Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

DEVELOPMENT OF DOWNHOLE PUMP FOR BINARY CYCLE POWER GENERATION USING GEOTHERMAL WATER

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Key Words : downhole pump, submersible motor-driven pump, geothermal water, binary cycle power plant.

ABSTRACT

NEDO (New Energy and Industrial Technology Development Organization) is currently engaged in the development of a binary cycle power plant, as part of MITI’s New Sunshine Project. A binary cycle power plant for geothermal power generation has two major advantages as compared to the conventional geothermal power generation. That is, a binary cycle power plant can utilize untapped geothermal energy such as great volume of geothermal hot water reinjected into underground in the conventional geothermal power plants. Although the conventional geothermal power generation is one of clean energy resources, a binary cycle power plant generates electricity under a closed system and therefore no carbon dioxide or other gases are emitted during operation. One main component of a binary cycle power plant under developing is a downhole pump (DHP). The feature of this pump is equipped with motors to drive a pump; therefore, deeper geothermal water resources could be utilized by using this DHP compared to other types of DHP. However, there exist many challenges have to be developed, since the pump must be operated at high temperature and pressure conditions in order to pump up hot water with medium and high temperature (from 150 to 200 ℃). In addition, it needs to withstand erosion in corrosive geothermal water environments. And, its motor with a slim and long-shaped configuration must have high output, because the pump is installed in a slim deep well and is used to pump up geothermal water at high discharge rate. To develop this submersible type DHP, we conducted factory and field tests using a test pump No.3 with an actual size between 1990 and 1992. In each test, the test pump No.3 operated successfully for about 1000 hours under hot water environment at the temperature of 200 ℃. Preceding to the development of a binary power plant, we will conduct a long-term hot water cycle test at Sugawara test site in Kyushu from 1999 to 2000. The main objects of this test are to evaluate the performance of the DHP developed etc.

1. INTRODUCTION

Even though both steam and hot water are produced from geothermal wells, conventional geothermal electric power generation in Japan utilizes only steam. The hot water produced from geothermal wells, although present in great volume, is not used for power generation and is eventually reinjected into the underground. With respect to hot water resources with medium and high temperature, a downhole pump must be needed to pump up the fluid to the surface economically. However, because current geothermal technology cannot widely utilize the hot water resources with medium and high temperature, these resources exploited are little.

From the reason mentioned above, we have conducted developing a downhole pump which could be widely applied to hot water resources with the medium and high temperature . It is estimated that large volume of the hot water resources exists in Japan. If we can develop a DHP with high performance, one of core devices in binary cycle power plant, a plenty volume of hot water could be supplied to the plant using a DHP. This would contribute increasing electric power generation capacity from geothermal energy. This paper describes conducts and results of DHP development (Koizumi et al., 1987; koizumi et al., 1994) .

2. DHP TYPE ADOPTED

Figure 1 illustrates the concept of a binary cycle power plant using a DHP. In binary cycle power generation, the heat energy in hot water pumped up from a production well by the DHP is transferred to working fluid that has a low boiling point. The boiling of the working fluid generates vapor, raising the fluid’s pressure high enough to drive a turbine for power generation.

At Sugawara test site for binary cycle power generation, the potential assessment of geothermal hot water resources had been carried out using wells drilled between 1978 and 1985. From the results of this assessment, it is estimated that installation depth of downhole pumps is from about 300 to 600 m in order to pump up hot water of below 200 ℃. Table 1, listed several types of DHP, describes the structure and characteristics of each type. The submersible water turbine and the submersible steam turbine in the table are eventually conceptual stage; therefore, there are large risks in developing actual machines that have enough performance for our targets. In the case of the lineshaft, the number of bearings used for each shaft increases with increasing installation depths. This results in the limitation of installation depth and/or the increase of maintenance cost. In addition, the lineshaft cannot install in inclined wells. On the other hand, the submersible motor does not have these disadvantages; therefore, we determined developing the submersible motor that could withstand in geothermal hot water environments of 200 ℃.

