Introduction to the Features and Technology of Geothermal Power Plants, Which Contribute to the Prevention of Global Warming

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Geothermal power generation is an effective method to mitigate global warming because it involves no fuel combustion, resulting in low CO_2 emissions. Mitsubishi Heavy Industries (MHI) provides the equipment for three types of geothermal power generation technology: superheated steam, flash cycle, and binary cycle. We have delivered 100 systems to 13 countries, including Japan, achieving a total installed capacity of 3,000 MW or about 26% of the geothermal power output worldwide. We will pursue the deployment of geothermal power generation through further improvement in its economic efficiency and reliability.

1. Features of Geothermal Power Generation

Figure 1 shows a schematic diagram of a geothermal resource. As rainwater penetrates into fault cracks and fractures more than 1,000 m underground over several decades, it accumulates there and is heated by an adjacent magma chamber to form a hydrothermal aquifer (reservoir) at high temperature and pressure. This hydrothermal water is the source of the energy used to generate geothermal power.

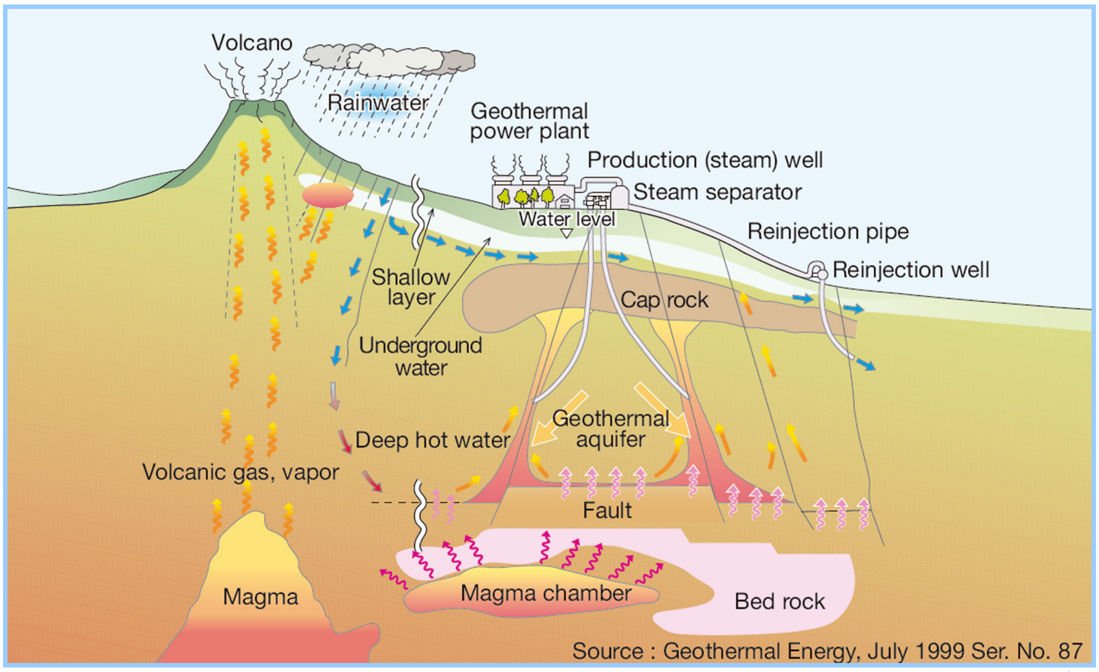

Figure 1 Schematic diagram of a geological resource showing the origin of geothermal energy[1]

As shown in **Figure 2**, geothermal plants, like nuclear plants, emit very little CO_2, which is one of the causes of global warming, because they use the internal heat of the earth and do not involve fuel combustion. Geothermal energy, which originates from heat flow or radioactive decay inside the earth, is a massive source of thermal energy. The world's largest geothermal plant is

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located in the Geysers geothermal area in California. The total amount of heat that the Geysers plant has consumed over the past 30 years accounts for only 5% of the total geothermal resources in this area. Geothermal is one of the sustainable energy sources and the power generation technology reaches the highest availability factor among renewable power technologies. The factor is the same level as fuel-fired power generation, due to geothermal is free of climate condition influences.

