An experimental study on drilling of methane hydrate formation by high pressure water jet

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1. INTRODUCTION

Methane hydrate (MH) exists in permafrost in many parts of the world and in formations at hundreds of meter below sea floor of 1,000 m depth. It is expected as non-existing-type natural gas resources. However, it cannot be produced by conventional production method because MH is neither liquid nor gaseous but solid at both low temperature and high pressure. In this study, a methods of horizontal drilling technology with water jet (WJ) used together with depressurization method was proposed, and the drilling performance of WJ on artificial MH formation under high ambient pressure was investigated to evaluate the drilling performance of WJ on methane hydrate formation.

2. DEVELOPMENT OF AN EXPERIMENTAL SYSTEM

An experimental system for drilling a specimen of simulated MH formation under high ambient pressure where MH formation exists was developed. The ambient pressure was determined to be 20 MPa at maximum considering a pressure at hundreds of meter below sea floor of 1,000 m depth. The dimension of the specimen is ϕ 400 mm × L 700 mm.

Fig. 1 shows a cross-section of the experimental apparatus developed in this study. This apparatus consists of a large pressure vessel (A), a small pressure vessel (B), and two mounts for moving the pressure vessels (C, D) and rails (E). The dimension of the large pressure vessel to set the large specimen is ϕ 600 mm × L 800 mm and the inner dimension of the small pressure vessel to install a nozzle system with a feed mechanism is ϕ 210 mm × L 1,000 mm.

Fig. 2 shows details of the nozzle system. The nozzle system mainly consists of a motor for feeding the nozzle, a torque limiter, a pinion, a rack, and a linear motion guide. The motor is installed at the upper part of the small pressure vessel and rotates the pinion through a motor shaft, which moves the rack installed on the linear motion guide and the rack board to feed the nozzle system toward the specimen. High pressure water from a high pressure pump is supplied to a high pressure water rod, and the rod is connected to the nozzle system through a flexible high pressure hose with two swivel joints to ensure smooth movement of the nozzle system.

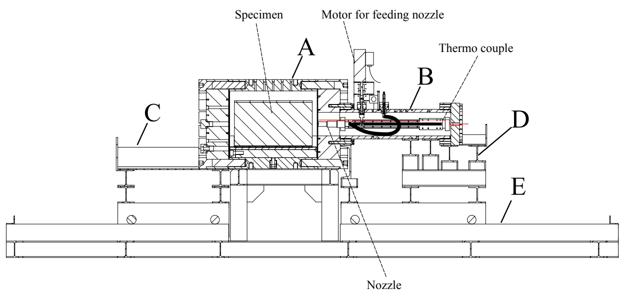

Fig. 1 Vertical cross section of experimental apparatus.

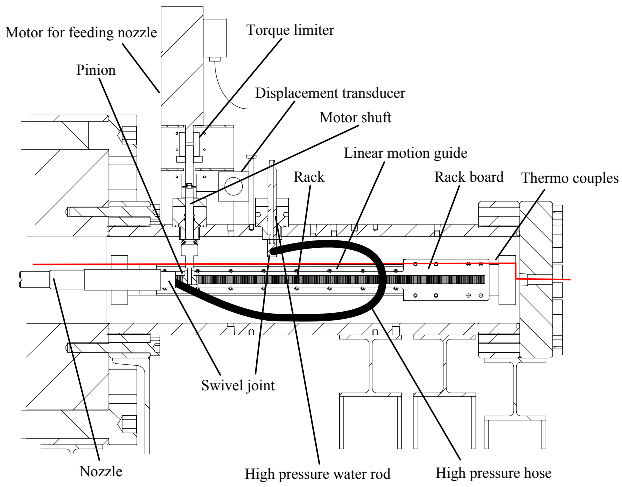

Fig. 2 Nozzle system.

3. SPECIMEN

Specimens offered by Tobishima Corporation were used for experiments. Although use of a natural rock was considered, it may be difficult to have a large specimen and furthermore its homogeneity is not secured. Therefore, artificial specimens (CB mortar) were used, for which CB (cement and bentonite) was used as a binding material of sands. Table 1 shows mechanical and physical properties of CB mortar compared with artificial and natural MH formations [1][2]. Artificial CB mortar closely simulates the MH formation for each parameter.

4. METHOD OF EXPERIMENTS

Testing conditions were determined as shown in Table 2 to clarify the effects of ambient pressure and feed rate on drilling performance and heating effect of WJ.

To evaluate the drilling performance, silicone was poured into a borehole to measure the depth, diameter and volume of the borehole from the mould of silicone.

To evaluate heating effect, the temperature of water was measured by thermocouples at several points. Temperature T_1 is that at 50 mm from the nozzle tip, and temperature Tu is that at switching valve, which exists upstream of water supply. In addition, the temperature of water in the water tank was measured before experiment, to include the effect caused by operation of high pressure water pump.

Table 2 Experimental conditions.

