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DEVELOPMENT OF DRILLING TECHNOLOGY FOR DEEP-SEATED GEOTHERMAL RESOURCES

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SUMMARY Deep-seated geothermal resources located below already-developed shallow reservoirs, if exploited, have the potential to supply a considerable amount of energy. However, present drilling and production techniques are, time consuming and costly. This is mainly due to the high temperatures and pressures of deep-seated reservoirs. Our department is working to overcome these obstacles through the development of new drilling and production technologies. In particular, we are developing heat-resistant, drill bits and drilling muds, and a heat resistant cement slurry .

1. INTRODUCTION

Deep-seated geothermal resources are defined as having depths of 3000-4000m and temperatures of approximately 350 degrees C. In Japan, the total geothermal power generation capacity is about 530 MW. To increase this capacity, pressure exists to explore deep-seated geothermal resources. However, there are technological problems requiring development of safe and efficient drilling methods. Accordingly, we are developing a heat-resistant bit and drilling mud, and a heat resistant cement slurry.

2. A HEAT-RESISTANT DURABLE BIT

In geothermal drilling, the average bit life below 2,000m is only about 30 hours. A deep-seated geothennal reservoir is likely to be hot and hosted by hard formations. In addition, more trip time for bit will be required. The total drilling cost can be cut by using bits which have longer life and better ROP (Rate of Penetration).

From our research which began in 1992, we proved that the maximum temperature tolerated by a bit depends on the heat-resistance of the elastomer parts used. We also proved that the durability of the bit depends on the abrasion of insert chips which are used for the bit.

The main specifications are as follows:

Diameter : 8-1/2"(215.9mm)
IADC code : 537X
WOB : 10 - 18 t
Revolutions : 40 - 100 rpm
Maximum temperature
: 350 "C (survival, 6 hours)
: 250 "C (drilling, 30 hours)

We improved the heat-resistance by replacing the elastomer-made part with metal. This required the development of the pressure compensated lubrication system and the bearing seal system. However, for environments of 300°.C, we adopted parts made of a fluoride elastomer for use in the bearing seal system. We also adopted a fluoride grease which can be used at high temperature. Then, we adopted a mechanical seal for the bearing seal system to prevent wear. Moreover, we developed insert chips for heel-rows, gauge rows and gauge protections.

The new parts were evaluated and tested which led to the manufacture of three bits. In 1996, we field tested the prototype bits at Kakkonda. The bits showed defects on the bearing seals made of silicon carbide and the heel-row insert chips and so in 1997 we improved the insert chips and the toughness of the bearing seals.

Table 1 Field test result in Sumikawa region

Bit	Depth (m)	Meter- -age	Time (hr)	ROP (m/h)	WB (ton)	RPM	Reason pulled	T.B.G.
350 A	1604 - - 1712	108	28:37	3.77	12 -15	70 - 80	BHA	2 , 2 , -1/32
Other Bit	1712 - -1793	81	41:30	1.95	-	-	-	4 , 3 , -3/32
Other Bit	1793 - -1828	35	25:50	1.35	-	-	-	8 , 8 , -1/4
		114	4:30		2 - 3	50 - 60	(Reaming)	
	1828 - -1871	43	21:30	2.0	12 - 13	50	PR & TQ	4, 4,-1/4

BHA : Change Bottomhole Assembly PR : Penetration Rate
TQ : Torque

Eight new bits were manufactured; three were for use up to 300 °.C and five were for use up to 350°.C. These bits were field tested at Sumikawa and Okuaizu. The drilling records of Sumikawa are shown in Table 1.

The results proved that both types of bits had longer life and higher ROP(Rate of Penetration) than conventional bits which had previously been used. No heel-row chips were broken in these field tests, and there was only one damaged bearing seal, which had been used for a long, reaming tight hole operation. Otherwise, there was no trouble at all.

In 1998, we used the Sinter-HIP treatment to improve the toughness of insert. Three new bits were manufactured for 350 °C with these tougher insert chips and bearing seal systems, and they are now awaiting field tests.

3. DRILLING MUD

The maximum temperature that conventional drilling mud can withstand is about 300 °C.
Once the temperature exceeds 300 °C, drilling mud tend to lose:

1. Fluidity, due to gellation.
2. Ability to convey and suspend cuttings, due to loss of viscosity.
3. Ability to form good mud cake.
4. Lubricating capacity.

The decline of the quality of the mud properties at high temperature causes drag, instability of bore hole and pipe sticking. The result leads to an increase in operation days and greater drilling costs. With the new drilling mud which can withstand 350 °C temperatures, we can avoid these problems; in addition, the amount of mud chemicals and mud disposal can be reduced.

