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DEVELOPMENT OF DRILLING TECHNOLOGY FOR DEEP-SEATED GEOTHERMAL RESOURCES

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ABSTRACT

New Energy and Industrial Technology Development Organization (NEDO) has been conducting a project designated "Development of Drilling and Production Technology for Deep-seated Geothermal Resources" since 1992. The constituents of the project can be divided into two categories: the development of drilling technology and that of production technology. This paper describes the progress of drilling technology development.

INTRODUCTION

By definition, deep-seated geothermal resources exist at depths of 3000-4000m at a formation temperature of approximately 350°C. Furthermore, it is considered that such deep-seated geothermal resources are evident below shallow geothermal reservoirs which have previously been exploited (Isaka et al., 1998).

In Japan, total geothermal power generation capacity is about 533,000kW, with nearly all of this electric generation conducted through the utilization of steam extracted from shallow geothermal reservoirs. Exploitation of deep-seated geothermal resources would contribute to a rapid increase in this capacity.

DEVELOPMENT OF DRILLING TECHNOLOGY FOR DEEP-SEATED GEOTHERMAL RESOURCES

In order to exploit deep-seated geothermal resources safely and efficiently, the heat resistance of conventional drilling equipment and materials must be improved, since the temperature of deep reservoirs exceeds the capability of such equipment and materials. NEDO is developing a bit, drilling mud and cement slurry, all resistant to high temperatures in the range of 350°C.

Development of highly durable heat-resistant bits

In geothermal well drilling beyond about 2000m, the average life of roller cone bits is only about 30 hours, while the formation temperature and the formation hardness generally increase with increasing depths. In the case of the exploitation of deep-seated geothermal resources, considerable trip time cannot be avoided as a result of short bit longevity. Thus, total drilling costs can be reduced by using bits which have longer lives and better ROP (rate of penetration).

In an investigation carried out in 1992 when this development commenced, it was proved that the heat-resistant temperature of the conventional roller cone bits is dependent on the heat resistance of the elastomer parts used. Moreover, it was found that the durability of the bits is dependent on the abrasion of insert chips used as cutters.

The bits developed in this project have the following features.

- A high heat-resistant bearing and a seal with a high durability system
- High abrasion-resistant cutters
- A self-compensating pressurized lubrication system
- A guage protection mechanism

The main specifications are as follows.

- Diameter: 8-1/2 in. (215.9 mm)
- IADC code: 537X
- WOB (weight on bit): 10-18 tons
- Rotational speed: 40-100 rpm
- Heat resistance: 350°C (survival, 6 hours)
  : 250°C (drilling, 30 hours)

We investigated improving the heat resistance by replacing the elastomer part with a metal component. The self-compensating pressurized lubrication system and the bearing seal system were further improved.

Table 1. Test Results from Hacchoubaru Geothermal Field

Bit	Depth (m)	Meter	Time (hr)	ROP (m/h)	WOB (ton)	RPM	Reason Pulled
350A	1548~1648	100	10:00				(Reaming)
	1648~1683	35	3:45	9.33	10~12	60~ 62	BHA
350B	1683~1757	73.8	19:50	3.72	8~12	53~ 60	PR & TQ
350C	1731~1757	26	4:00		0~ 4	60	(Reaming)
	1757~1795	38.2	9:05	4.21	10~12	60	

BHA: Bottomhole Assembly Change
PR: Decrease in ROP TQ: Increase in Torque

Preceding the development of a roller cone bit with a heat resistance of 350°C, a bit with a heat resistance of 300°C was developed. For development of this bit, we adopted some parts made of fluorocarbon rubber for the bearing seal system and adopted high-temperature fluorocarbon grease to lubricate the bearing. Similarly, we adopted a mechanical seal for the bearing seal system to prevent wear. In addition, we developed insert chips for heel rows, gauge rows and gauge protection. The parts developed were laboratory-tested under high-temperature conditions. Following the evaluation tests, we fabricated three bits composed of the fluorocarbon rubber bearing seal systems and the insert chips.

