How Geothermal Power Plants Help to Reduce CO_2 Emission

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Geothermal power generation is an environment-friendly power-generation method with extremely low CO_2 emission. It generates power cleanly because it requires no combustion of fuels on the ground. Mitsubishi Heavy Industries, Ltd. (MHI) has adopted various methods to generate power from geothermal sources such as superheated steam process, and flash cycle and binary cycle configurations. As of this writing, MHI has delivered 25% of the geothermal power plants now operating in the world. In the future, MHI aims to further develop and spread the geothermal power generation by improving the economy of the process. This will help curb global warming.

1. The process of geothermal power generation

1.1 Geothermal resource

Figure 1 shows a model of a geothermal resource. Rainwater seeps down through cracks in rock around faults to underground depths of 1,000 m or more. It sinks further and further through the crust over a period of several decades, and stays underground. This water is heated by a magma chamber in its vicinity, forming a high temperature and high pressure zone of hot water (aquifer). This hot water is the energy source for geothermal power generation. When drilling a well towards an aquifer, hot water gushes out in a combined process of depressurization and flashing. In some wells, the water is converted into superheated steam. In other wells, the water remains in a two phase state of water and steam. The former type of well is called a “superheated steam production well”; the latter, a “water-dominated production well.”

1.2 Power-generation plant cycle

Figure 2 shows a typical example of a power-generation cycle applied for geothermal power generation. In the flash cycle, the geothermal steam is introduced directly to the turbine. In the binary cycle, geothermal fluid is introduced to a heat exchanger, the heat is recovered using a low-boiling-point medium (a secondary working fluid), and all of the geothermal fluid is returned underground.

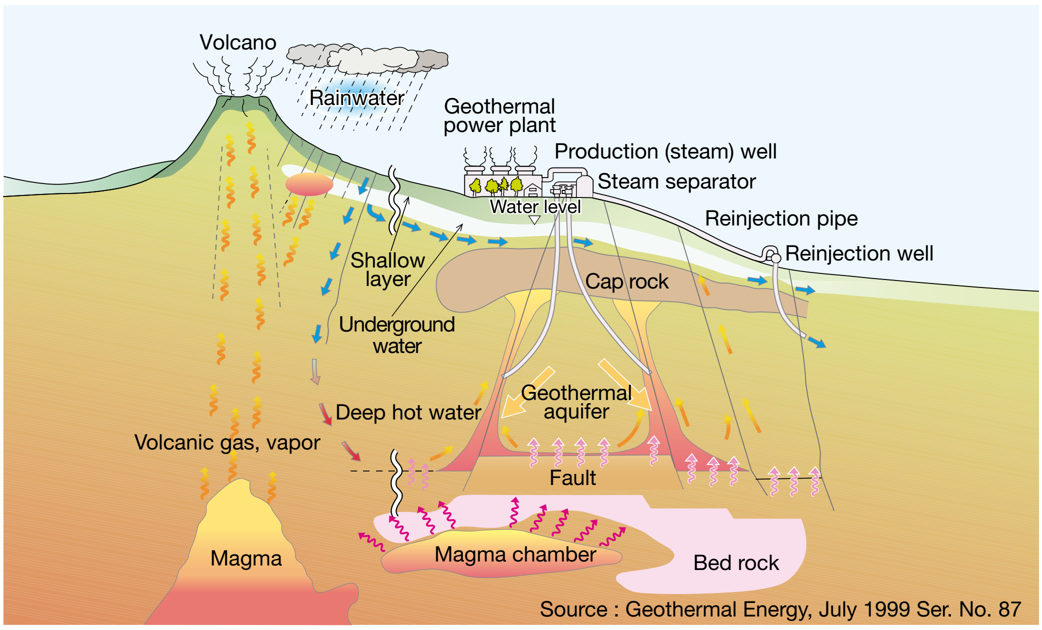

Fig. 1 Underground resource model (Model showing the origin of geothermal energy)

