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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 ºC, 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 50kW class Kalina system that potential is estimated as 723MW using hot spring fluid in japan without drilling. Before starting generation, we analyzed geochemistry of Takanoyu#3 test well, and surrounding well to estimate stability of production of hot spring fluid. And we estimated low scaling risk to heat exchanger from equilibrium calculation.

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

INTRODUCTION

As one of geothermal direct use, bathing in hot spring 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 at 2010. And total guests staying hotels of hot springs are about 130 million as same as population in Japan.

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

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

Especially, in Kyushu Island, several hot spring sources has high temperature heat source enough to power generation by single flush system, for example, Suginoi-hotel power plant (1,900kW), Kuju-hotel power plant (990kW) and Kirishima-International hotel power plant (100kW). 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 flush type geothermal power plants.

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

To useful utilization high temperature hot spring water (about 100 ºC), a development project of a 50 KW class Kalina cycle power generation system is 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 ºC that is adequate to bridge over the bath use after the power generation. And we can use heated cooling water for space heating etc.

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

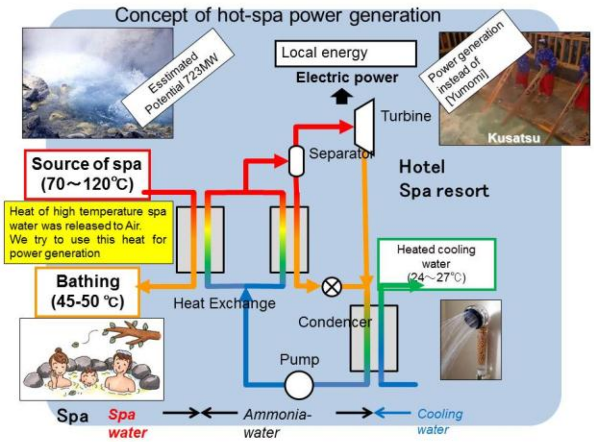

Figure 1: The concept of power generation system using hot spring fluid

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 by the thermal water less than 100 ºC, because the boiling point of ammonia is -33.48 ºC 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 ºC 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 ºC 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 ºC for the water cooling system by Muraoka (2007) based on the data from Osato (2003) as shown in Fig. 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 ºC or more. If a flow rate is very high, the initial water temperature 70 ºC may be considered. A utilization temperature limit is determined by the discharge temperature and discharge rate of thermal water.

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 of 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 is originally known to be higher than the organic Rankine cycle, particularly in the lower temperature range (Fig. 3; Osato, 2005). This efficiency should be kept as far as possible even in the down-sizing process. A 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.

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 Eular turbine technology is developed with a high speed generator and magnetic bearings. The length is about 80 centimeter. The rotor is about 13 cm in diameter and 500 g weigh. The operating speed is 56,000rpm. The Euler turbine technology can also be applied to ORC’s, replacing the radial inflow turbine. (Welch et al.,2010, 2011).

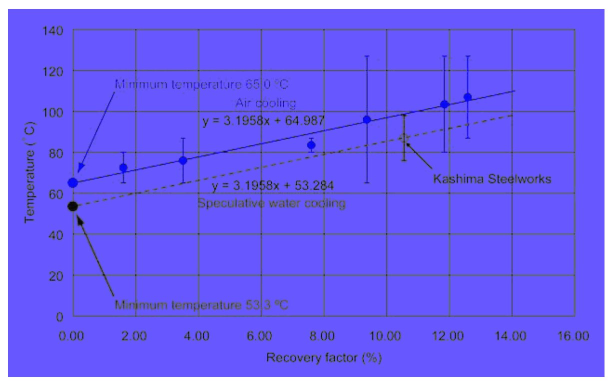

Figure 2: Relation between the inlet water temperature and recovery factor in the net electricity output ratio to the thermal energy input in the Kalina cycle (Muraoka, 2007; Osato, 2003).

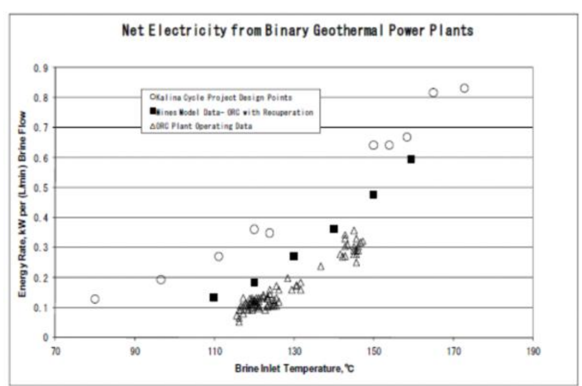

Figure 3: Comparison between the inlet temperature and net electricity of Kalina and organic Rankine cycles (Osato, 2005).

