DEVELOPMENT OF A DOWN-HOLE PUMP FOR BINARY CYCLE POWER GENERATION USING GEOTHERMAL WATER

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SUMMARY - NEDO (New Energy and Industrial Technology Development Organisation) is currently engaged in the development of a binary cycle power plant as part of MITI's New Sunshine Project. One main components under development is a a down-hole pump (DHP). This pump has a submersible motor that needs to withstand hot temperatures (150-200 "C) and corrosive effects of deep geothermal fluids. The motor also have a slim design to fit into the well and a high output. We have tested a model (no 3) for over 1000 hours at 200 °C. In the next phase, we will undertake longer tests at the Sugawara test site in Kyushu.

1.0 INTRODUCTION

Conventional geothermal power stations in Japan utilise steam separated at the well-head from steam-water discharge. The hot water produced from a geothermal well is voluminous but is not used for power generation, and instead it is reinjected underground. Binary cycle plants provide a means of using more of the heat energy contained in the deep geothermal liquid. In medium temperature reservoirs, a down hole pump (DHP) can be used to pump thermal water to the surface economically.

We are developing a DHP that can be used in medium to high temperature reservoirs that could be used for binary power plants. In this paper we briefly describe the design and results of the DHP development (Koizumi et al., 1987, Koizumi et al., 1994).

2.0 DOWN HOLE PUMP

Figure 1 illustrates the layout of the binary power plant using a DHP. The heat energy in the hot water, which is pumped to the surface from a production well, is transferred to a working fluid that has a low boiling point. The boiling point of this working fluid generates vapour which can be used to drive a turbine for power generation.

At the Sugawara test site, a binary cycle power station was installed to assess generation capacity using wells drilled between 1978 and 1985. From the results, down hole pumps were installed between 300 and 600 m depth in order to pump hot water (<200° C) to the surface.

Table 1 lists several types of DHP and their features. The submersible water turbine and the submersible steam turbine are still in the conceptual stage; there are large risks in developing pumps that meet our specifications. In the case of the line shaft DHP, the number of bearings used for each shaft increases with installation depth. This limits the installation depth and increases the maintenance cost. In addition, the line-shaft DHP cannot be installed in inclined wells. The submersible DHP overcomes these problems, therefore we planned to develop this type of pump that could withstand temperatures up to 200" C.

3.0 DEVELOPMENT

A number of technical challenges have to solved in the development of the submersible motor driven pump which can be used in severe geothermal hot water environments. In order to reduce the risks, we 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 equalisers, and cables. With this as a basis, DHP development proceeded step by step in the construction of models No. 1 through 3.

Table 2 lists targeted design features of each test pump. No. 1 was fabricated to confm the feasibility of DHP development. For No. 2, the flow rate was increased and the heat resistance improved. In No 3., the flow rate was increased further.

Figure 2 shows the schedule of DHP development. The demonstration pump No. 3 has almost the same specifications as test pump No, 3; the demonstration pump was fabricated for long-term testing at the Sugawara test site, which will be conducted in 1999-2000.

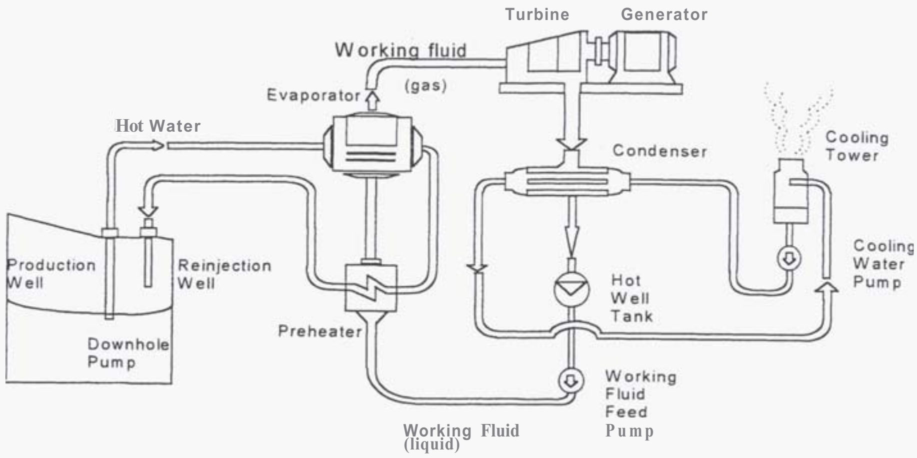

Figure 1. Concept of a binary cycle power plant

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) Line-shaft	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.

