COMPREHENSIVE PNEUMATIC TRANSPORTATION SYSTEM FOR GEOLOGICAL DISPOSAL FACILITIES

T. Esaki, K. Okutsu
Civil Engineering Design Division, Kajima Corporation
5-30, Akasaka 6-chome, Minato-ku, Tokyo, 107-8502, Japan

N. Matsui
Civil Engineering Technology Division, Kajima Corporation
2-7, Motoakasaka 1-chome, Minato-ku, Tokyo, 107-8388, Japan

T. Fukunaga
Energy Facilities Engineering Division, Sumitomo Metal Industries, Ltd.
8-11, Harumi 1-chome, Chuo-ku, Tokyo, 104-6111, Japan

K. Saito
Industry Machinery Design Division, Kansai Design Company, Ltd.
4-8, Tosabori 1-chome, Nishi-ku, Osaka, 550-0001, Japan

ABSTRACT

The pneumatic capsule pipeline transportation is a method to transport various materials by utilizing differential pneumatic pressure. It has advantages over conventional methods (e.g., vertical transport using a lift in a shaft) in terms of safety and economical efficiency when it is applied to the deep radioactive waste disposal facilities (Hane, et al., 2002).

In this paper, focusing attention on the safety and efficiency of transportation, we propose a concept of the comprehensive transportation system for the high-level radioactive wastes disposal facilities. By introducing a curved pipe section to the pipeline system, we show the applicability and practicability of the system for the facility by analytical study.

INTRODUCTION

Many research studies about geological disposal have been carried out in the countries where geological disposal is being planned. There is no established technology to transport high-level radioactive wastes safely and efficiently from harbor facilities to surface facilities, and from surface facilities to underground facilities. Currently, both rail transportation and truck transportation are being considered as probable methods to transport the wastes from the harbor facilities to the surface facilities. As the method to transport them from the surface facilities to the underground facilities, both truck transportation in an inclined tunnel and lift transportation in a shaft are being considered. However, these conventional methods have been pointed out to have some disadvantages.

DISADVANTAGES OF CONVENTIONAL METHODS

In the waste transport within the site (i.e., from the surface facilities to the underground facilities), it is one of the most important issues to transport the wastes deep into the underground safely. However, the conventional transport methods are considered to have several issues in this respect. If a lift is used for transportation, it needs other transport equipment to shift the transport directions. Furthermore the surface and the underground facilities need to have transfer facilities, where complicated transshipping operations between systems are performed by remote control. An increase in the number of equipment items and complication of processes might lead to mechanical or human errors.

In the case of lift-based vertical transportation from the surface facilities to the underground facilities, these methods need costly devices to keep the reliability of the carrying equipment at the required level.

ADVANTAGES OF PNEUMATIC CAPSULE PIPELINE SYSTEM

The pneumatic capsule transportation system is a method to transport various materials by using differential pneumatic pressure. The Images of a Comprehensive Pneumatic Transportation System for Geological Disposal Facilities is shown in Figure 1. This system, also, can be easily operated by remote control, so that radioactive wastes can be transported safely. Detailed information on the transport mechanism and principle of the system is given in "Applicability of Pneumatic Capsule Pipeline System to Radioactive Waste Disposal Facility" (Hane, et al., 2002)[1]. The advantages of the system are summarized below.

Safety and Reliability

Even when the power supply to transport the capsule is accidentally terminated, the air in the pipe prevents a sudden fall and crash of a container, behaving like an air damper. The transportation mechanism is so simple that it enables to reduce the risk of any accidents caused by remote control. The system is also easy to maintain because it consists of a small number of components. The system has been applied in many fields such as concrete plants[2] and construction sites[3], and practically no accidents or machine troubles in operation have been reported (Kosugi, et al., 2000).

