

DEVELOPMENT OF DOWNHOLE PUMP FOR BINARY CYCLE POWER GENERATION

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ABSTRACT

NEDO launched a project on the development of binary cycle power generation in 1980. The development of a down-hole pump is one of the major goals of the project as well as the evaluation of the geothermal reservoir for the medium to high temperature water (from 150 to 200°C). The submersible motor-driven down-hole pump could be used in severe geothermal environments.

The development of the pump has progressed step by step using test pumps No. 1 to No. 3. A long-term circulation test was performed to confirm the stability of the demonstration pump and to evaluate the reservoir from 1999 to 2001. This paper briefly describes the down-hole pump performance and results of the operation test.

1.0 INTRODUCTION

NEDO was established in order to manage the development of renewable energies after two steep rises in crude oil prices. After rises of the oil price NEDO launched several projects to promote geothermal energy and to make better use of the geothermal resources. The development of a binary cycle power plant is one of the long-term projects in NEDO.

The binary cycle power plant (Fig. 1) can utilize untapped geothermal fluid such as reinjection hot water separated at the wellhead from steam-water discharge at the conventional geothermal power plant. The binary cycle plants have been constructed all over the world as they can generate electricity with lower enthalpy geothermal fluid than the conventional steam generation. NEDO estimated that the potential of the resources for the binary cycle power plants, is about 1,500MW in Japan. Although conventional geothermal power generation is one of the clean energy resources, a binary cycle power plant generates electricity using a

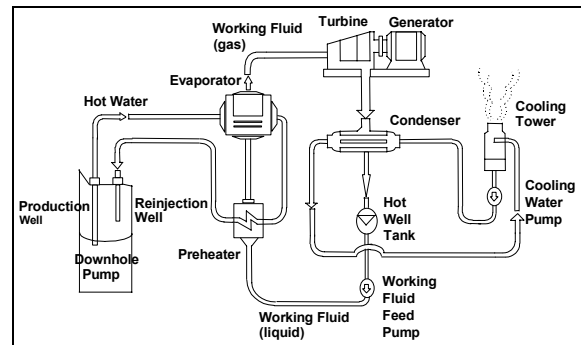


Figure 1. Concept of a binary cycle power plant.

closed system and therefore no carbon dioxide or other gases are emitted during operation. The generating system is suitable to help prevent environmental damage.

The binary cycle power generation utilizes a great amount of hot water and an electrical pump is necessary to pump the hot water to the surface. One main component of a binary cycle power plant under development is, therefore, a down-hole pump (DHP). Another objective is a long-term circulation field test because we have no experience on the reinjection of low temperature water into subsurface reservoir. The long-term circulation test was performed to evaluate the environmental effects of the water injection and reinjection.

2.0 DHP TYPES

Several types of DHP are listed in Table 1 with the structure and characteristics of each type. The submersible water turbine and the submersible steam turbine in the table are conceptual; 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

Table 1. Several types of DHP.

(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.

Research Item	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01
Test Pump No.1				Field Test															
Test Pump No.2																			
Test Pump No.3																			
Demo Pump																			

Figure 2. Process of DHP development.

maintenance cost. In addition, the lineshaft cannot be installed in inclined wells. On the other hand, the submersible motor does not have these disadvantages; therefore, we focused our efforts on designing a submersible motor that could withstand the geothermal hot water environments of 200°C.

3.0 DHP IN THE NEDO'S PROJECT

On the basis of basic technical research such as materials, submersible bearings, motor tandem connection structures and so on, the

development of the DHP was conducted step by step. Figure 2 shows the process of the DHP development. The test pump No. 1 was made in 1985 and the field test of the pump was carried out in the next year. The test pump No. 2 and No. 3 were constructed in 1987 and in 1991, respectively. Table 2 shows the detailed specifications of the test pumps Nos.1 to 3. 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

Table 2. Test pump rated specifications.

Item	Test Pump No. 1	Test Pump No. 2	Test Pump No. 3
Nom. Well Dia. (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 Temp. (C)	170	200	200
Hot-Water Flow (measured, t/h)	52.5	103	220
Head (m)	300	340	380
Pump Efficiency (measured, %)	62	66	74
Speed (rpm)	2980	3450	3450
Impeller Stages	24	24	13
Motor Type	3-phase squirrel-cage	Same as No.1	Same as No.1
Rated Output (kW) (Tandem Structure)	100	200 (100×2)	400 (200×2)
Frequency (Hz)	50	60	60
Poles	2	2	2
Voltage (V)	1500	1500	1500
Rated Current (measured, A)	54	106	247
Max. Outside Diam.(mm)	210	210	305
Unit Length (m)	8	11	10.5
Unit Weight (kgf)	1600	2000	3500

No. 3 with the final targets. 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.