In 1996, we conducted performance tests on the three bits in the Kakkonda geothermal field of Japan. The tests revealed that the heel-row insert chips and the bearing seal systems have drawbacks with respect to toughness; therefore, the durability of these parts was improved in 1997. After the improvement, we fabricated eight new bits; three for the 300°C range and five for the 350°C range. The eight bits were tested in Sumikawa and Okuaizu geothermal fields in Japan, revealing that both types have longer bit lives and increased ROP as compared to the conventional bits used in these fields. In addition, it was proved that the heel-row chips have sufficient durability as none were broken. The self-compensating pressurized lubrication system mechanism with mechanical diaphragms in like manner operated satisfactorily. Moreover, no significant problems were observed with respect to the bearing seal systems, except for damage to one bearing seal.

In 1998, we analyzed these bits and some points to be rectified were elicited and improvements were designed. Based on these improvements, we fabricated three bits for the 350°C range.

The three bits were tested in the Hacchoubaru geothermal field of Japan. Table 1 shows the results of this field test.

In addition, no damage was found with respect to the insert chips for heel rows and, therefore, sufficient durability of the insert chips was verified. From the results of the tests, it was confirmed that the developed bits can be practically applied. As the performance of the roller cone bit reached the development target, development of the 350°C range bit was concluded in 1998.

Development of high-temperature drilling mud

The heat resistance of several types of conventional drilling mud is about 200-260°C. When the temperature of mud exceeds that range, the following problems occur.

- Decrease in fluidity due to gelation
- Decrease in ability to convey and suspend cuttings due to loss of viscosity
- Difficulty in formation of good mud cake on walls in a well
- Decrease in lubricity

The degradation of mud properties at high temperatures causes difficulties, including increase in drag force, well instability and drill pipe sticking—conditions resulting in longer down time, extended number of days of operation and higher drilling costs.

If we were to develop a new drilling mud which could withstand 350°C conditions, not only the troubles mentioned above could be prevented, but the amount of mud itself and the amount of mud to be disposed of could also be reduced.

The main specifications are as follows.

- Heat resistance: 350°C
- Viscosity: 10-20 cp
- Yield value: 2-15 $lbs/100ft^2$
- API water loss: less than 75 ml
- Mud cake: less than 2 mm
- Specific gravity: 1.03-1.20

The above specifications should be sustained even after exposure for 3 days at 350°C.

We first tested existing mud ingredients at 350°C, thereby selecting optimal ingredients for the new mud. Secondly, we prepared three types of new mud based on the test results; they were tested at 350°C for 3 days, including contaminators, such as saline, that exist in actual geothermal fluid. Finally, we selected one type as our new mud. The new mud is primarily composed of bentonite, synthetic mica, and polymer (dubbed 'BMP mud').

BMP mud(prototype for 300°C) was field tested in Kakkonda, Japan in 1996. According to computer simulations, the bottomhole static temperature was estimated to be 356°C while the bottomhole circulating temperature was approximately 203°C. Test conditions are shown below.

- Yield value: 2-3 $lbs/100ft^2$
- API water loss: less than 12-20 ml
- Mud cake: less than 1.0-1.6 mm
- Specific gravity: 1.02-1.03
- Rock (cuttings): Kakkonda granite

The BMP mud was successfully applied, though test results revealed the necessity to improve the long-term thermal stability of the BMP mud, which was subsequently carried out.

In 1997, we implemented the field test of the BMP mud (prototype for 350°C) in the Okuaizu geothermal field and confirmed that there were no problems such as gelation. Test conditions are shown below.

- Formation temperature: 250°C
- Yield value: 3-4 $lbs/100ft^2$
- API water loss: less than 12 ml
- Mud cake: less than 1.2 mm
- Specific gravity: 1.03-1.07
- Rock (cuttings): tuff

The ingredients of the drilling mud used for the test in Okuaizu are shown in Table 2.

Table 2. Drilling Mud Ingredients

Fresh Water	100 g
Viscosifier	7 g (Bentonite : Synthetic Mica 50:50)
Dispersant	2 g (G-500S and AMPS genus polymer)
Fluid Loss Additive	0.3 g (AMPS genus polymer)
Lubricant	0.3 g (Synthetic soap)
H_2S Scavenger	Zn Compound
pH Additive	NaOH

As the properties of the mud in the field test were confirmed satisfactory, we ended mud development in 1997.

