

STARTING FIELD TEST OF KALINA SYSTEM USING HOT SPRING FLUID IN JAPAN

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ABSTRACT

To apply smaller-scale geothermal generation such as high temperature hot spring field about 90°C, we carried out a development project of a 50 kW class Kalina cycle geothermal power generation system. From 2010, on site generation project is progressing at Matsunoyama hot spring field in Niigata Prefecture at middle of Japan. This is first test using a 50 kW class Kalina system that potential is estimated as 723 MW using hot spring fluid in Japan without drilling. Before starting generation, we analyzed geochemistry of Takanoyu #3 test well, and surrounding wells to estimate the stability of production of hot spring fluid. And we estimated low scaling risk to heat exchanger from equilibrium calculation.

At the end of 2011, we started power generation test to estimate stability generation system and to solve several technical and law problems for promotion of this business model.

INTRODUCTION

As one of geothermal direct use, bathing in hot springs is used for many people and countries, especially in Japan.

In Japan, about 28,000 hot springs (Onsen) and 15,000 hotels related hot springs exist in 2010. And total guests staying at hotels of hot springs are about 130 million as same as population in Japan.

And the range of temperatures of hot springs is very wide from 25 to over 100°C. In non-volcanic area, for example Shikoku Island, in Kanto plane etc., the temperature of over 95% of the hot springs are lower than 42°C. In this case, the owners of springs, mainly official public baths, have to heat water using boilers to bathing temperature and people living in the non-volcanic areas are able to enter the springs in their living area.

And in volcanic area, for example Hokkaido, Tohoku area, Kyushu Island, etc., the temperature of over 60% of the hot springs are higher than 42°C. Kimbara (2005) collected temperature data of 4,536 hot springs. According to this data, the temperature of about 15% of the hot springs are higher than 60°C and 4% are higher than 90°C.

Especially on Kyushu Island, several hot spring sources have high temperature heat sources enough for power generation by single flash system, for example, Suginoi-hotel power plant (1,900 kW), Kuju-hotel power plant (990 kW) and Kirishima-International hotel power plant (100 kW). The

depth of the production wells of these plants are less than 400 meters and much shallower than depth of production well (about 2,000 meters) of usual commercial flash type geothermal power plants.

In several areas, the temperature of hot springs shows about 90 to 100°C especially near volcanic areas. This is not enough for flash power generation. And in this case, the initial temperature of the hot springs are too high for bathing (about 42°C), hot spring owners are making various efforts such as cooling by a long channel or stirring by human power. It means the energy of the hot springs are wasted.

To usefully utilization the high temperature hot spring water (about 100°C), a development project of a 50 KW class Kalina cycle power generation system was conducted (Muraoka et al., 2008c).

The concept of this system is as shown in Figure 1. If we incorporate a small-scale Kalina cycle power generation system into the upper stream of the high-temperature hot springs, we could obtain electricity and adjust the bath temperature without any dilution of balneological constituents. The minimum power generation temperature by the Kalina cycle is 53°C which is adequate to bridge over for bath use after power generation. And we can use heated cooling water for space heating, etc.

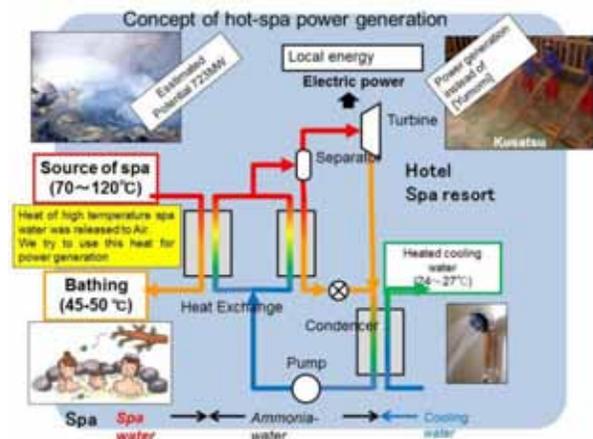


Figure 1. The concept of power generation system using hot spring fluid

This paper describes an outline of our ongoing projects for the development of a small and low-temperature geothermal (high temperature hot spring) power generation using Kalina system at Matsunoyama field.