3. DEVELOPMENT

It is predicted that a number of technical challenges has to be solved to develop the submersible motor-driven pump which could be used in severe geothermal hot water environments. In order to reduce risks of developing the DHP, we first conducted basic technical research with respect to materials, submersible bearings, shaft seals, thrust bearings, stator coils, hydraulic closed loop cooling systems, motor tandem connection structures, lubricating/insulating oil, pressure equalizers, and cables etc. On the basis of the basic research, the development of the DHP was proceeded step by step using test pumps Nos.1 to 3. Table 2 lists the targets of each test pump. The test pump No.1 was fabricated to confirm the feasibility of developing a DHP with final targets. In the case of the test pump No.2, the flow rate was increased and heat-resistance was improved. The increasing of the flow rate was mainly performed in developing the test pump No.3 with the final targets. Figure 2 shows the process of the DHP development mentioned above. The demonstration pump No.3, which has almost the same specifications with the test pump No.3, was fabricated to apply to a long-term hot water cycle test at Sugawara test site. This test will be conducted from 1999 to 2000.

Figure 3 illustrates the configuration of the test pump No.3. Two motors with tandem structure are used to operate the pump. The diameter and length of the DHP are 310 mm and about 10.5m respectively. Table 3 shows the detail specifications of the test pumps Nos.1 to 3. Factory and/or field tests using the test pumps Nos.1 to 3 were conducted to evaluate the performance. Table 4 summarizes the test conditions and results. As can be seen in the table, the test pump No.3 operated successfully for about 1000 hours under hot water environment at the temperature of 200 ℃. Figure 4 shows the relation between the flow rate and the performance of the test pump No.3 in the factory tests. The performance (the pump shaft power, the pump efficiency and the total head) was obtained from the tests which were conducted before and after 1000 hours operation. From the figure, it is clear that the performance obtained from both tests exhibits almost the same values.

Through the factory and field tests, not only the performance and reliability of the developed DHP were confirmed, but also its practical usage as a pumping system was verified. In addition, operational technique and management technique, such as DHP installation and lifting methods, were established.

4. FEATURES OF TEST PUMP No.3

4.1 Materials

Following materials were selected for the test pump No.3 in order to withstand in aggressive geothermal hot water.

Impellers, Casings:	Duplex stainless steal
Pump shaft:	High nickel stainless steal

To improve wear resistance against small rock fragments contained in geothermal hot water, cobalt-base hard metal was coated on the surface of moving parts where the water contacts.

4.2 Thermal Resistance and Thermal Stability

All parts used for the DHP must have high thermal resistance, since both pump and motors are installed in geothermal water of 200 ℃. Based on the results of the basic research, the best insulator and filling oil were selected from many materials.

Temperature of various devices of the DHP become higher than that of hot water due to electrically and mechanically generated heat. Therefore, it is necessary to cool the devices, especially the motors, in order to prevent troubles due to heating. Suitable cooling system was developed to avoid local heating by means of technical analysis and research.

When the pump is operated, temperature change of hot water occurred surrounding the pump. Design techniques of the DHP were investigated for preventing troubles at such conditions by means of thermal expansion and stress analyses.

4.3 Rotational Stability

To improve the rotational durability of thirteen impellers equipped in the pump, a ceramic radial bearings lubricated by hot water were developed and installed between each stage of impellers.

A tandem mechanical seals were used at a pump thrust bearing to prevent invasion of geothermal water and lubricating oil was filled in the bearing for smooth rotation of a pump shaft. Also, a spiral groove bearing with self-aligning structure was developed to improve its vibration resistance.

The tandem structure at a motor section (200 kW×2) was employed, in order to maintain low vibration and high rotational stability in operation.

4.4 Insulation Reliability

To improve insulation reliability, a can structure was employed and thermally stable insulation oil was filled for fabricating the submersible motors.