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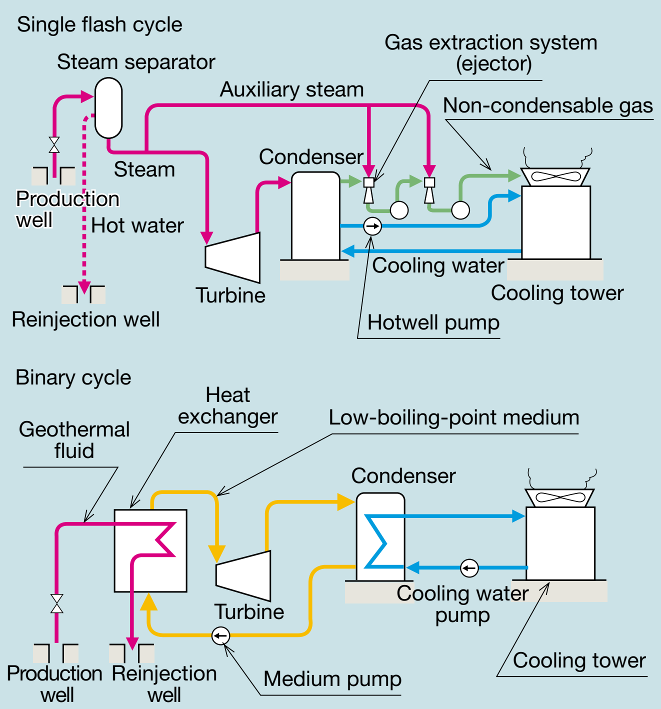

Fig. 2 Cycle schematic diagram
Schematic diagram showing a typical geothermal power-generation cycle.

When a superheated steam production well is used, the geothermal steam is introduced directly to the turbine without processing the steam (except in some cases, when the steam is scrubbed or otherwise treated). In a water-dominated production well, the hot water and steam are separated by a separator, and the steam is introduced to the turbine for power generation. Unlike the artificial steam used in a thermal power plant, geothermal steam contains impurities and non-condensable gases with extremely high concentration. The corrosion-related damage caused by these impurities and the deposition of scales is a problem unique to geothermal power generation.

1.3 Features of geothermal power generation

Geothermal power generation uses the heat in the Earth's interior rather than combustible fuels extracted from the ground. Therefore, the process exhausts very little atmospheric CO_2 (one of the main greenhouse gases responsible for global warming). The CO_2 emission level is about as low as that of nuclear power generation. Geothermal heat is originated from the transfer of heat in the interior parts of the earth, or from the decay of radioactive materials. The amount of thermal energy is huge. In Geysers, California, the site of the world's largest-scale geothermal power-generation facilities, the thermal energy consumed for more than 30 years of power generation has reportedly reached only 5% of the thermal energy of the underground resources existing in the area. Clearly, geothermal heat is an energy that's hard to deplete. And since it isn't affected by the weather, its availability factor is the highest among natural energies—nearly equal to that of a thermal power plant.

2. Approach of MHI

2.1 History of development

The world's first geothermal power generation was carried out using superheated geothermal steam at Larderello in Italy, in 1904. About three-quarters of 1 horsepower was harnessed from the steam. A geothermal power-generation technology using water-dominated production wells was first developed in New Zealand and later applied practically at the Wairakei Geothermal Power Plant in 1958.

Based on this success, MHI began developing a geothermal power-generation facility using a water-dominated production well jointly with Kyushu Electric Power Co., Inc. As a basis for material selection, we chemically analyzed the geothermal fluid, and carried out material tests on the major components such as the turbine under a geothermal steam atmosphere. We also analyzed the characteristics of the major components required for geothermal power plants, such as the direct contact type condenser, two-phase flow transmission pipe, non-condensable gas extraction system, etc. Finally, we performed verification tests to collect the basic data for the component design. The Otake Power Plant of Kyushu Electric Power Co., Inc. (11 MW), the facility designed and constructed based on these data, commenced operation as Japan's first water-dominated geothermal power plant in 1967. Since then, MHI has developed and applied various technologies to improve the performance, economy, and reliability. The company has delivered 96 sets of geothermal power-generation facilities, with a total capacity to produce 2,780 MW of power, in 13 countries, including Japan. This corresponds to 25% of the geothermal power-generation capacity in the world.