High Usability

The system is capable of carrying heavy loads so that wastes and buffer materials can also be transported as an assembled capsule. Also the system can be used to transport other types of loads, such as equipment, materials (e.g., concrete, temporary struts) and excavated debris during the construction phase of underground facilities as well as transporting the wastes during operation phase.
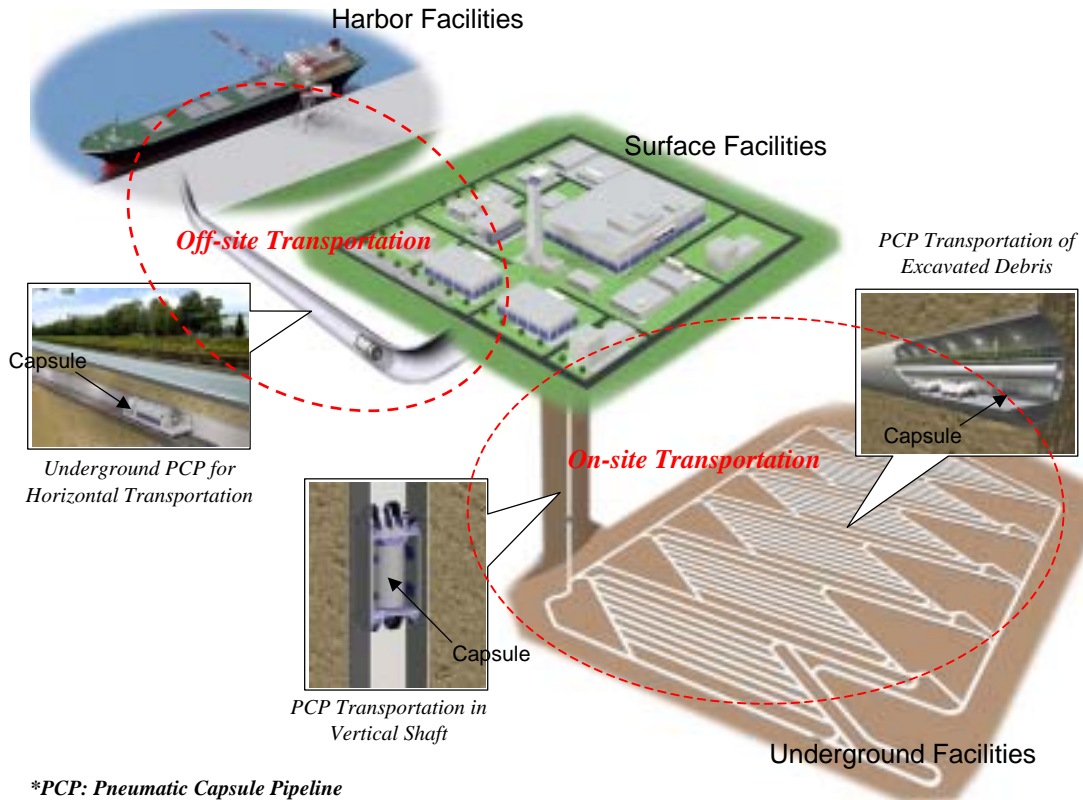
Fig. 1. The Images of a Comprehensive Pneumatic Transportation System

for Geological Disposal Facilities

Flexibility in shaft layouts

The shaft for pneumatic transportation does not need necessarily to be vertical or horizontal. An inclined or curved tunnel can also be used as long as it is so curved as to pass a capsule. It implies that waste packages can be transported to any locations in the underground facilities without transshipment.

CONCEPT OF THE TRANSPORTATION SYSTEM

Figure 1 illustrates the concept of the comprehensive pneumatic transportation system to transport high-level radioactive wastes to/within the disposal facilities. Transportation of the wastes in a geological disposal project can be classified into two parts: transportation from the harbor facilities to the surface facilities (off-site transportation) and transportation from the surface facilities to the underground facilities (on-site transportation). Each concept is described as follows:

Off-site transportation (from the harbor facilities to the surface facilities)

A cask containing the high-level radioactive wastes is transshipped from a vessel to a capsule at the harbor facility to be sent to the surface facilities. A cask is currently designed to be a 6.6m-long cylindrical container with about 2.2m-diameter and weights about 1,200kN. The 1,200 kN-weight cask can be transported with the pneumatic capsule pipeline system at an appropriate speed. Transportation routes can be optimized according to the surrounding conditions (e.g., geographic conditions, social situations) since the pipelines for transportation are constructed below ground.