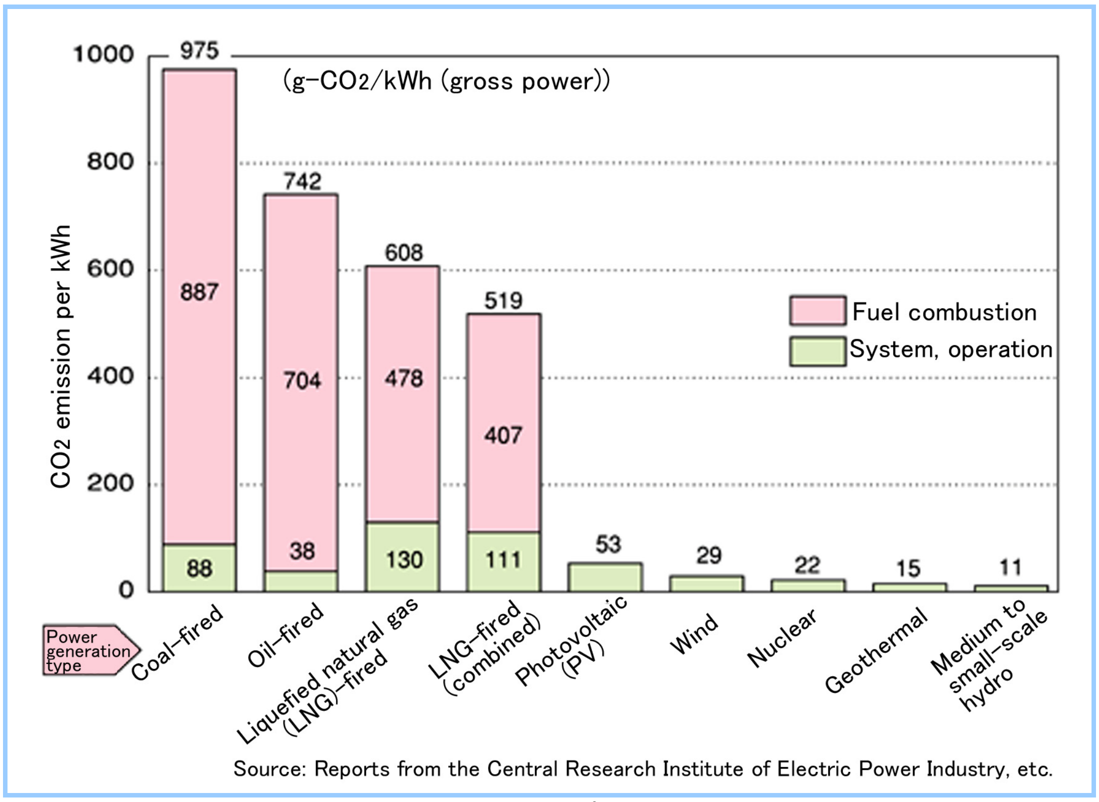

Figure 2 CO_2 emissions based on power source type[2]
These values show the volume of CO_2 emissions by each power sector.

2. Our Approach

2.1 Development history

In 1904, the world's first geothermal power was generated in Larderello, Italy, using self-flowing superheated steam to generate three-quarter horse power. Geothermal energy from water-dominated production wells was first developed in New Zealand, where it was applied in the Wairakei geothermal plant in 1958. Following this success, we started to develop geothermal power systems for water-dominated production wells jointly with the Kyushu Electric Power Co., Inc. Chemical analyses of geothermal fluids and material tests of the main equipment (e.g., turbines) in a geothermal steam environment based on our material selection methodology were conducted. Other main components required for geothermal plants, such as separators, direct-contact steam condensers, two-phase flow transmission piping, and non-condensable gas extraction system, were characterized and validated to accumulate basic data for equipment design. Based on the data, we designed and constructed the Kyushu Electric Power 11 MW Otake geothermal power plant, which started operation in 1967 as Japan's first geothermal plant using water-dominated production wells. Subsequently, several technologies were developed and applied to improve the technical and economic performance and reliability. We have delivered 100 systems to 13 countries, including Japan, reaching an installed capacity of about 3,000 MW, or approximately 26% of the total global geothermal capacity.

2.2 Lineup

Figure 3 shows models of the equipment used in geothermal power technology. We have designed and fabricated all of these models. Flash cycle technology can cover a wide output range from a 200-kW system that uses steam produced by flashing hot water (ca. 100°C) at lower than atmospheric pressure (0.6 bara) to a 121-MW single casing turbine that uses steam at 204°C and 16.8 bara at about 700 t/h.

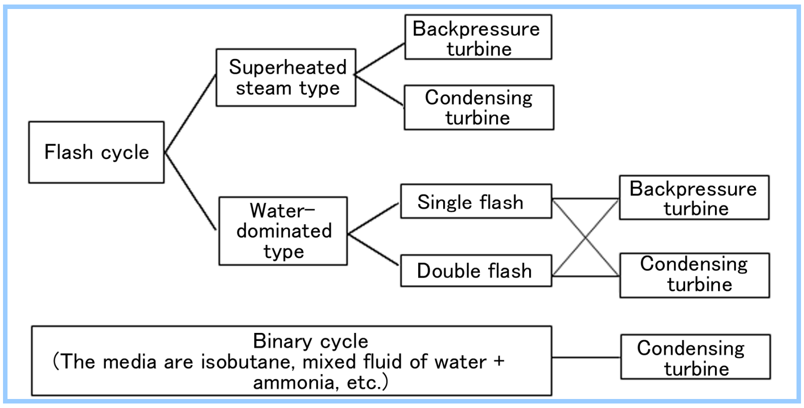

Figure 3 Classification of facility type
These are the types of facilities that are generally possible in geothermal power technology.

