DEVELOPMENT OF A METHOD FOR REMOVING GEOTHERMAL SCALE USING A LOW-SPEED SELF-ROTATING WATERJET NOZZLE SYSTEM UNDER HIGH AMBIENT PRESSURE

Kazuyuki SHIOYA

1. INTRODUCTION

In a geothermal power plant, two-phase gas/liquid fluids with high enthalpy are produced from production wells and used to generate electricity. Separated hot water is transported to injection wells through pipelines and injected underground. Since the temperature of the hot water decreases during transport, the minerals dissolved in the hot water are deposited as geothermal scale on the inner surfaces of pipelines and injection wells. This scale can cause many problems in the operation of a geothermal power plant, and, in particular, scale deposited on perforated casings can severely reduce injection performance. Therefore, the removal of well scale is needed, as well as methods for suppressing scale formation.

There are two main types of geothermal scale: calcium carbonate and amorphous silica. The former can be dissolved by treatment with acid, while the latter is difficult to remove chemically. Therefore, to remove silica scale effectively, a mechanical method is required. Drilling-out and milling are effective methods for removing various kinds of scale, almost regardless of their strength. However, to prevent casing damage during scale-removal, the outer diameter of a bit or a mill has to be sufficiently smaller than the inner diameter of the casing, and accordingly, thin scale is inevitably left on the inner wall of the casing after the operation. Figure 1 shows the schematic illustrations of the vertical cross-section of the slotted casings before the scale removal (Fig.1 (a)) and after the scale removal (Fig. 1 (b). The remaining scale may prevent water from being injected into the formation through the slots of casings. Therefore, methods for removing silica scale from the inner wall of a casing are needed.

The purpose of this study is to establish a method for removing geothermal silica scale using a low-speed self-rotating waterjet nozzle system. In this study, we firstly conducted a scale-removal experiment under high ambient pressures of up to 10 MPa to clarify the effects of the rotational speed of the nozzle system and the ambient pressure on scale removal. Then, the brake torque of the nozzle system was measured to clarify the effects of the ambient pressure and the water temperature on the

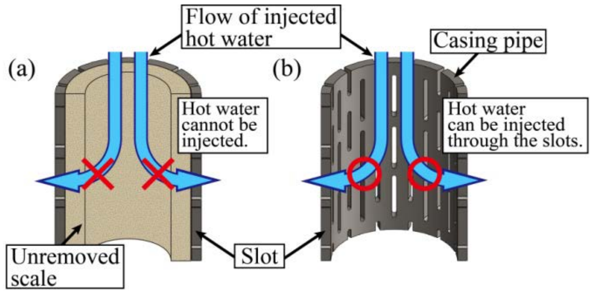

Fig. 1 Schematic illustrations of the vertical cross-section of the slotted casings ((a) before scale removal and (b) after scale removal).

rotational speed of the nozzle system. Finally, to estimate the rotational speed of the nozzle system in the well condition, a physical model for the brake torque of the nozzle system was proposed.

2. SCALE-REMOVAL EXPERIMENT

To clarify the effects of the rotational speed of the nozzle system and the ambient pressure on the scale removal performances, we conducted the scale-removal experiments for the simulated silica scale specimens, which were made of Kimachi sandstone. The Kimachi sandstone has mechanical properties similar to those of hard silica scale.

Figure 2 shows the low-speed self-rotating nozzle system (Tokyo ISUZU Motor, T60 type turbo nozzle) used in this study. This nozzle system mainly consists of a rotational head with two waterjet nozzles and a hydraulic pump unit for breaking the rotational speed. The axis of the rotational head acts as a drive shaft for the hydraulic pump unit, which is driven at the same time as when the nozzle system rotates.

Figure 3 shows the schematic illustration of the hydraulic pump and fluid path for the brake system. The hydraulic pump is an internal type gear pump. The suction and discharge ports of the hydraulic pump are connected to each other in a line so that fluid in the pump can be circulated. The pressure induced at the discharge port is increased by closing a needle valve, which is situated in the flow line between the suction and discharge ports. Accordingly, the torque required to rotate the nozzle system can be increased by closing the needle valve to decrease the rotational speed.

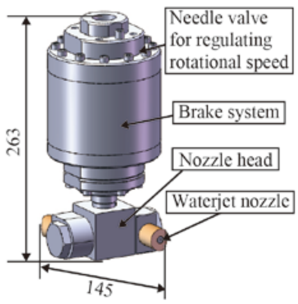

Fig. 2 Low-speed self-rotating nozzle system.