On-site transportation (from the surface facilities to the underground facilities)

In the vertical transportation of the capsule from the surface facilities to the underground facilities, the capsule can be made to fall at a constant velocity by adjusting the air gap between the pipe wall and the capsule. According to analysis results, in the case where a 3.13 m-high, 360 kN capsule about 3.4 m in diameter, assuming a transport of an overpack, is made to fall vertically through the pipeline, the capsule falls at a constant velocity of about 5 m/s if the air gap is adjusted to 4 mm.

One of the greatest advantages of the use of the pneumatic capsule pipeline system in transporting packaged wastes is that vertical transport can be switched to horizontal transport smoothly without transshipping the wastes by adding a curved section to the pipeline (see ANALYTICAL STUDY). Furthermore, the pneumatic capsule pipeline system with a curved pipe section shown in Figure 2 is an inherently safe system because the capsule velocity decreases gradually in the horizontal section. This deceleration, in addition to the air damper effect of the conventional straight vertical system, will contribute to further enhancement of the degree of safety of the transportation system.
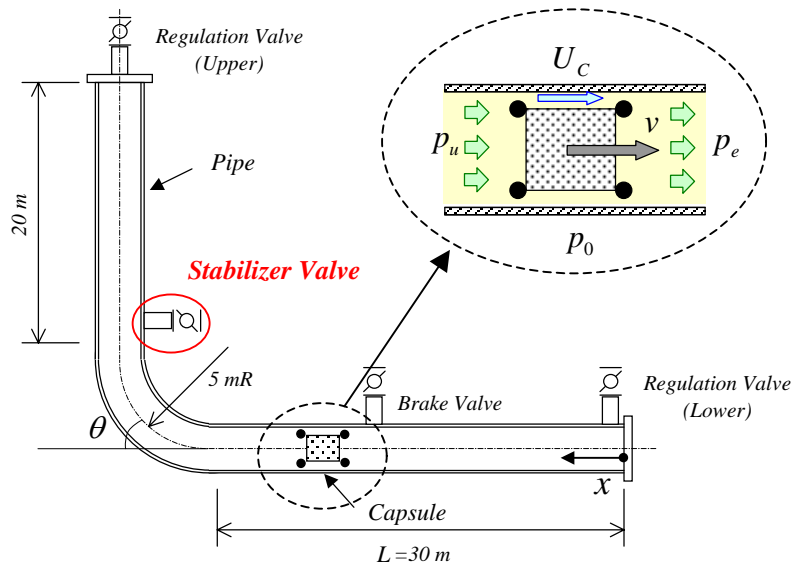

Fig. 2   Pneumatic Capsule Pipeline Model

Since the pneumatic capsule transport method makes it possible to simplify the transportation equipment, it is an ideal transportation method for the disposal facility and superior to the conventional type of transport methods in terms of efficiency, economy and safety.

ANALYTICAL STUDY

The behavior of the capsule when it is transported both in a vertical shaft and a horizontal tunnel has already been investigated in detail by Kosugi, et al. The most notable characteristic of the proposed transport system in applying to the facilities is the smooth switchover from vertical transportation to horizontal transportation. In this study, a transportation simulation is performed to investigate the behavior of the capsule while it is passing through a curved pipe section after the theory of the pneumatic capsule transportation.

This study also aims to improve the economical efficiency of the pneumatic capsule pipeline transportation because the waste transport is repeated over a period of several tens of years in the facility.