WJ nozzle diameter, d (mm)	1.0×2
Driving pressure, p (MPa)	85
Ambient pressure, p_a (MPa)	9 , 13
Specimen.	CB mortar
Nozzle feed, h (mm)	250
Nozzle feed rate, v (mm/s)	2.5 , 5 , 15 , 25 , 50

Table 1 Mechanical and physical properties of CB mortar compared with those of artificial and natural MH formations.

	Property	Unit	CB mortar No. 18	MH in situ	Artificial MH sediment
Mechanical properties	Uniaxial compressive strength	N/mm^2	1.191	-	0.74 ~ 1.5
	Cohesion C_{cd}	N/mm^2	0.422	-	0.5 ~ 5.4
	Angle of internal friction ϕ_{cd}	°	28.2	-	18 ~ 33
	Modulus of deformation E_{50}	N/mm^2	324	-	200 ~ 600
Physical properties	Coefficient of permeability	md	1.27E+01	A few to several tens	-
	Wet density	g/cm^3	1.885	1.2 ~ 2.0	1.730 ~ 1.904
	Dry density	g/cm^3	1.543	-	-
	Effective porosity	%	34.16	42.1 ~ 46.7	36.3 ~ 38.2
	P-wave velocity v_p	km/sec	2.10	1.5 ~ 2.0	-

5. RESULTS AND DISCUSSION

As an example, a photograph of a borehole after drilling experiment is shown in Fig. 3.

The effect of nozzle feed rate v on excavation rate V/t for two ambient pressures p_a is shown in Fig. 4. Red symbols indicate the results for p_a = 9 MPa, and black symbols indicate those for p_a = 13 MPa. Note that the experimental results for nozzle feed rate of 50 mm/s and ambient pressure of 13 MPa were excluded since effective drilling was not performed. As nozzle feed rate increases the excavation rate increases.

Fig. 5 shows the relations between nozzle feed rate v and average cross-sectional area V/h of borehole. The equivalent hole diameter d' which was calculated from the average cross-sectional area of borehole is also shown in the figure. It is seen that both V/h and d' decrease with an increase of nozzle feed rate v. Furthermore, the drilling performance under ambient pressure p_a of 13 MPa is slightly higher than that under p_a = 9 MPa.

Next, as an example, the temperature changes during the drilling experiment are shown in Fig. 6. The tips of a thermocouple were set at 50mm (T_1), 150mm (T_2), and 300mm (T_3) from the nozzle tip. The temperatures begin to increase right after water jetting started, and become constant at about 28 ℃ after the thermocouples for T_1 and T_2 are fed into the borehole.

Table 3 summarizes the maximum temperature increase after water jetting. An average of 16.5 ℃ was obtained as heating effects of WJ for ambient pressure of 9 MPa, and an average of

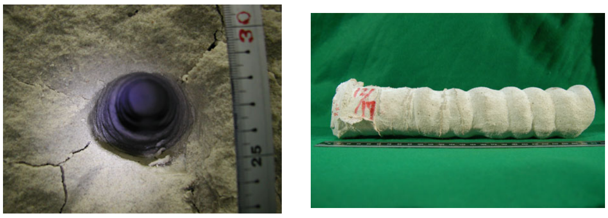

Fig. 3 An example of a borehole after drilling experiment (p_a = 9 MPa, v = 2.5 mm/s).

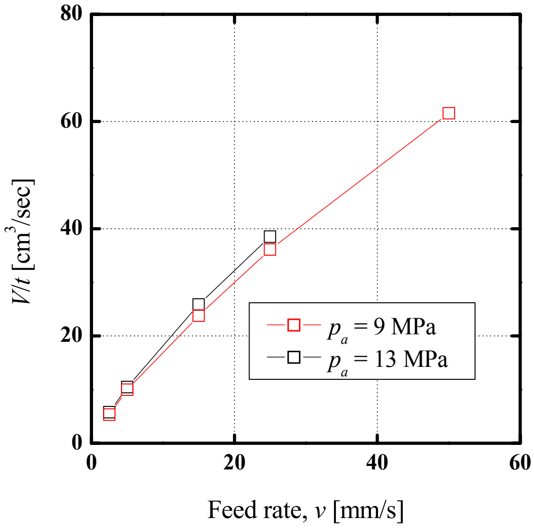

Fig. 4 Effect of feed rate v on excavation rate V/t.

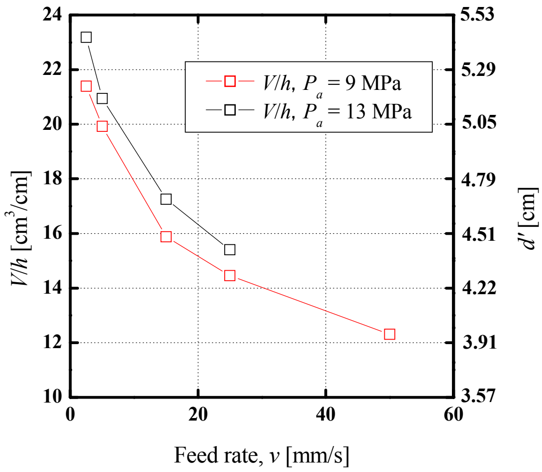

Fig. 5 Effect of feed rate v on V/h and equivalent hole diameter d'.