2.2 Lineup

Figure 3 shows the types of components generally required for geothermal power generation. MHI has designed and manufactured all of these types. In the flash cycle, we cover a wide power range. At the small end of the scale, we made a 0.2 MW power generation facility run on steam from flashing hot water of about 100°C under a pressure of only 0.06 MPa (below atmospheric pressure). On the large end of the

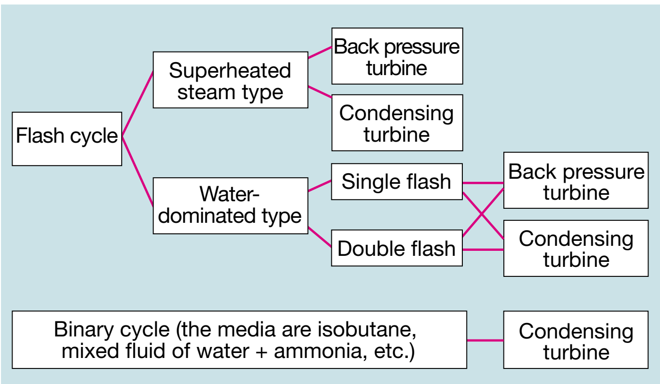

Fig. 3 Classification of facility types
Types of generally assumed geothermal power-generation facilities.

Table 1 Chemical compositions and mechanical properties of geothermal turbine rotor materials of MHI

Material code	Chemical composition (% of mass)									Mechanical properties (N/mm^2)	
	C	Mn	P	S	Si	Ni	Cr	Mo	V	0.2% yield strength	Tensile strength
10325MGB	0.23-0.3	0.7-1.0	≤ 0.015	≤ 0.005	0.2-0.4	≤ 0.5	1.0-1.3	1.0-1.3	0.21-0.29	≥ 635	≥ 740
GSR1	≤ 0.06	≤ 1.0	≤ 0.015	≤ 0.005	≤ 0.30	5.0-5.5	11.5-12.5	0.8-1.2	≤ 0.1	≥ 635	≥ 740

scale, we made a 121 MW power-generation facility with a single-cylinder turbine run with about 700 tons of steam per hour at a pressure of 1.68 MPa and temperature of 204°C.

In the binary cycle, we have carried out all stages of plant development, from design and manufacture up to commissioning, using three types of low-boiling-point media (isobutane, Freon (HCFC-123), or a mixed fluid of ammonia + water) in proto-model power-generation facilities (in the Otake and Takigami areas of Oita Prefecture, and in MHI's Nagasaki Research and Development Center). These prototype operations verified the practicability of the new systems.

2.3 Reliability

Technology is required to protect the rotating parts of the turbine from corrosion fatigue and stress corrosion cracking (SCC), the typical failure modes under corrosive geothermal steam contaminated with impurities and corrosive non-condensable gases. To cope with SCC of turbine rotors, we pay close attention to low-stress designs while applying rotor materials with low SCC susceptibility. MHI has developed two types of materials for the geothermal turbine rotors, as shown in **Table 1**. The material 10325 MGB has a low SCC susceptibility because it contains extremely low levels of sulfur, an impurity. GSR 1 is a 12% Cr-5 Ni material applied to turbine rotors exposed to highly corrosive geothermal steam. To cope with corrosion fatigue of the rotor blade, we use 12 Cr steel, 17-4 PH steel, or titanium alloy in accordance with the corrosive environment and blade length. Applying and integral shroud structure to a long blade, we avoid the corrosion fatigue by suppressing the vibrating stress to 20% or less of the stress imposed on a conventional blade. This is achieved by the high dumping effect of the mutual contact of adjacent blades at the shroud part. These are examples of technologies we have developed to assure reliability. The probability of damage of rotating parts has been significantly reduced through the accumulation of these technologies, and the availability factor nowadays is comparable to that of a thermal power-generation facility.

3. Conclusion

Geothermal power generation is an excellent power-generation method with the following features:

- Low CO_2 emission, and environment-friendly
- High availability factor
- Runs on an energy resource that's hard to deplete

But because the steam condition is low and the sizes of the components are big, the construction cost per power tends to be higher than that for a thermal power plant. We will make our utmost efforts to further spread geothermal power generation by improving its economy.


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