REVIEW OF THE KALINA CYCLE POWER GENERATION SYSTEM

The Kalina cycle, one of the binary cycle power generation methods using an ammonia-water two component mixture as a low-temperature boiling medium, was invented by Dr. Aleksandr (Alex) I. Kalina in 1980. This system can generate electricity with thermal water less than 100°C, because the boiling point of ammonia is -33.48°C under an atmospheric pressure.

The first Kalina cycle power plant of 3,100 kW has been operated at the Kashima Steel Work, Sumitomo Metal Industries, Ltd., Ibaraki Prefecture, Japan since 1999, where the thermal water 98°C from a steel revolving furnace is used. The first geothermal Kalina cycle power plant of 1,700 kW has been operated at Húsavík, northern Iceland since 2000. The second geothermal Kalina cycle power plant of 3,300 kW has been operated at Unterhaching, the southern suburb of München, Germany since 2007, where deep thermal water at a temperature 120°C is produced from the molasse sediments at a depth of 3.4 km in the non-volcanic region.

The minimum power generation temperature of the Kalina cycle is estimated to be 53°C for the water cooling system by Muraoka (2007) based on the data from Osato (2003) as shown in Figure 2. This, however, means the minimum temperature when a thermal conversion range ΔT is consumed for power generation. To realistically generate electricity using an effective thermal conversion range, the initial water temperature is expected to be 80°C or more. If a flow rate is very high, the initial water temperature 70°C may be considered. A utilization temperature limit is determined by the discharge temperature and discharge rate of thermal water.

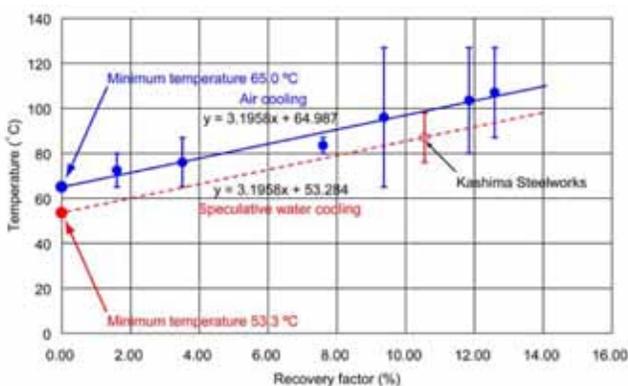


Figure 2. Relation between the inlet water temperature and recovery factor in the net electricity output ratio to the thermal energy input in the Kalina cycle (Muraoka, 2007; Osato, 2003).

Kalina cycle power generation systems of a 2 MW class and larger scales are practically utilized as described above. To apply the Kalina cycle to hot springs, we need down-sizing of the system, because discharge rates of most hot springs are small. Then, we aim to assemble a Kalina cycle system as small as 50 kW in the net electricity and 64.5 kW

in the gross electricity. The energy conversion efficiency of the Kalina cycle was originally known to be higher than the organic Rankine cycle (ORC), particularly in the lower temperature range (Figure 3) (Osato, 2005). This efficiency should be kept as far as possible even in the down-sizing process. The cost of the system will be important as a market force in the near future, but the efficiency is more important in the prototype assembly.

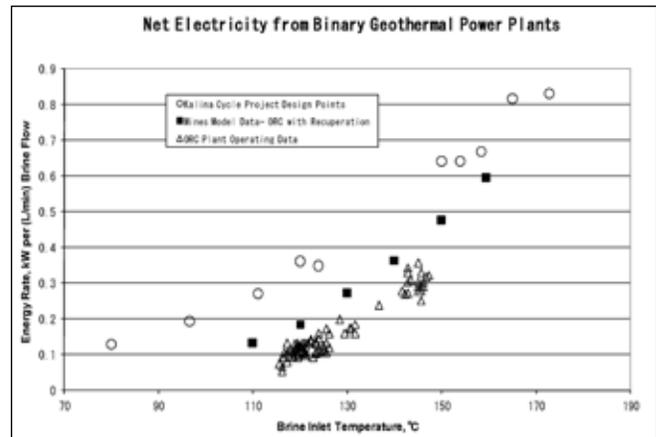


Figure 3. Comparison between the inlet temperature and net electricity of Kalina and organic Rankine cycles (Osato, 2005).