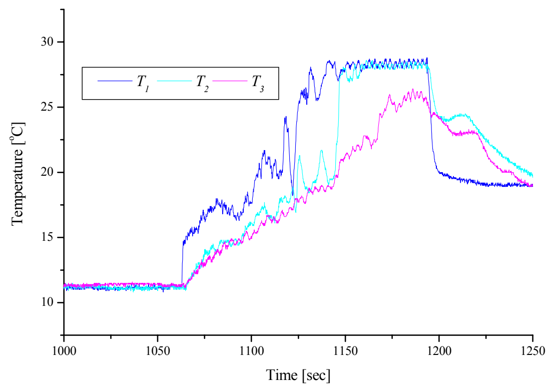

Fig. 6 Examples of temperature change (p_a = 9 MPa, v = 2.5 mm/s).

14.5 ℃ was obtained for ambient pressure of 13 MPa. Thus, it can be said that MH reaches an unstable state by the heating effect of water jetting when the temperature of MH was 10 ℃ and the depth is about 1200 m from the sea surface.

The ratio of the energy E_n necessary to dissociate MH contained in cuttings and the thermal energy E_w produced by WJ was calculated based on the experimental results. When E_w / E_n exceeds 1, all MH contained in cuttings can be dissociated. Fig. 7 shows the result, which shows all MH in cuttings can be dissociated since E_w / E_n exceeds 1 for all conditions.

Finally, I proposed a MH production method that used depressurization of MH formation together with WJ technology. This method is schematically shown in Fig. 8. Production rate may be low if only main production wells which are drilled by a conventional method are used, since the distance between the production wells cannot be small. Therefore, WJ technology is used to quickly make a lot of side drilling at low price. Thus, MH in a wide area can be rapidly dissociated because the pressure can be decreased more widely and the improvement of the natural gas production rate can be achieved.

6. CONCLUSIONS

Drilling experiments were performed with the artificial specimen whose properties were nearly the same as those of the MH formation to investigate both drilling performance and heating effect of WJ for the MH formations. The experiments were performed for two parameters of ambient pressure p_a and nozzle feed rate v. The experimental results show that the excavation rate increases and the average cross-sectional area of the drilling hole decreases as the nozzle feed rate increases. Moreover, it was shown that heating effect caused by WJ was sufficient for dissociation of MH in cuttings.

Table 3 Temperature data.

p_a [MPa]	v [mm/s]	A temperature rise by a WJ [℃]
9	2.5	16.8
9	5	17
9	15	16.5
9	25	15.7
9	50	16.4
		Ave = 16.5
13	5	15
13	15	13.8
13	25	14.6
		Ave = 14.5

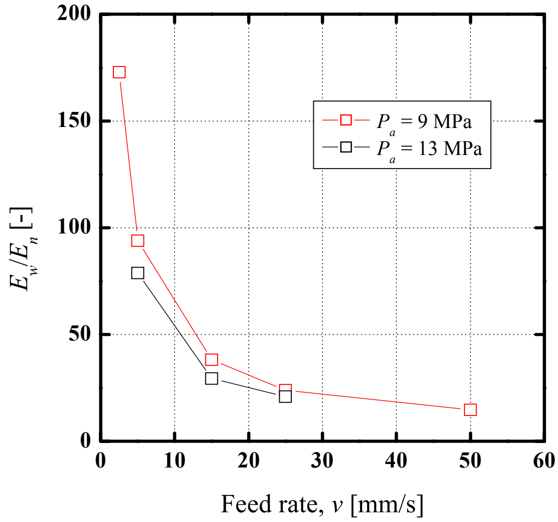

Fig. 7 Relation between feed rate v and E_w/E_n.

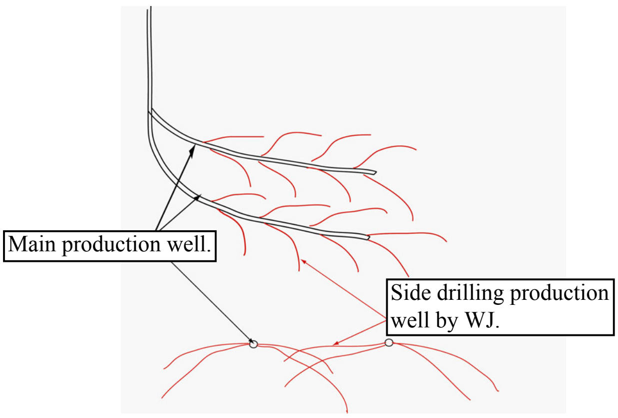

Fig. 8 An example of layout of side drilling with WJ from main production well.

REFERENCES

[1] Masui *et al.*, A dynamic property of methane hydrate simulation sediment, The Mining and Materials Processing Institute of Japan, Japan, 2005.

[2] Tobishima Corporation inside document.