Electric submergible power cables are covered with metal sheath to prevent water invasion into the cables.

4.5 Monitoring System

In order to control the DHP precisely, monitoring system for temperature, pressure and vibration of it operated in a well was developed.

To reduce maintenance cost and to improve durability of the DHP, monitoring and replacing system for lubricating oil was developed without lifting the DHP to the surface.

5. CONCLUSIONS

The development of the submergible motor-driven DHP is thought to be a key technology to increase capacity of binary cycle power generation. In the factory and field tests, the test pump No.3 operated successfully for about 1000 hours under hot water environment at the temperature of 200 ℃.

The next step is to confirm the performance of the DHP developed through using under actual operating conditions in the field. NEDO is now planning to conduct the hot water cycle test at Sugawara test site for a binary cycle plant from 1999 to 2000. Through the test, the long-term stability of the pump will be evaluated. Moreover, total technology needed to operate the geothermal water pump system will be established, including maintenance and operational techniques.

ACKNOWLEDGEMENT

We express our great appreciation to Prof. Hideo Ohashi of Chairman of Binary Cycle Plant Development Committee and to the members of the Committee, who give us appropriate advice for this project. We also greatly appreciate supports from the staff of New Sunshine Program Head Quarter of the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry.

REFERENCES

Koizumi, T., Yoshioka, J., and Takayasu, M. (1987). Development of Downhole Pump for Geothermal Water. *Current Technical Report of EBARA corporation.,* No.138, pp.29-38.

Koizumi, T., Takayasu M., Sumita, G. and Ueda. Y. (1994). Development of Downhole Pump for Geothermal Water(2nd Report). *Current Technical Report of EBARA corporation.,* No.163, pp.2-9.