The main specifications are as follows:

Max. temperature : 350 "C
Viscosity : 10-20cp
Yield value : 2-15 lbs/100ft^2
API water loss : less than 75 ml
Mud cake : less than 2 mm
The specific gravity : 1.03-1.20

The above properties must be maintained for three days at 350° C.

First we tested conventional mud chemicals to 350 °.C, and then we mixed three types of new mud, tested them at 350 °C for three days, adding contaminants such as sodium which may exist in the geothermal fluid. Finally we made up BMP mud that includes bentonite, synthetic mica, and polymer to increase the viscosity.

The drilling mud was field tested at Kakkonda in 1996, and the properties of the BMP mud exceeded the performance specifications. According to the computer simulation, the estimated bottom hole static temperature was 356°.C and the bottom hole circulating temperature was about 203 °.C. Test conditions and measured values follow:

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

We then enhanced the mud viscosity and the lubricant to see if the BMP mud could maintain its properties at high temperatures. We conducted a field test using this enhanced version of mud in the Okuaizu region in 1997, under the test conditions shown below:

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**

There were no problems. In this field test the formations temperature was 100" C lower than the target temperature. In order to test the properties of the mud at 350° C, mud **from** the **Okuaizu** test hole was bought to the laboratory then heated at 350" C for 3 days, and the various properties were measured. The results show that the mud was free from any deterioration. Chemicals of the drilling mud field tested in Okuaizu region are shown in Table **2.**

Table **2** Chemicals of the drilling mud

Freshwater	100g	
Viscosifer	7 g	(Bentonite & Synthetic Mica)
Dispersant	2g	(Polymer : G-500S & AMPS)
Fluid Loss Additive	0.3g	(AMPS genus polymer)
Lubricant	0.3g	(Synthetic soap)
H_2S Scavenger	Zn Compound	
pH Additive	NaOH	

4. HEAT RESISTANT CEMENT SLURRY

Cementing is essential for maintaining steam production for a long period. Geothermal wells in general involve many weak formations (or lost circulation **zones),** fiom which cement slurry may leak and cause a cementing failure A cementing failure may occur where gaps between the bore hole and casing are not filled with cement; subsequent heating may lead to a break in the casing.

To prevent such failures, operators may use light-weight cement. However, conventional light-weight cements have the following problems:
- low compressive strength
- diminished strength at high temperature.

Therefore, a light-weight cement slurry with high strength at high temperature can bring about the following effects:
-prevention of cement leaks in fragile formations
- prevention of casing collapse
- reduce additional work.

These reduce the total operation cost drastically.

The three main factors are:.
- low specific gravity slurry
- dehydration of the slurry under the high temperature is prevented
-high compressive strength under high temperature.

The **main** specifications are:
-specific gravity of the slurry : 1.35
more than 3 hours thickening time :
maximum bottom hole circulation temperature of. 230 °.C
compressive strength after 24hrs of 35kgf/cm^2
withstand exposure to 350 °.C

We succeeded in lowering the specific gravity to 1.50 in 1995. We did not add light-weight material, instead we added more water to the cement slurry. Three types of slurries were made having a specific gravity of 1.50, and they satisfied the specifications. In 1996, we lowered the specific gravity fiom **1.50** to 1.35 by adopting **API** Class **J** cement (belite base) as the base cement with fine silica **flour.** However, the compressive strength of *this* slurry after 7 days at 350 °.C was less **than** 70kgf/cm. Therefore, we added calcium-base flour.

The chemicals contained in this 1.35 cement slurry are shown in Table 3.

Table 3 Chemicals of the cement slurry

	Fineness	%
Base cement : class J cement:	0.36m^2/g	46.0
(Belite or C_2S : $2CaO \bullet SiO_2$)		
Silica powder	13m^2/g	25.0
Silica Flour	14.8m^2/g	12.5
Finer Silica Flour	151.9m^2/g	4.6
Calcium Base Flour	5.4m^2/g	3.3
Another Additive		8.6
(Fluid Loss Additive, Dispersent, Retarder)		

The ratio of cement to water is 1 to 1.15. The measured bonding strength, between the cement and casing,, was higher than that of conventional geothexmal cements. In the future, we will carry out a two-month exposure test in a well with high temperature geothermal fluids. Here we will measure the compressive and bonding strength of the cement slurries and examine the microscopic structures by electron microscope, in order to investigate the effect of geothermal fluid.

5. CONCLUSIONS

The development of heat-resistant durable bits and drilling mud, and a heat-resistant cement slurry have been nearly completed. Although there are few companies with **an** earnest interest in developing deep-seated geothermal resources in Japan, these new developments can reduce the total **drilling** cost in hot and hard formations.

6. REFERENCES

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