(1) Theory of Capsule Transportation

The theory of capsule transportation in a curved pipeline section is almost the same as that in a vertical pipeline shown in References. The capsule moves downward by its own weight. We define the direction of x (capsule position measured from the end of pipeline) and v (velocity of capsule) as shown in Figure 2.

$$\frac{dx}{dt} = -v \qquad\qquad\qquad\text{(Eq. 1)}$$

The equation of capsule motion is given by

$$M\frac{dv}{dt} = (p_u - p_e)A_c + Mg(\sin\theta - \mu\cos\theta) \qquad\qquad\text{(Eq. 2)}$$

Where

M : mass of the capsule

p_u : pressures acting on the back of capsule

p_e : pressures acting on the front of capsule

A_c : pressure bearing area (cross sectional area of seal plate)

g : gravitational acceleration

μ : coefficient of rolling resistance

θ : angle of slope gradient

The velocity increment is

$$\Delta v = \left\{ \frac{(p_u - p_e)A_c}{M} + g(\sin\theta - \mu\cos\theta) \right\}\Delta t \tag{Eq. 3}$$

The change in the state of air in the region of front of the capsule is given by

$$(p_e + \Delta p_e)A\{(L - x) + \Delta(L - x)\} = p_e A\{(L - x) - v\Delta t\}$$

$$+ \frac{p_u + p_e}{2}AU_C\Delta t - \frac{p_e + p_0}{2}AU_B\Delta t \tag{Eq. 4}$$

Then we have

$$\Delta p_e = \frac{\Delta t}{2(L - x)}\left\{(p_u + p_e)U_C - (p_e + p_0)U_B\right\} \tag{Eq. 5}$$

Where

  A : cross sectional area of pipeline

  p_0 : atmospheric pressure

  U_C : air velocity near the capsule based on the pipeline diameter

  U_B : air velocity based on the inside diameter of pipeline

By using these equations, the capsule velocity on each position of the curved section is determined.

(2) Analytical Conditions

The velocity of the capsule in the curved pipeline section is analyzed with the following conditions.

 Pipeline

  Diameter of the pipe: 0.8 m

  Length of the pipeline in the vertical section: 20 m

  Length of the pipeline in the horizontal section: 30 m

 Capsule

  Diameter of the seal plate: 0.79m

  Diameter of the capsule: 0.71 m

  Capsule mass: 29 kN

 Capsule velocity

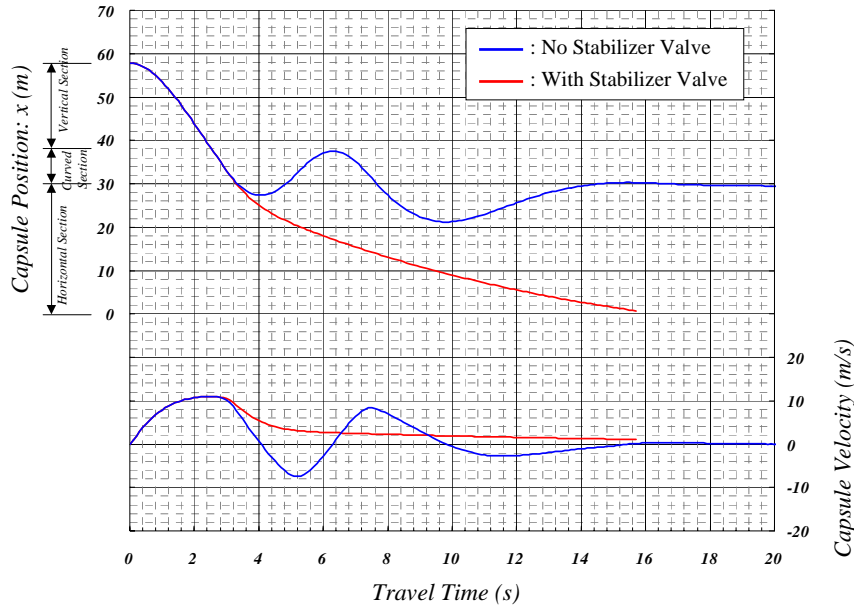 Capsule velocity in the vertical section (steady state): 11 m/s

Fig. 3. Capsule Motion in the Pneumatic Capsule Pipeline System

(3) Behavior of the capsule in a curved pipe section

According to the analysis results, when a capsule is passing through a curved pipe section, an unusual phenomenon that is not seen during liner transportation occurs. The position and velocity of the capsule, which are based on the system shown in Figure 2, change as shown with the blue line in Figure 3. The upper part of the vertical axis in Figure 3 represents the capsule position along the pipeline axis and the lower part of the axis represents the capsule velocity. Analysis results indicate that the capsule falls at a velocity of about 11 m/s, then rapidly decelerates and moves backward in the curved section, and then begins to fall again and accelerates rapidly. After repeating these processes, the capsule arrives and stops near at the interface between the curved section and the horizontal section. The reason why the falling capsule moves backward temporarily is thought to be that although the pipe axis component of the gravity acting on the capsule decreases as the capsule inclines in the curved section, the negative pressure in the vertical pipe does not decrease in a short period of time.