For our project, the Kalina cycle system was developed at Energent Corporation with the Geothermal Energy Research & Development Co., Ltd. (GERD). A 90 kW unit using the Euler turbine technology was developed with a high speed generator and magnetic bearings. The length is about 80 cm. The rotor is about 13 cm in diameter and 500 g weigh. The operating speed is 56,000 rpm. The Euler turbine technology can also be applied to ORC's, replacing the radial inflow turbine. (Welch et al., 2010, 2011).

POTENTIAL OF HOT SPRING POWER GENERATION IN JAPAN

The potential of hot spring generation using 50 kW class of Kalina system was estimated at about 723 MW by Muraoka et al. (2008c). This value was estimated as follows;

1. We apply 50 kW Kalina cycle power generation system to currently wasting energy from high temperature hot springs such as Beppu, Tamagawa without new drilling
2. We ignore less than 30 kW output.

When we allow new drillings, the width of potential areas of hydrothermal resources at a temperature from 53°C to 120°C above the pre-Paleogene basement units are estimated to be 22.2 % of the entire on-shore territories (Figure 4), where hydrothermal resources higher than 120°C are ignored. Compared with the potential areas of the hydrothermal resource higher than 150°C (Muraoka et al., 2008a), it is obvious that the lowering of the power generation temperature dramatically enlarges the resource fields toward the non-volcanic fields. The total electricity potential is estimated to be 8,330 MW in entire Japan (Muraoka et al., 2008b).

MARKET AND PROBLEMS FOR HOT SPRING POWER GENERATION SYSTEM

Firstly, this system is useful for hot spring hotels and towns including many hotels. And the market for Kalina and ORC binary cycle systems is not only for hot springs but also the high temperature wells of oil, gas, coal and metal mining field. This system is useful for the waste high temperature fluid of factories such as the Kashima Steel Work, Sumitomo Metal Industries, Ltd. The potential of generation from waste heat of factory is estimated about 2,000 MW.

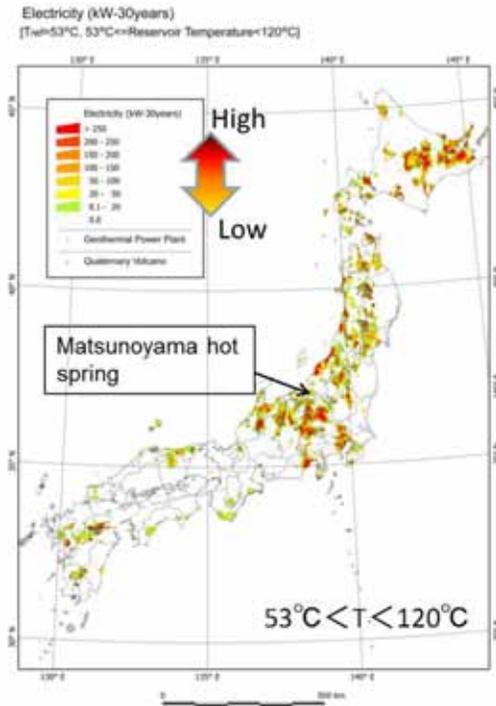


Figure 4. Distribution of hydrothermal resources at a temperature from 53 to 120°C above the pre-Paleogene basement units and the site of Matsunoyama hot spring.

This market area of Kalina and ORC systems is important for decreasing CO₂ release and self power generation in hot springs and factories. Especially, after the big earthquake of eastern Japan at March 11, 2011, the nuclear power plant accident was very serious with many radioactive materials release to the air and sea. Due to decreasing electric power from nuclear power plants, geothermal and hot spring power generation becomes important and we have to use hot spring fluid usefully.

Power generation from hot springs has the possibility to be the symbol of the hot spring resorts. Many guests will visit the hot spring resorts with power generation system.

To progress small hot spring power generation systems, we have to solve several problems. Firstly, the small Kalina system is under development and still high cost. The machine cost has to be decreased by spread market and development technology. And to decrease cost, we have to check the long-term stability of the generator and pipeline system including scale problem.