<u>The development of high-temperature cement slurry</u>

Good cementing is essential for maintaining steam production from wells over a long period. In general, there are many weaker formations (or lost circulation zones) in geothermal wells that cause failures in the cementing operation. In such cases, cement may not permeate the annuli between the casing and the formation, causing collapse of the casing as a result of heat expansion.

Conventional ultra lightweight cement contains near weightless material such as micro balloons. The disadvantages of such cement are as follows.

- Low compressive strength at high temperatures
- Breakage of cement at high temperatures

With new ultra lightweight cement, which has high heat resistance and high compressive strength, we can:

- avoid lost circulation while cementing;
- prevent casing collapse; and
- reduce rework.

The new ultra lightweight cement is therefore capable of contributing extensively to reducing operational costs. It is essential that such cement exhibit the following performance.

- Low specific gravity slurry
- Prevention of dehydration of the slurry at high temperatures
- High compressive strength at high temperatures

The specifications of the new ultra lightweight cement are:

- Specific gravity of the slurry: 1.35
- Thickening time: greater than 3 hours
- Bottomhole circulation temp.: max. 230°C
- Compressive strength after 28 days: 70 kgf/cm^2
- Heat resistance: 350°C

In order to develop the ultra lightweight cement with high heat resistance and high compressive strength without adding lightweight material such as micro balloons, we increased the amount of water in the cement slurry. We first prepared three types of slurries with a specific gravity of 1.50. They satisfied all the above specifications except for specific gravity.

In 1996, we succeeded in decreasing the specific gravity from 1.50 to 1.35 by adopting API Class J cement (belite-based) as the base with very fine silica flour. However, the compressive strength of this slurry after 28 days at 350°C was less than 70 kgf/cm^2. Therefore, we developed a cement slurry by adding calcium carbonate flour to this slurry, thereby achieving the desired compressive strength of 70 kgf/cm^2 (Table 3).

Table 3. Cement Slurry Ingredients

Ingredient	(Fineness)	%
Base cement: class J cement (Belite or C_2S : 2CaO SiO_2)	(0.36 m^2/g)	50%
Silica Powder	(1.13 m^2/g)	27%
Silica Flour	(14.8 m^2/g)	12%
Very Fine Silica Flour	(151.9 m^2/g)	5%
Calcium Carbonate Flour (CaCO3)	(5.4 m^2/g)	4%
Other Additives (Fluid Loss Additive, Dispersant, Retardant)	Total	2%

We also measured and compared the bonding strength with the casing. The results indicated that the bonding strength of the cement slurry developed is higher than that conventionally employed.

In 1998, samples of the cement slurry with specific gravities of 1.35 and 1.50 were exposed for 2 months in hot geothermal fluid (260°C) at a depth of 1,950m at the Hijiori hot dry rock test site in Japan. As a result of compression tests on the samples after exposure, it was confirmed that the compressive strength of the well-hardened samples exceeded the target value. Because the performance of the new cement slurry had reached the intended specifications, development of cement slurry with a specific gravity of 1.35 was terminated in 1998.

On the other hand, demand has increased significantly for a cement slurry of low specific gravity (1.50) and high compressive strength on account of recent progress in the area of cementing technology. In 1999, NEDO initiated development of a new cement slurry with a specific gravity of 1.50, a high compressive strength (greater than 200kgf/cm^2), and high durability in acidic, corrosive geothermal water. At present, its development schedule is being established.

CONCLUSIONS

The development of the high heat-resistant bit, the drilling mud, and the cement slurry (specific gravity: 1.35) has been completed. It is contemplated that the exploitation of deep-seated geothermal resources will grow considerably in the near future. The equipment and materials developed in this project will contribute to reducing total drilling costs of deep geothermal wells, while being applicable to many aspects of geothermal development, including production technology development (Kondo et al., 1999).

REFERENCES

Isaka, S. et al. (1996) "Development of Drilling and Production Technology for Deep Geothermal Resources," *Geothermal Resources Council TRANSACTIONS*, **19**, 617-621.

Kondo, T. et al. (1999) "Development of Production Technology for Deep-seated Geothermal Resources," *Proceedings*, 24th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, January 1999, 94-101.