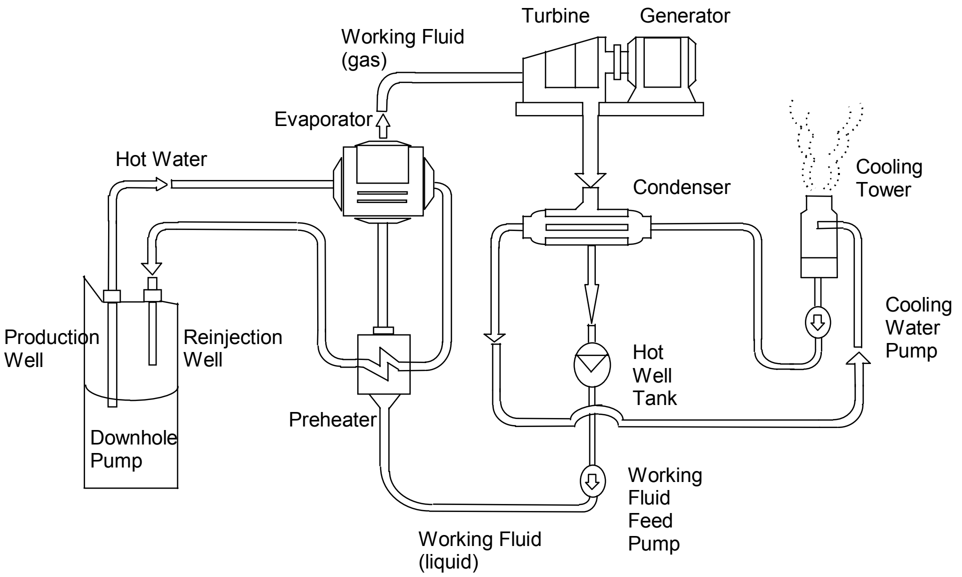

Figure 1. Concept of a binary cycle power plant

Table 1. Several types of DHP

Type	Structure	Characteristics
(1) Submersible motor	Pump/motor unit is lowered inside the well via the discharge pipe. Power is supplied to the motor using a long cable to drive the pump.	Power consumption is low and installation/lifting is easy. This DHP can set in inclined wells. Because the motor is submerged in geothermal water, it is needed to develop technology that ensures insulation reliability in high temperature environments.
(2) Lineshaft	Motor is set above ground and drives the pump (which is installed within the well) using a long rotating shaft.	Power consumption is low; however, This DHP has problems with respect to installation in a case of inclined wells. Also, because the drive shaft is long, the number of bearings increases.
(3) Submersible water turbine	Pump/submersible turbine unit is lowered inside the well via a high pressure pipe. High pressure water is fed to the water turbine to drive the pump.	Installation/lifting is more difficult than those with (1) but easier than those with (2). Also, power consumption greatly increases.
(4) Submersible steam turbine	Pump/steam turbine unit is lowered inside the well via a high pressure steam pipe and exhaust pipe. High pressure steam is fed to drive the pump.	It is difficult to predict the performance. Also, structure is complex, making it difficult to predict technical feasibility.

Table 2.　Targets for DHP development

Item	Targets of test pumps		
	Test Pump No.1	Test Pump No.2	Test Pump No.3
Nominal Well Diameter. (in.)	9-5/8	9-5/8	13-3/8
Well’s Actual Inside Diameter. (mm)	224	224	317
Hot Water Flow Rate (t/h)	50	100	200
Head (m)	300	340	380
Hot Water Temperature. (℃)	170	200	200
Installed Depth (m)	400	400	400
Motor Output (kW)	100	200	400

