STATUS OF DEVELOPMENT OF POWER GENERATION SYSTEM USING HOT SPRING FLUID

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ABSTRACT

To apply smaller-scale geothermal generation such as hot spring field, we carried out a development project of a 50 kW class Kalina cycle geothermal power generation system from 2007. 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. Until now, we analyzed geochemistry of Takanoyu#3 test well and surrounding well to estimate stability of production and scaling risk to heat exchanger. From end of 2011, we will start power generation about one year. If this system will be completed, not only a business model of hot spring power generation will be realized in Japan, but also the geothermal power market will be widely expanded to Asia-Pacific regions including non-volcanic fields.

Keywords: geothermal power generation, low-temperature system, Kalina-cycle, hot spring power generation, Japan, Matsunoyama

1. INTRODUCTION

Geothermal utilization for electric power in Japan is about 535MW and about only 2.5% of estimated geothermal potential. And new geothermal power plants did not build over 10 years. To progress utilization of geothermal energy, we have to solve several problems, for example, high drilling, survey and building cost, high grade resources in national park and the concerns of local hot spring owners. Actually, several geothermal projects have been delayed or stopped due to the concerns of local hot spring owners. However, in many cases, the initial temperature of hot spring are too high for bathing (about 42 ℃), 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 ℃), 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 power generation project was supported by the New Energy and Industrial Technology Development Organization (NEDO) from fiscal year 2007 (FY2007) to 2009, firstly. During this stage, this project mainly consists of three subjects: (1) market evaluation, (2) development of a method to inhibit mineral precipitates, and (3) development of hardware. We estimated scaling problem based on our hydrothermal chemistry database (Muraoka et al., 2007), it is found that the 70 % of Japanese hot springs are supersaturated with calcium carbonates (Sasaki et al., 2008).

Then we carried out scale precipitation test at Otari (Yanagisawa et al., 2008) and scale preventing test at Kawazu (Sasaki

et al., 2010). And Kalina cycle system was developed at Energent Corporation with the Geothermal Energy Research & Development Co., Ltd. (GERD) to this project as figure 2 (Welch et al.,2010).
Secondary, 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), Institute for Geo-Resources and Environment (GREEN), AIST and Hirosaki University.
In this stage, power generation test by 50kW class Kalina cycle system using about 100℃ hot spring water will be carried out at Matsunoyama hot spring field in Nigata prefecture, middle part of Japan. And 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 spa system,
This paper describes an outline of our ongoing project for the development of a small and low-temperature geothermal power generation system at Matsunoyama field and future possibility of this system.

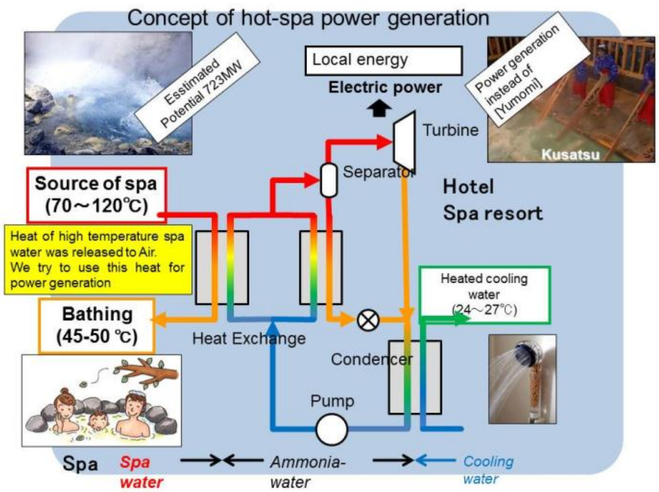

Fig. 1 The concept of power generation system using hot spring water


Fig.2 Kalina power generation system

2. 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 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. 3. 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. An utilization temperature limit is determined by the discharge temperature and discharge rate of thermal water.

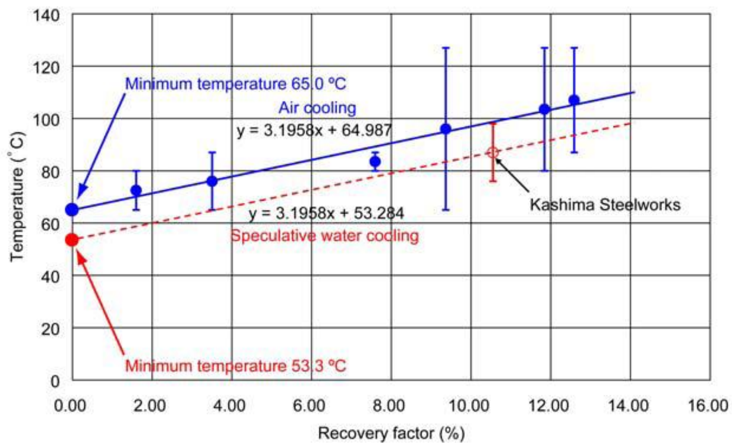

Fig .3 Relation between the inlet water temperature and recovery factor in the net electricity output ratio to the thermal energy input in the Kalina cycle (Muraoka, 2007; Osato, 2003).