A binary cycle uses any of the following three types of medium with low-boiling points: isobutane, Freon (HCFC-123), or a liquid mixture of ammonia and water. Prototype models using each medium have been designed, fabricated, and operated in the Otake and Takigami areas in Oita Prefecture and MHI's Nagasaki R&D Center, respectively, demonstrating their practicality.

2.3 Reliability

Establishing geothermal reliability through damage prevention technologies is essential to protect turbine parts from stress corrosion cracks (SCCs) and corrosion fatigue (CF) due to centrifugal force and geothermal steam containing corrosive impurities and non-condensable gas. To reduce SCCs in rotors, we use less SCC-sensitive rotor materials and emphasize lower-stress designs. As shown in **Table 1**, we use two standard materials for geothermal turbine rotors. The material code 10,325MGB has achieved lower SCC-sensitivity by limiting sulfur impurities to very low levels. GSR1, a 12% Cr-5Ni material, was developed to be used in geothermal steam, especially in highly corrosive environments. To reduce CF in moving blades, 12Cr steel, 17-4PH steel, and titanium alloy can be selected, depending on the corrosion environment and blade height. An integral shroud blade (ISB) is applied to rotating blades. Conventional blades have tenon riveted parts and welds at the stubs. Impurities accumulate in the areas surrounding the tenon riveted parts, forming a corrosive environment, and welds at the stubs have relatively high SCC-sensitivity because of the thermal influence. The tenon riveted parts and stab weld zones can be eliminated by using ISB blades (**Figure 4**), resulting in the prevention of the SCCs and CF that frequently occur in these areas and improving the reliability of geothermal turbines.

The ISB blades cut vibration stress by >80% compared with conventional blades due to the large damping effects produced by the interconnection between the shroud parts of adjacent blades, resulting in the prevention of CF.

Figure 5 compares the blade root shapes of the conventional and new blade designs. The new blade design significantly reduces the centrifugal stress at the blade roots and grooves by increasing the size of the blade roots, corner radius, and blade teeth thickness, leading to a significant improvement in the resistance of the blade roots and grooves to SCCs.

The accumulation of the technological experience mentioned above to assure reliability has reduced the probability of damage of rotating parts significantly.

We also established a weld repair method for turbine rotors using 12%Cr-5Ni rotor material to enable quick restart operations if turbine rotors are damaged by corrosion.

The technologies mentioned here increase the availability factor of geothermal power systems to that of fuel-fired power systems.

Table 1 Chemical composition 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
GSR 1	<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

Figure 4 Overview of the ISB long blade

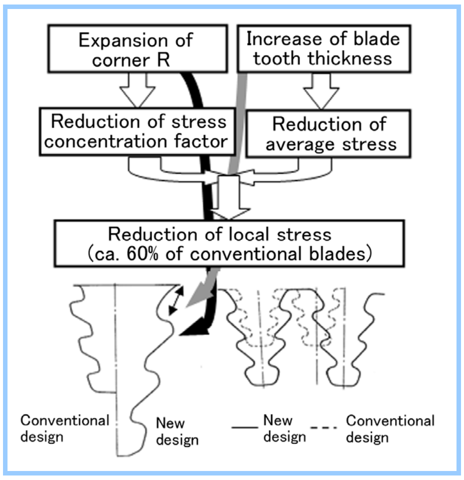

Figure 5 Comparison of the blade root shapes between new and conventional design

3. Conclusions

Geothermal power generation has the following profitable features:

- Lower emission of CO_2, which is a main source of global warming
- Higher availability factor
- Use of more sustainable energy

Due to the steam conditions and larger equipment size, geothermal power generation tends to involve higher capital costs per output compared with fuel-fired power systems. We plan to improve the economic efficiency by improving turbine efficiency and increasing unit capacity. We will continue to extend efforts for the further deployment of geothermal power technology, which is an effective option to mitigate global warming, through the continuous development of anticorrosion technology to increase equipment reliability.

References

1. Japan’s New Energy Foundation, Geothermal Energy Serial No.87 (July, 1999)
2. Japan’s Central Research Institute of Electric Power Industry, Research Report