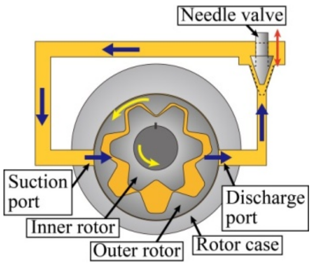

Fig. 3 Schematic illustration of the hydraulic pump and fluid path for the brake system.

Figure 4 shows a schematic diagram of the experimental system. This system mainly consists of a water tank, two high-pressure water pumps (Sugino Machine, JCM-100055E), a pressure vessel, a cyclone separator for removing cuttings from drained water, an ambient pressure control valve and a nozzle system set in the pressure vessel.

Figure 5 shows a vertical cross-section of the pressure vessel in the scale-removal experiment. The nozzle system was installed in the pressure vessel and fed upward during the experiments by aradial drilling machine, which was set above the pressure vessel. In addition, after the nozzle system moved to the central height of the specimen, the ambient pressure was changed. Thus, the experiment was conducted under two conditions for each specimen, in the upper and lower parts.

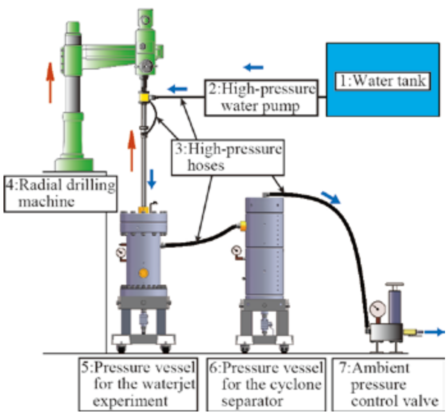

Fig. 4 Schematic illustration of the experimental system.

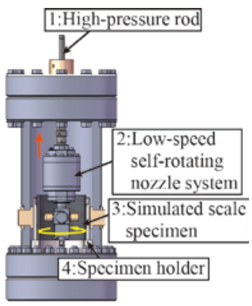

Fig. 5 Vertical cross-section of the pressure vessel in the scale-removal experiment.

Experimental conditions for the scale-removal experiment are described as follows: The driving pressure (p) was 59 MPa which was the maximum design pressure of the nozzle system. The ambient pressure (p_a) was changed from 4 to 10 MPa since the well depth of the injection wells are typically approximately 1,000 m. The rotational speed of the nozzle system (ω) was changed in three steps from 10 to 100 rpm to obtain different surface profiles after the scale-removal experiments. The feed rate of the nozzle system (v) was fixed at 200 mm/min considering the time required for the operation.

Figure 6 shows the scanned surface images of the specimens after the scale removal (p_a = 4, 10 MPa, ω = 10 ~ 15 rpm). In this figure, the white regions indicate the complete scale-removals, and the other colors indicate the unremoved scales. Figure 7 shows the relation between the ambient pressure and the removal rate of the simulated silica scale for three rotational speeds of the nozzle system. The removal rate decreases with the ambient pressure regardless of the rotational speed of the nozzle system. This is because that the jetting pressure, which is defined as the difference between the driving and ambient pressures, decreases with the ambient pressure, and as a result, the depth of cut decreases with the ambient pressure.

The removal rates obtained by the rotational speed of the nozzle system of 10 ~ 35 rpm were greater than those obtained by the rotational speed of 75 ~ 100 rpm. This result means that a greater performance of scale removal is achieved with a decrease in the rotational speed even with the same duration of cutting, since sufficient impingement time is provided for water to penetrate into rock for cutting. This suggests that a sufficiently low rotational speed is required to remove hard scale.

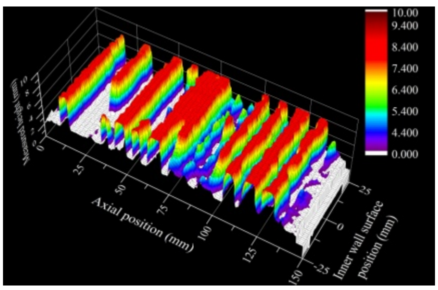

Fig. 6 Scanned surface images of the specimens after the scale removal (p_a = 4, 10 MPa, ω = 10 ~ 15 rpm).