We have to check and change the laws related to small power generation. For example, even in small power generation systems, an official boiler technician is needed to run the generator and many procedures and high cost machines are needed to connect with commercial electric lines in Japan. These add to the high cost of maintaining the generation system.

Also if a lot of hot spring fluid is need to generate more power, the owners of hot springs tend to worry about sustainability of production. We then need to estimate the sustainable maximum power for the hot spring field based on the production temperature and rate and the mechanism of origin of the hot spring.

The Ministry of the Environment (MOE) of Japan started to support this hot spring generation three year project, titled “Development and Demonstration of Small-Grid Power Generation System using Hot Spring Heat Source” from fiscal year 2010 (FY2010). This project is managed by the Geothermal Energy Research & Development Co., Ltd. (GERD), the Institute for Geo-Resources and Environment of AIST, and Hirosaki University. In this stage, power generation test by 50 kW class Kalina cycle system using about 100°C hot spring water will be carried out at Matsunoyama hot spring field in Niigata prefecture in middle part of Japan. This project mainly consists of several subjects: (1) production of hardware and estimation of long term stability including scale problem, (2) connection to electric line and estimation of maximum power with spring water flow, (3) estimation and monitoring of surrounding hot spring system.

MATSUNOYAMA TEST FIELD

The Matsunoyama hot spring field exists in Tokamachi city of middle part of Niigata prefecture about 200 km NNW from Tokyo shown in Figure 4. In Matsunoyama hot spring resorts, about 20 hotels and several hot spring wells exist. The oldest well, Takanoyu #1, was drilled in 1938 to 170 meters depth and about 90°C, 60 l/min flow. After that, several wells such as Takanoyu #2, Kagaminoyu, Yusaka were drilled and these temperatures are about 90°C

In 2007, a new hot spring well, Takanoyu #3, was drilled to about 1,200 meters depth. At the first production test, the fluid temperature was about 97°C and flow rate was about 630 l/min. This production rate is the largest in Matsunoyama hot spring resort.

After this test, the production rate from Takanoyu #3 is about 230 l/min and several parts of the fluid is not used for bathing and released to river directly due to over production to hotels.

Then, Takanoyu #3 is selected for the test well of the hot spring generation project, “Development and Demonstration of Small-Grid Power Generation System using Hot Spring Heat Source” from fiscal year 2010 (FY2010) by MOE due to high temperature and flow rate.

GEOCHEMISTRY OF MATSUNOYAMA

After October 2010, we started the flow rate, temperature and geochemical monitoring of Takanoyu #3 for generation test well and Kagaminoyu, Yusaka, Koshinnoyu and the mixture of Takanoyu wells as surrounding well from Takanoyu #3 less than 1 km due to estimate influence of power generation test as shown in Figure 5.



Figure 5. Site of Takanoyu#3 and surrounding monitoring hot spring well.

From October 2010 the flow rate, temperature and geochemistry of the monitoring wells are almost constant and these values will be the background for the power generation test at the end of 2011.

Table 1 shows the fluid composition of Matsunoyama wells with high Cl concentration about 9,000 mg/l in all wells measured in November 2010. Takanoyu #3 has about 3,700 mg/l Na, 140mg/l K, 2,070 mg/l Ca and 27.3 mg/l HCO₃ and did not change from production start in September 2007.

Table 1: Geochemistry of hot spring of Takanoyu #3 and surrounding wells (mg/l)

	Na	Cl	K	Ca
Takanoyu #3	3700	9400	140.3	2070
Yusaka	3708	9252	103.3	1980
Kagaminoyu	3392	8764	83.4	1882
Kousinnoyu	5680	8661	30.7	205
	HCO ₃	SO ₄	Mg	Si
Takanoyu #3	27.3	85.5	0.6	66.7
Yusaka	23.0	80.0	7.7	36.7
Kagaminoyu	19.3	81.1	15.7	20.1
Kousinnoyu	316.6	2.6	44.1	11.5

Figure 6 shows the isotope diagram of the hot spring fluid and river water. This shows that the hot spring fluid did not match on meteoric line.

ESTIMATION OF SCALING

From this composition, we estimated the possibility of scaling in this system by calculating equilibrium of silica and carbonate minerals using Solveq-Chiller by Reed

(1982). The diagram of mineral equilibrium is shown in Figure 7.