In order to reduce this peculiar phenomenon and improve the stability of capsule movement, a "stabilizer valve" is provided in the vertical pipe section as shown in Figure 2. The effect of this improvement is indicated by the changes over time in the velocity and position of the capsule, as shown with a red line in Figure 3.

(4) System efficiency

In order to study the system efficiency, power consumption to transport the capsule is estimated. Power consumption can be obtained from the following formula (Kosugi, et al., 1999). [4]

$$P_W = Qp_0 \frac{\kappa}{\kappa-1} \left\{ \left(\frac{P}{p_0} \right)^{\frac{\kappa-1}{\kappa}} - 1 \right\} \frac{1}{\eta}$$

(Eq. 6)

Where

P_W : power consumption

Q : inlet volume of blower

κ : ratio of specific heat

P : blower mean pressure

η : efficiency of blower

The power consumption can be evaluated in terms of the air leak coefficient ψ defined as follows:

$$\psi = \frac{1}{2} \left(\frac{A}{A_c} - 1 \right)$$

(Eq. 7)
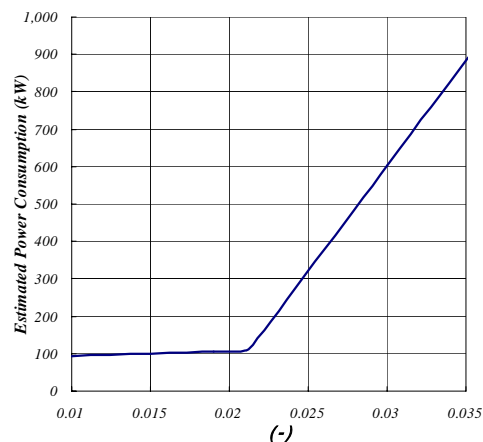

Fig. 4   Power consumption for the vertical PCP

Figure 4 shows that power consumption increases rapidly with increase in the leak coefficient ψ when ψ exceeds a value around 0.021. This indicates that the decrease in the leak coefficient is important to reduce power consumption and transportation efficiency can be evaluated in terms of the leak coefficient.

CONCLUSION

This study has attempted to show the applicability of the pneumatic capsule pipeline transportation system to geological disposal facilities. The following results have been obtained through analytical study.

• A seesaw movement, which is never seen in linear transportation, is observed when the capsule is transported in the curved pipe section. This peculiar behavior can be improved by applying the "stabilizer valve" as shown in Figure 2.

• Sealing performance is closely related to the amount of energy required for transportation. It is considered that transport efficiency can be enhanced by ascertaining the accurate relationship between the leak coefficient and power consumption.

For further study on the application of the pneumatic capsule pipeline transportation system to the high-level radioactive waste disposal facilities, it is necessary to conduct large scale empirical experiments of the pneumatic capsule pipeline transportation system and investigate the influence of the radiation of the wastes on the pneumatic capsule pipeline transportation system.

REFERENCES

1   K. Hane, K. Okutsu, N. Matsui and S. Kosugi, "Applicability of Pneumatic Capsule Pipeline System to Radioactive Waste Disposal Facility", WM02, 2002
2   S. Kosugi, "A Capsule Pipeline System for Limestone Transportation", Proc. of 7th International Symposium on Freight Pipelines (1992) pp.13-17
3   S. Kosugi, K. Saitou, N. Matsui and Y. Tomita, "Development of Vertical Pneumatic Capsule Pipeline System for Deep Underground", ISUFT 2000
4   S. Kosugi, "Effect of Traveling Resistance Factor on Pneumatic Capsule Pipeline System", Power Technology 104 (1999) pp.227-232