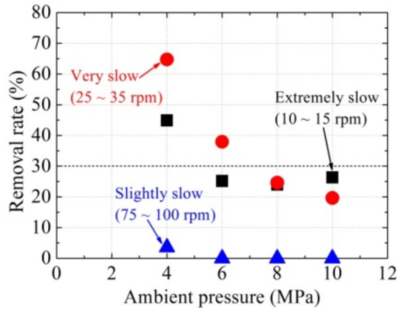

Fig. 7 Relation between the ambient pressure and the removal rate for three rotational speeds of the nozzle system.

3. MEASUREMENTS OF THE BRAKE TORQUE OF THE NOZZLE SYSTEM

The rotational speed of the nozzle system is determined by the torque balance among the rotational torque, the brake torque, and the frictional torque of the nozzle system. The rotational torque is given by the product of the reaction force of the waterjets and offsets of the waterjet nozzles. The brake torque is given by the brake system of the nozzle system. However, it is also affected by the environmental parameters of the ambient pressure and temperature. Therefore, to clarify the effects of the ambient pressure, water temperature and the rotational speed on the brake torque of the nozzle system, the brake torques under the high ambient pressure of up to 10 MPa with the water temperature of 20 ~ 60 ºC were measured.

Figure 8 shows the relation between the ambient pressure (p_a) and the brake torques of the nozzle system (T_b) for five rotational speeds of the nozzle system (ω) (s = 12.0 mm^2, T = 50 ºC). Regardless of the water temperature and the rotational speed of the nozzle system, the brake torque increases linearly with the ambient pressure. This is because the frictions due to the sliding parts increase with the ambient pressure.

Figure 9 shows the relation between the pressure at the discharge port of the brake system (p_d) and the brake torque of the nozzle system (T_b). The brake torque increases approximately linearly with the pressure at the discharge port. The reason of the scatter on the brake torque was considered to be the effects of the ambient pressure as described previously.

As a result of the experiment, we obtained a physical model for the brake torque of the nozzle system (Eq. 1).

$$T_b = 40.9\,p_d + 0.160\,p_a + 1.269. \qquad (1)$$

This model shows the relation among the brake torque (T_b) (N·m), the pressure at the discharge port of the pump for brake system (p_d) (MPa) and the ambient pressure (p_a) (MPa). The pressure at the discharge port was estimated using the kinematic viscosity of the fluid in the pump, the opening area of the needle valve, and the rotational speed of the nozzle system.

Figure 10 shows the comparison between the measured and the estimated brake torques. The brake torque of the nozzle system can be estimated by Eq. 1 with the error of approximately ±1 N·m.

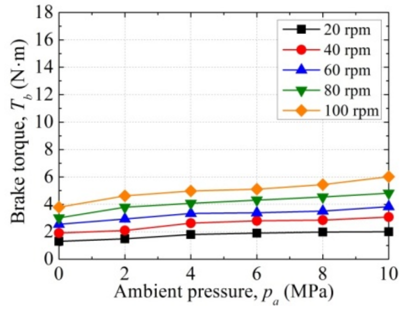

Fig. 8 Relation between the ambient pressure and the brake torque of the nozzle system for five rotational speeds of the nozzle system (s = 12.0 mm^2, T = 50 ºC).

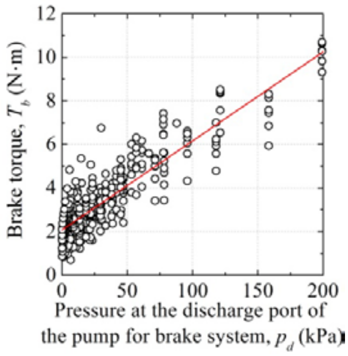

Fig. 9 Relation between the pressure at the discharge port of the pump for brake system and the brake torque of the nozzle system.

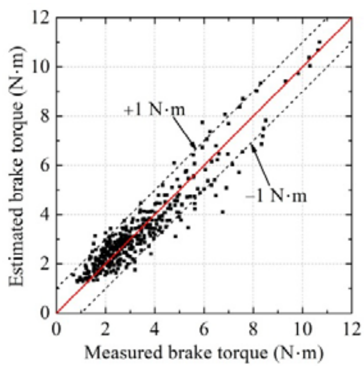

Fig. 10 Comparison between the measured and the estimated brake torque of the nozzle system.