POTENTIAL OF HOT SPRING POWER GENERATION IN JAPAN

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

(1) We apply 50kW 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 30kW output.

When we allow new drillings, the width of potential areas of hydrothermal resources at a temperature from 53 ºC to 120 ºC above the pre-Paleogene basement units are estimated to be 22.2 % of the entire on-shore territories (Fig. 4), where hydrothermal resources higher than 120 ºC are ignored. Compared with the potential areas of the hydrothermal resource higher than 150 ºC (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).

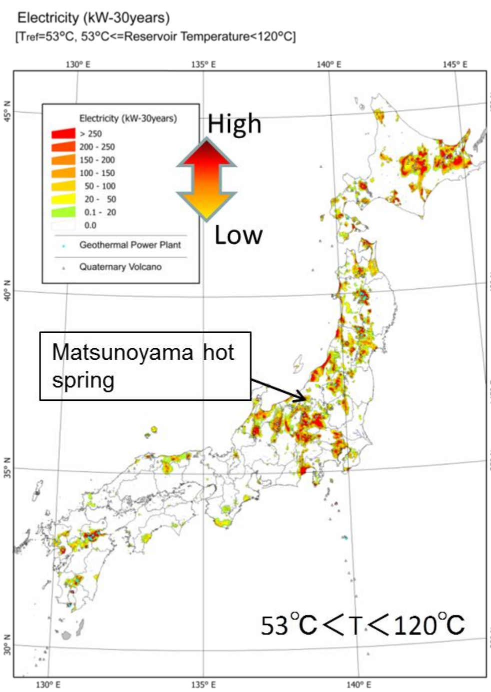

Figure 4: Distribution of hydrothermal resources at a temperature from 53 to 120 ℃ above the pre-Paleogene basement units and the site of Matsunoyama hot spring.

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 of Kalina and ORC binary cycle system is for not only hot springs but also the high temperature well of oil, gas, coal and metal mining field. And 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 2,000Mw.

This market area of Kalina and ORC system is important for decreasing CO_2 release and self power generation in hot springs and factories.

Especially, after big earthquake of eastern Japan at March 11, 2011, the nuclear power plant accident was very serious with many radioactive materials release to air and sea. Due to decreasing electric power from nuclear power plants, geothermal and hot spring power generation become important and we have to use hot spring fluid usefully.

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

And we have to check and change the laws related small power generation. For example, even if small power generation system, the official boiler technician is needed to generator and many procedures and high cost machine are needed to connect to commercial electric line in Japan. These are cause to high cost to maintain the generation system.

And, if a lot of hot spring fluid need to generate more power, the owners of hot spring tend to worry to sustainability of production. Then we 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 hot spring.

Then, the Ministry of the Environment (MOE) of Japan started to support this hot spring generation three years 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 50kW class Kalina cycle system using about 100 ^{o}C hot spring water will be carried out at Matsunoyama hot spring field in Nigata prefecture, middle part of Japan. This project mainly consistes of several subjects: (1) production of hardware and estimation of long term stability including scale problem, (2) connection to electric line and estimation maximum power with spring water flow, (3) estimation and monitoring of surrounding hot spring system.

MATSUNOYAMA TEST FIELD

Matsnunoyama hot spring field exist in Tokamachi city of middle part of Niigata prefecture about 200km NNW from Tokyo shown in figure 4. In matsunoyama hot spring resorts, about 20 hotels and several hot spring wells exist. Oldest well, Takanoyu#1, was drilled in 1938 until 170 meters depth and about 90 ºC, 60 l/min flow. After that, several wells such as takanoyu#2, Kagaminoyu, Yusaka were drilled and these temperatures are about 90 ºC.

In 2007, new hot spring well, Takanoyu#3, was drilled until about 1,200 meters depth. At the first production test, the fluid temperature is about 97 ºC and flow rate is 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 fluid is not used for bathing and released to river directly due to over production to hotels.

Then, Takanoyu#3 is selected to the test well foe 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.

Figure 5: Wellhead of Takanoyu#3.