3.1 Materials

Following materials were selected for DHP operated in aggressive hot geothermal water:

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

Wearing parts were treated with hard facing based on cobalt.

3.2 Thermal Resistance and Thermal Stability

The best insulator and the best filling oil were selected from basic technical research conducted on dozens of items. By means of technical analysis and research, suitable cooling system was developed to avoid local heating.

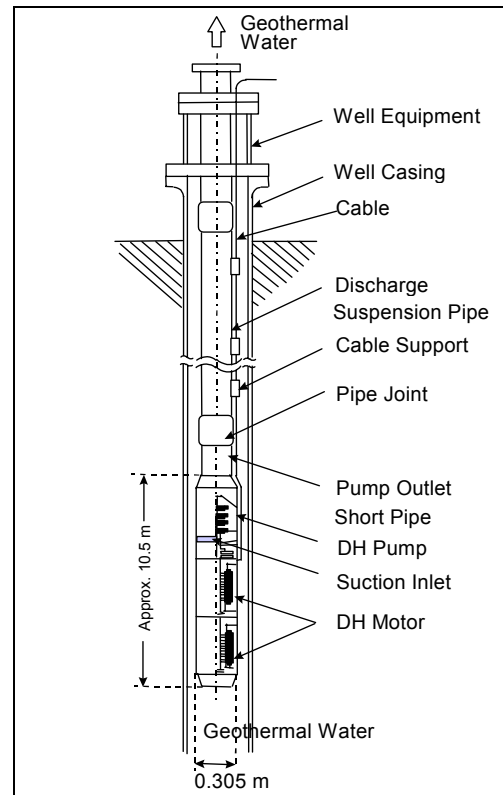


Figure 3. Configuration of test pump No. 3.

Suitable constructions were designed by mean of thermal expansion and thermal stress analysis.

3.3 Rotation Stability

Ceramic radial bearings lubricated by pumping liquid, were developed and installed between each stage. A pump thrust bearing in a chamber separated from geothermal water by a tandem mechanical seal and filled with lubricating oil, is a spiral groove bearing with self-aligning device, permitting stable operation for heavy duty. A tandem motor (200kW×2) was developed, in order to keep low vibration and high stability in operation.

3.4 Insulation Reliability

A submersible motor is of oil-sealed canned construction. In order to withstand use in high temperature water, superior heat resistant oil sealed insulation is employed together with waterproof insulation. Electric submersible power cables are enclosed by a welded metal sheath to prevent water intrusion.

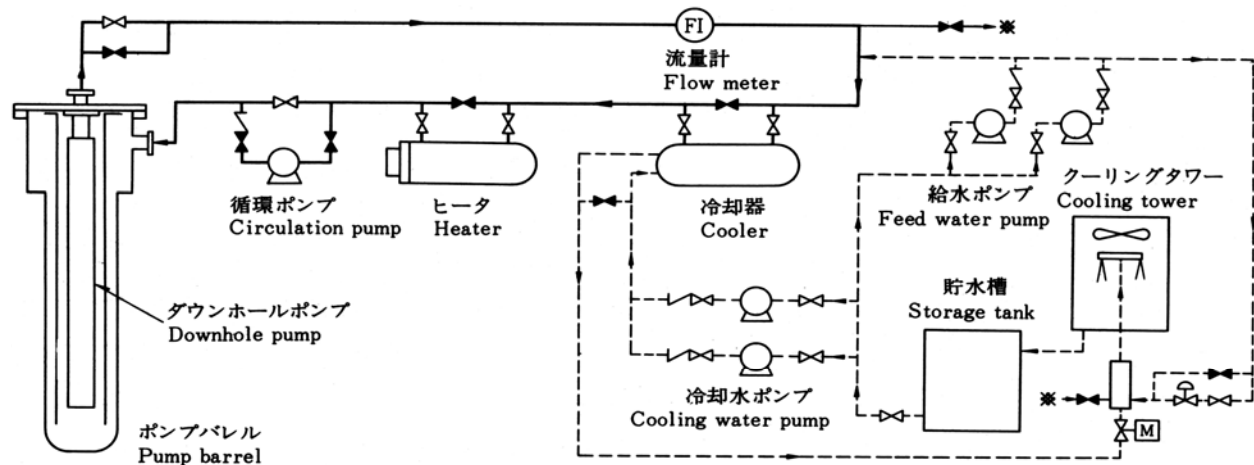


Figure 4. Flow diagram of factory test.