4. ESTIMATION OF THE ROTATIONAL SPEED OF THE NOZZLE SYSTEM IN THE WELL CONDITION

To propose the effective operational parameters for the scale removal, we estimated the rotational speed of the nozzle system in the well condition using the model formula developed previous chapter. Figure 11 shows the relation between the depth and the rotational speed of the nozzle system for six kinds of oil (MC-18E (VG 32) and the ISO viscosity grade VG 68, 100, 150, 220 and 320). The maximum well depth was 1,000 m. The water temperatures at the surface and the well bottom were assumed as 20 and 60 ºC, respectively. The opening area of the needle valve was 12.0 mm^2.

The hatched region shows the suitable rotational speeds of the nozzle system which were obtained from the scale-removal experiments. The brake torque decreases with the depth since the kinetic viscosity of the oil in the brake system decreases with the temperature. As a result, the rotational speed of the nozzle system was estimated to be increased with the depth in the well condition. Accordingly, to obtain the appropriate rotational speed of the nozzle system, the brake torque should be changed by changing the opening area of the needle valve, and also by changing the hydraulic fluid with different kinetic viscosity. The high viscosity index oils are considered to be effective to obtain the moderate rotational speed of the nozzle system in the well condition.

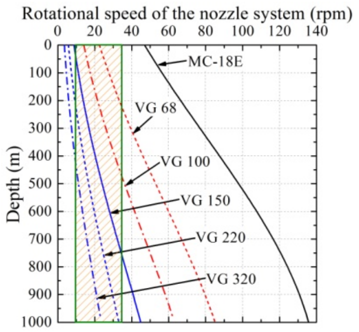

Fig. 11 Relation between the depth and the rotational speed of the nozzle system for six kinds of oil (s = 12.0 mm^2).

5. CONCLUSIONS

To establish a method for removing geothermal silica scale using a low-speed self-rotating waterjet nozzle system, the scale-removal experiments for the simulated silica scale specimens under the high ambient pressures of up to 10 MPa were conducted in this study. And also, the brake torque of the nozzle system was measured to clarify the effects of the ambient pressure and the water temperature on the rotational speed of the nozzle system. The main results obtained in this study are summarized as follows:

(1) The removal rates obtained by the rotational speed of the nozzle system of 10 ~ 35 rpm were greater than those obtained by the rotational speed of 75 ~ 100 rpm. This result means that a greater performance of scale removal is achieved with a decrease in the rotational speed.

(2) The brake torque of the nozzle system was measured, and the effects of the pressure at the discharge port of the pump for brake system and the ambient pressure were clarified. As a result of the experiment, we obtained the physical model for the brake torque of the nozzle system.

(3) To propose effective operational parameters for the scale removal, we estimated the rotational speed of the nozzle system in the well condition using the model of the brake torque. The rotational speed of the nozzle system was estimated to be increased with the depth in the well condition. Accordingly, to obtain the appropriate rotational speed of the nozzle system, the brake torque should be changed by changing the opening area of the needle valve, and also by changing the hydraulic fluid with different kinetic viscosity.

REFERENCES

[1] Japan Geothermal Energy Association (ed.), *Scaling Problem on Utilization for Geothermal Energy*, (1991).

[2] Frenier. W. W. and Ziauddin. M, *Formation, Removal, and Inhibition of Inorganic Scale in the Oilfield Environment*, SPE, Richardson, Texas, (2008).

[3] Matsuki, K., Okumura, K., Sugimoto, H., *Removal of Geothermal Scales with High Speed Water Jets*, Journal of the Geothermal Research Society of Japan, Vol. 9, No. 4, pp.255-270, (1987).

[4] Okumura. K, Iino. W, Matsuki. K. and Kume. S, *Fundamental Study on Removal of Geothermal Scales with High-Pressure Waterjets*, Proc. Int. Symp. on New Applications of Water Jet Tech., Ishinomaki, pp.191-196, (1999).

[5] Kizaki. A, Tanaka. H, Matsuki. K, Kon. T, Ogatsu. T and Igi. T, *Removal of geothermal scale through the use of self-rotating nozzle systems with pure waterjets*, Proc. 20th Int. Conf. on Water Jetting, Graz, pp.19-21, (2010).

ACKNOWLEDGMENT

This work was conducted as a cooperative research project between Tohoku University, Sendai, Japan and Kanto Natural Gas Development Co., Ltd., Mobara, Japan.