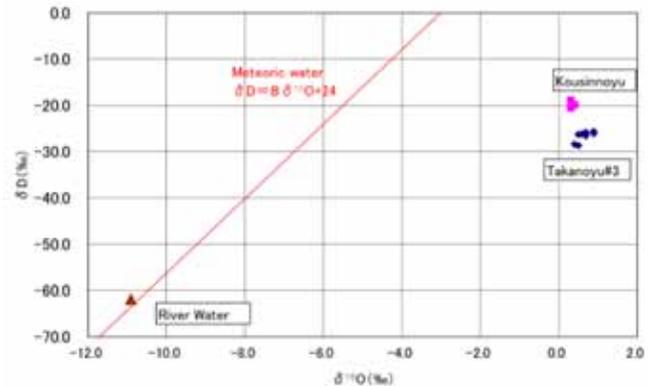


Figure 6. Isotope diagram of hot spring fluid of Matsunoyama field and river water.

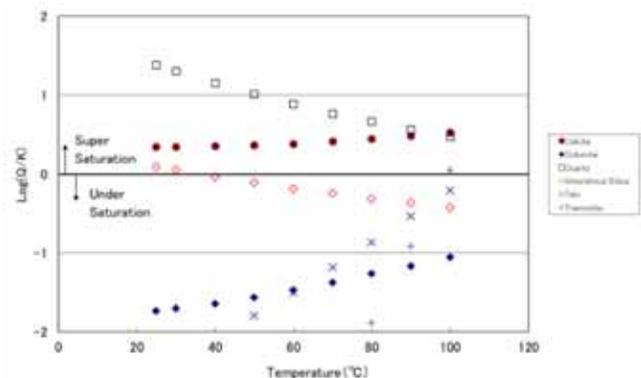


Figure 7. Estimation of equilibrium of scale minerals of Takanoyu#3.

During the cooling process of the hot spring fluid from 100 to 40°C, on heat exchanger, quartz (SiO₂) and calcite (CaCO₃) are supersaturated, but other minerals such as dolomite (MgCaCO₃), talc (Mg₃Si₄O₁₀(OH)₂) tremolite (Ca₂Mg₅Si₈O₂₂(OH)₂) and amorphous silica (SiO₂) are under saturation. And we estimated the scale problem will not be so serious because silica scaling usually as amorphous silica under saturation over 40°C at Matsunoyu #3 and the degree of super saturation of calcite is decreased with temperature decreasing. Then to prevent scaling, we have to take care to prevent vaporize fluid in heat exchanger.

The reason for low risk of scaling is due to low HCO₃ and Mg concentration at Takanoyu#3. Then, the scaling risk will increase in high HCO₃ regions near volcanic area.

STARTING POWER GENERATION TEST

The power plant system was installed at Takanoyu #3 in December of 2011. The power generation system contains about one meter length power generator, heat exchanger for hot spring fluid with ammonia/water mixture, separator ammonia gas from water, ammonia tank and pumping system. The system size is about 5 m³ as shown in Figure 8 with control system in the building to cover from 3 m depth snow.



Figure 8. The Kalina power generation system using hot spring fluid at Matsunoyama.

Outside of the building, as shown in Figure 9, there is the wellhead of Takanoyu #3, cooling tower and transformer to connect electric line.



Figure 9. Wellhead of Takanoyu#3.

On 16 December 2011, the opening ceremony for this project was carried out with the senior vice minister of the Ministry of the Environment (MOE) and the Governor of Niigata prefecture attending. After this ceremony, power generation test was carried out and we survey the sustainability of generation system and hot spring fluid.

Recently, several companies are developing small binary power generation system for hot springs and several hot spring resorts are planning to start small power generation project.

To promote the small hot spring power generation system, the result of Matsunoyama project is important.

SUMMARY

We started a 50 kW class Kalina cycle power generation test at Matsunoyama hot spring field in December 2011. In this test, we will survey the stability of generation system and environment of hot springs mainly geochemistry.

In Japan, there are about 723 MW generation potential to develop small Kalina system for hot spring field. To promote this system, we have to survey and solve several technical and social problems.

EDITOR'S NOTE

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