3.5 Monitoring System for Long-Term Stability

Monitoring system for temperature, pressure and vibration of a downhole pump operated underground, was developed. Lubricating oil monitoring and replacing system was adapted.

4.0 FACTORY AND FIELD TESTS OF THE TEST PUMP

Factory and/or field tests using the test pumps Nos.1 to 3 were conducted to evaluate the performance (Table 3). 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 and management technique, such as DHP installation and lifting methods, were established.

Table 3. Pump test conditions.

	Test Pump No.1	Test Pump No.2	Test Pump No.3
Factory Test			
Year Conducted	1986	1987	1991
Hot-Water Temp. (C)	170	200	200
Operating Time (hr)	2010	333	1028
Appraisal	Good	Good	Good
Field Test			
Year Conducted	1986	—	1992
Hot-Water Temp. (C)	170	—	200
Operating Time (hr)	1080	—	1028.5
Appraisal	Good	—	Good

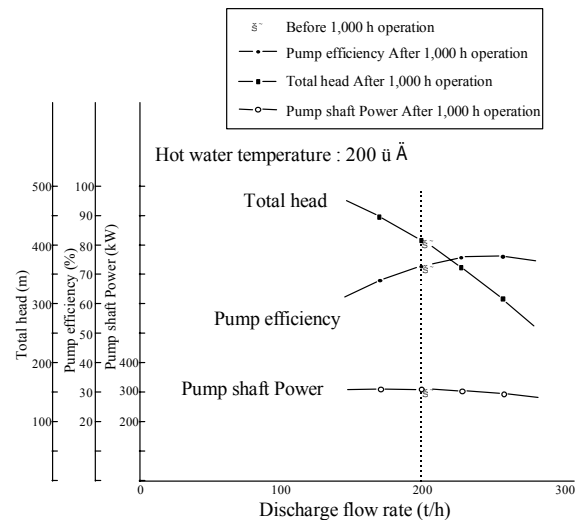


Figure 5. Performance of test pump.

4.1 Factory Tests

Flow diagram of the factory tests is shown in Figure 4. The test pump was set in the barrel with actual well conditions simulated to test its operation in hot water (200°C). Figure 5 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 that were conducted before and after 1000 hours operation. From the figure, it is clear that the performance obtained from both tests exhibit almost the same values.

the well bore surface accumulated at the header of the balance piston room, where hot water flow in the pump compensate the downward force caused by the main water wheels. The accumulated sludge made the balance of the shift unstable and caused the vibration of the shift, resulting in damage to the coupling wheels between the pump and motor.

The second challenge for the long-term hot water circulation test was commenced on September 20, 2000. The test was conducted satisfactorily for 460 hours but terminated due to the leakage of the lubricating oil and damage to the thrust bearings.

The third test was begun on January 15, 2001 but the pump stopped after 60 hours operation. The DHP was pulled to move it to the factory again. After dismantling the pump motors at the factory, we found that the oil-lubricated radial bearing was damaged by rubbing and thought the trouble caused by iron dusts existed in the lubrication due to inadequate flushing. We carried out precision oil flushing used ultrasonic wave in the frame and installed two dust pockets. Unfortunately the long-term circulation test was not completed because of the project deadline (Table 4). Finally, factory test was carried out to evaluate their countermeasures for 111 hours.

Table 4. Long-term circulation test results.

Date	Operating time	Source of trouble
October 21, 1999	110 hours	Sludge from well surface
September 20, 2000	460 hours	Leakage of lubricating oil
Jan. 15, 2001	60 hours	Iron dusts existed in the lubrication oil

6.0 CONCLUSION

NEDO has developed a submersible DHP as one of the key technologies in the binary cycle power generation in Japan. Three test pumps were constructed to clear the targets in each pump. The long-term circulation test at the test field was designed with the demonstration pump based on the test pump No. 3 for confirming the stability of the pump. The test was not completed. We investigate the cause of the problems on the DHP. The development of the submersible DHP is a challenging target. The final goal of the development in NEDO is very

high as the binary cycle power plant needs the operation of the DHP in high temperature environments. The length of the DHP is also essential for the easy operation in the field and we designed 10.5m in length. Unfortunately the NEDO project for the development of the binary cycle power generation with the submersible DHP has been finished. We estimated the potential of the Sugawara reservoir for the binary cycle power and the evaluation on the DHP is conducted for the collaborative companies (Ebara corporation, Mitsubishi electric company and two others) to make the submersible DHP practical.

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