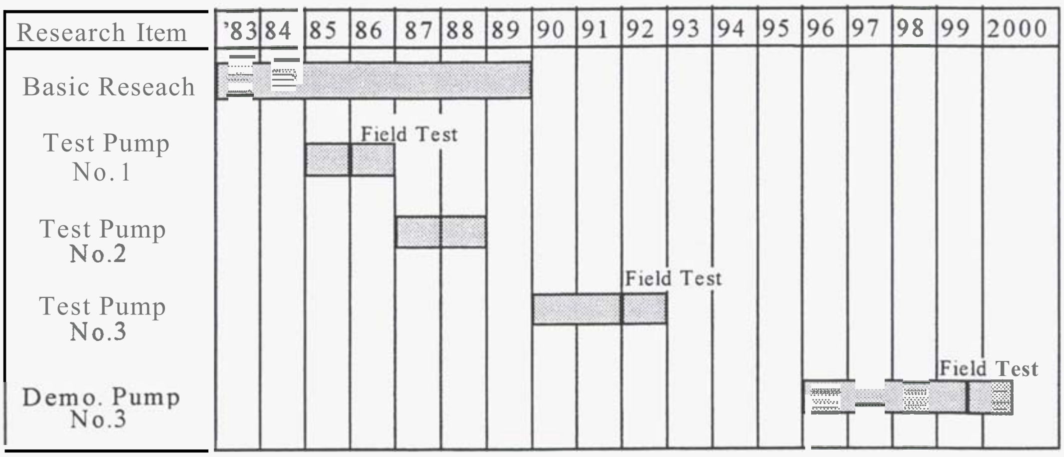

Figure 2. Process of DHP **development**

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
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

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	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) (Structure)	100 Single(100 x 1)	200 Tandem (100×2)	400 Tandem (200×2)
Frequency (Hz)	50	60	60
Poles	2	2	2
Voltage (V)	1,500	1,500	1,500
Rated Current measured, A			
Max. Outside Diameter (mm)			
Unit Length (m)			10.5
Unit Weight (kg)	1,600	2,000	3,500