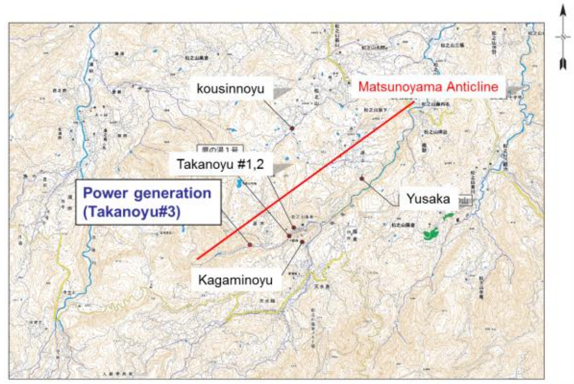

Figure 6: Site of Takanoyu#3 and surrounding monitoring hot spring well.

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 well, 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 6.

From October 2010 the flow rate, temperature and geochemistry of monitoring wells are almost constant and these values will be background for power generation test from 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 at November 2010. Takanoyu#3 has about 3,700 mg/l Na, 140mg/l K, 2,070 mg/l Ca and 27.3 mg/l HCO_3 and did not change from production start at September 2007.

And figure 7 shows the isotope diagram of hot spring fluid and river water. This shows that the hot spring fluid did not match on meteoric line.

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
Kousinnnoyu	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

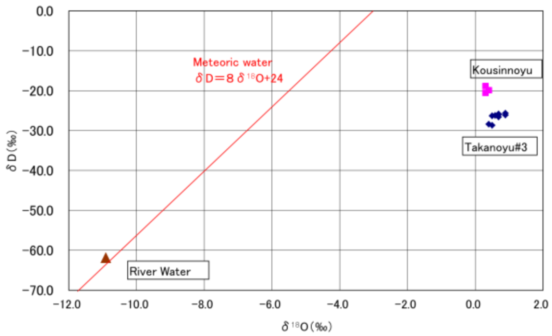

Figure 7: Isotope diagram of hot spring fluid of Matsunoyama field and river water.

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 8.

During cooling process of hot spring fluid from 100 to 40 ºC, on heat exchanger, quartz (SiO_2) and calcite ($CaCO_3$) are supersaturated, but other minerals such as dolomite ($MgCaCO_3$), talc ($Mg_3Si_4O_{10}(OH)_2$) tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$) and amorphous silica (SiO2) are under saturation. And we estimated the scale problem will be not so serious because silica scaling usually as amorphous silica under saturation over 40 ºC at Matsunoya#3 and the degree of super saturation of calcite is decrease with temperature deceasing. Then to prevent scaling, we have to take care to prevent vaporize fluid in heat exchanger.

The reason of low risk of scaling is due to low HCO_3 and Mg concentration at Takanoyu#3. Then, the scaling risk will increase in High HCO_3 region near volcanic area etc.

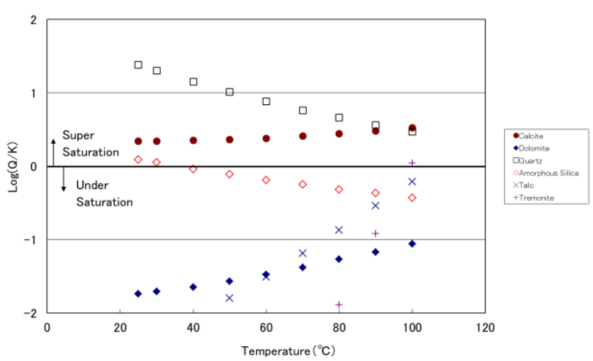

Figure 8: Estimation of equilibrium of scale minerals of Takanoyu#3.

STARTING POWER GENERATION TEST

The power plant system was installed at Takanayu#3 at December of 2011. The power generation system is 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 5meter cubic as shown in figure 9 with control system in building to cover from 3meter depth snow.

Outside of the building, as shown in figure 5, there are the wellhead of Takanoyu#3, cooling tower and transformer to connect electric line.

At 16 December 2011, the opening ceremony for this project was carried out with attending the senior vice minister of the Ministry of the Environment (MOE) and the Governor of Niigata prefecture.

After this ceremony, power generation test is 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 spring. 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.

Figure 9: TheKalina power generation system using hot spring fluid at Matsunoyama.

SUMMARY

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

In Japan, there are about 700 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.

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