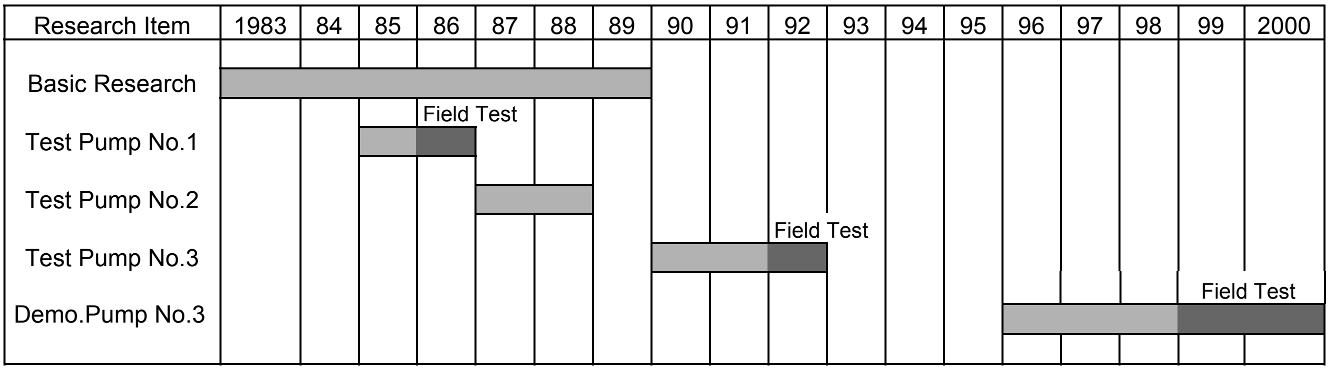

Figure 2.　Process of DHP development

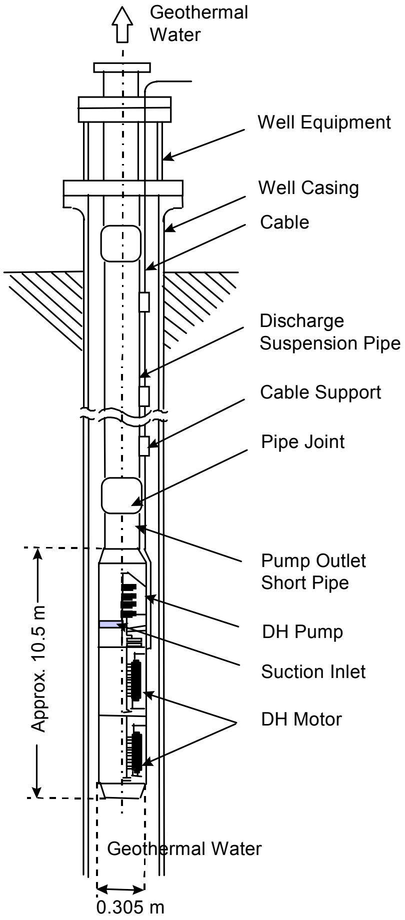

Figure 3. Configuration of test pump No.3

Table 3. Specifications of test pumps

Item	Test Pump No.1	Test Pump No.2	Test Pump No.3
Nominal Well Diameter (in.)	9-5/8	9-5/8	13-3/8
Pump Type	Vertical shaft, multistage mixed flow	Same as No.1	Same as No.1
Hot Water Temperature (℃)	170	200	200
Flow Rate (measured, t/h)	52.5	103	220
Head (m)	300	340	380
Pump Efficiency (measured, %)	62	66	74
Speed (rpm)	2,980	3,450	3,450
Impeller Stages	24	24	13
Motor Type	3-phase squirrel-cage	Same as No.1	Same as No.1
Rated Output (kW)	100	200	400
(Structure)	Single(100×1)	Tandem(100×2)	Tandem(200×2)
Frequency (Hz)	50	60	60
Poles	2	2	2
Voltage (V)	1,500	1,500	1,500
Rated Current (measured, A)	54	106	247
Max. Outside Diameter (mm)	210	210	305
Unit Length (m)	8	11	10.5
Unit Weight (kg)	1,600	2,000	3,500

Table 4. Test conditions of pumps

	Test Pump No.1	Test Pump No.2	Test Pump No.3
Factory Test			
Year Conducted	1986	1987	1991
Hot Water Temperature (℃)	170	200	200
Operating Time (h)	2010	333	1028
Result	Good	Good	Good
Field Test			
Year Conducted	1986	—	1992
Hot Water Temperature (℃)	170	—	200
Operating Time (h)	1080	—	1028.5
Result	Good	—	Good

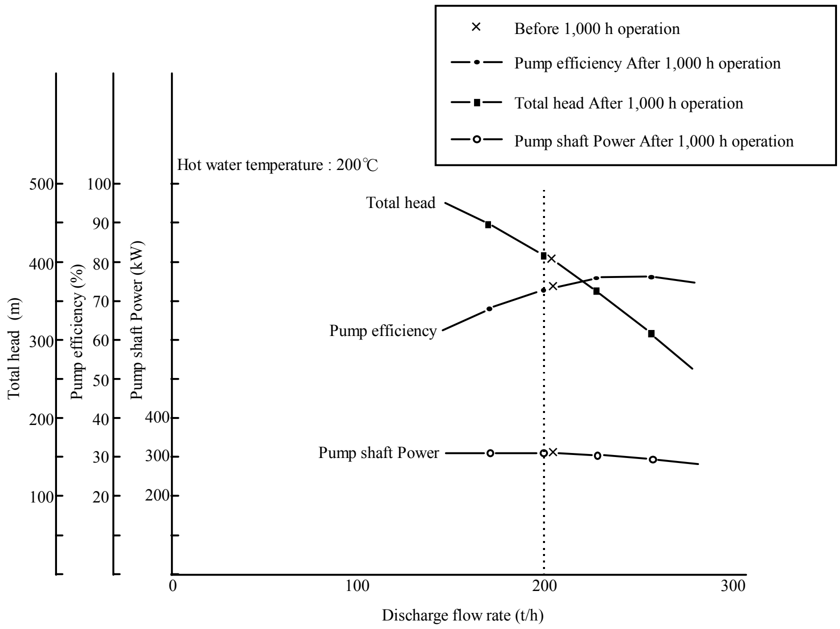

Figure 4. Performance of test pump No.3