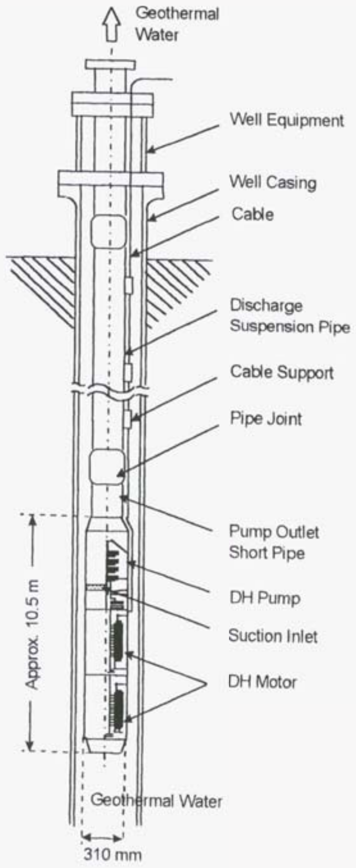

Figure 3. Configurat ... pump No.3

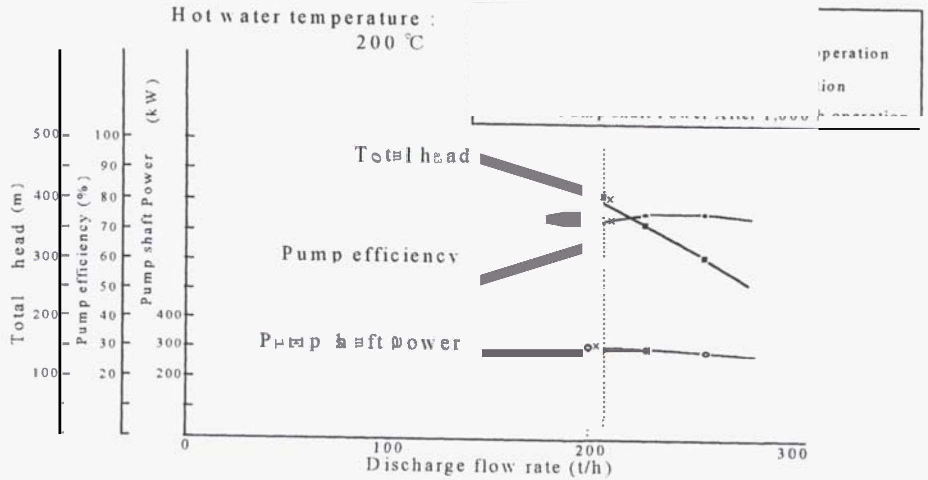

Figure 4. Performance of test pump No.3

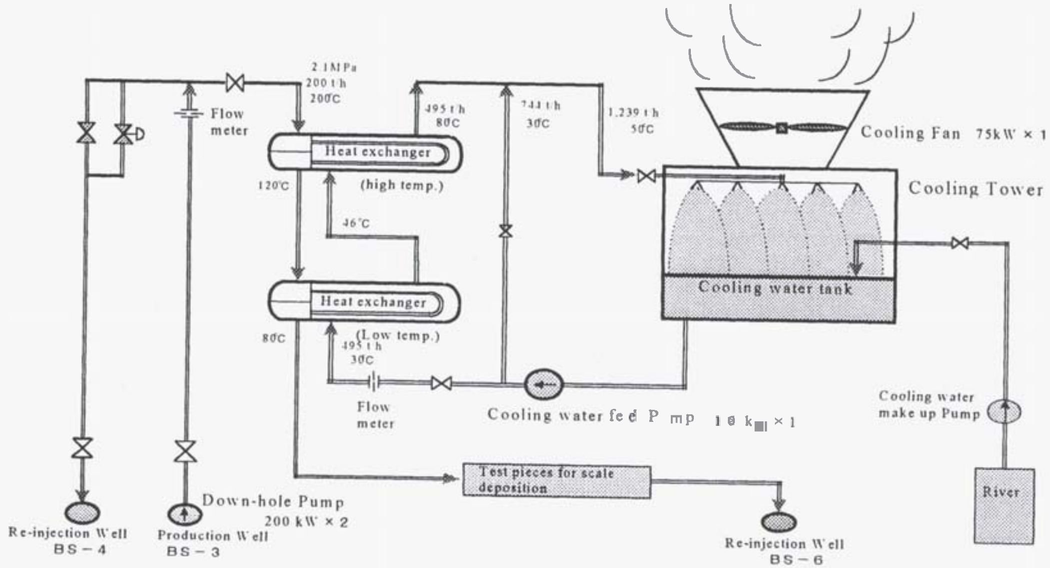

Figure 5. Flow diagram of Field test at Sugawara Site

Figure 3 illustrates the configuration of test pump No. 3. Two motors with tandem connections are used to operate the pump. The length of the DHP is 10.5 m, with a diameter of 310 mm.

Table 3 shows the specifications of test pumps Nos 1 through 3. Factory and field tests were conducted to evaluate their performance. Table 4 summarises test conditions and results. As can be seen, test pump No. 3 operated successfully for about 1000 hours in a hot water environment at 200° C.

Figure 4 shows the relationship between the flow rate and the performance of test pump No. 3 in the factory tests. The performance (pump shaft power, efficiency and total head) was obtained from the tests conducted before and after completing 1000 hours of operation. It is clear that performance is the same before and after this period of operation. The factory and field tests confirmed the performance and reliability of the DHP and demonstrated its practical useage. In addition, the techniques of operation and management (e.g. DHP installation and lifting methods) were established.

4.0 FEATURES OF THE TEST PUMP No. 3

4.1 Materials

The following materials were selected for test pump No.3 in order to test its tolerance in aggressive geothermal hot water.

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

To improve resistance against small rock fragments, a cobalt-base hard metal was coated on the surface of the moving parts where the thermal water comes into contact.

4.2 Thermal Resistance and Stability

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

Since the temperature of various parts of the DHP become higher than that of the hot water due to electrically and mechanically generated heat, a suitable cooling system was developed to avoid local heating. DHP designs were investigated to preventing trouble with thermal expansion and stress.

4.3 Rotational Stability

To improve the rotational durability of thirteen impellers in the pump, ceramic radial bearings lubricated by hot water were developed and installed between each stage of the impellers. Tandem mechanical seals were used for pump thrust bearings to prevent invasion of geothermal water; the bearing was filled with lubricating oil so the pump shaft would rotate smoothly. Also, a spiral groove bearing with self-aligning structure was installed. The tandem structure at a motor section (200 kW2) was employed, in order to maintain low vibration and high rotational stability during operation.

4.4 Insulation Reliability

To improve insulation reliability, a can structure was employed and thermally stable insulation oil was used in the submersible motors. Electric submersible power cables are covered with a metal sheath to prevent water invasion.

4.5 Monitoring System

In order to control the DHP, a system for monitoring temperature, pressure and vibration during operation in the well was developed. To reduce maintenance costs and to improve durability of the DHP, a monitoring and replacement system for lubricating oil was developed without lifting the DHP to the surface.

5.0 FIELD TEST

From 1999 to 2000, we will conduct a production and re-injection test for 6 months at the Sugawara test site in Kyushu Japan, using geothermal wells and the down-hole pump No.3 (Demo type). Figure 5. shows the flow diagram of this test. The objectives are:

a. evaluation of the geothermal reservoir at the Sugawara area
b. evaluation of the scale deposition on equipment and in wells.
c. evaluation of the durability and reliability of the down-hole pump

6.0 CONCLUSIONS

The development of the submersible motor-driven DHP is considered a key technology for increasing the capacity of binary cycle power generation. In the factory and field tests, the test pump No.3 operated successfully for about 1000 hours under a hot water environment at the temperature of 200° C. The next step is to confirm the performance of the DHP developed using actual operating conditions in the field. NEDO is now planning to conduct a hot water cycle test at the Sugawara site from 1999 to 2000. Using this test, the long-term stability of the pump will be evaluated. Moreover, the total technology needed to operate the geothermal water pump system will be established, including maintenance and operational techniques.

ACKNOWLEDGEMENTS

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