many environmental and safety benefits including reduction of traffic jam, accidents, air and noise pollution and damage to roads and bridges—all caused by the reduced use of truck for freight transport resulting from using PCP.



**FIGURE 5 A LIM donated by Force Engineering in England for PCP research at University of Missouri-Columbia**

Limited use of PCP for transporting limestone, construction materials, rocks and so forth has taken place in both the former Soviet Union and Japan. The Japanese use of PCP seems to be especially successful. However, widespread use of PCP is not expected unless and until the cost effectiveness of this new technology is substantially improved. The current system is not cost effective because of its small throughput capacity, limited by the use of blowers to pump the air through the pipe, and by in-line loading/unloading. Drastic improvement in the throughput and control of PCP is possible if linear induction motors (LIMs) are used for capsule pumping, injection, ejection and control, and if off-line loading/unloading is used. Such a revolutionary new PCP system can greatly increase the freight throughput, resulting in a much lower unit freight transport cost by PCP in \$/ton.

Research is needed to complete the development of the PCP-LIM, to design an off-line loading/unloading, to study the construction of PCP along highway easement, and to test a reliable sensor system based on bar code scanning. Government, industry, and universities need to work together to complete such R&D of the new (improved) PCP system so that this meritorious technology can find widespread early use.

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