3. POTENTIAL OF HOT SPRING POWER GENERATION IN JAPAN

The potential of hot spring geoneration 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 kalian 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).

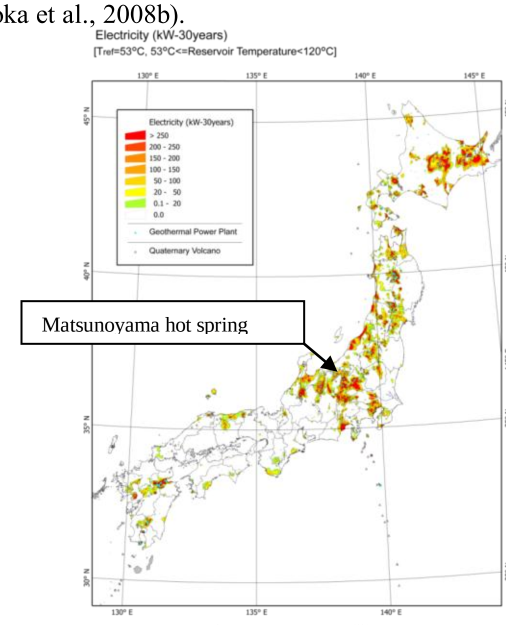

Fig.4 Distribution of hydrothermal resources at a temperature from 53 to 120 ℃ above the pre-Paleogene basement units and the site of Matsunoyama hot spring.

4. MATSUNOYAMA TEST FIELD

Matsunoyama 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 ℃, 60 l/min flow. After that, several wells such as takanoyu#2, Kagaminoyu, Yusaka were drilled and these temperature are about 90 ℃.
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℃ and flow rate is about 630 l/min. This production rate is the largest in Matsunoyama spa 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.
The land space for power generation system is about 20 meters square and we can use the space near Takanoyu#3well as shown in figure 5. And near Takanoyu#3 well, a small river exists for cooling water.

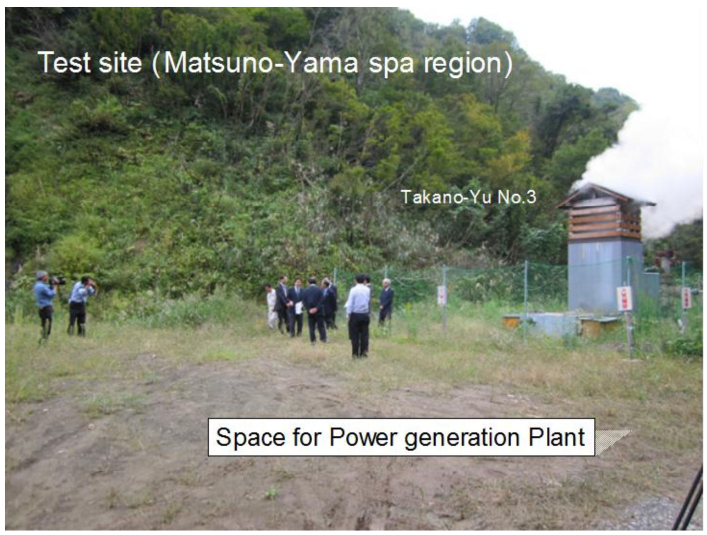

Fig.5 Test site for hot spring power generation

5. 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 5.
From October 2010 the flow rate, temperature and geochemistry of monitoring wells are almost constant and these values will be bachground 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 3700 mg/l Na, 140mg/l K, 2070 mg/l Ca and 27.3 mg/l HCO_3 and did not change from production start at September 2007.
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 5.
During cooling process of hot spring fluid from 100 to 40 ℃, on heat exchanger, quartz (SiO_2) and calcite ($CaCO_3$) are supersaturated, but other minerals such as dolomite ($MgCaCO_3$), amorphous silica (SiO_2) , talc($Mg_3Si_4O_{10}(OH)_2$) and tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$) 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 ℃ 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.

Table 1 Geochemistry of hot spring of Takanoyu#3 and surrounding wells

	Na	K	Cl	SO4	HCO3	Ca	Si	Mg
Takanoyu#3	3700	140	9400	85.5	27.3	2070	66.7	0.6
Yusaka	3708	103	9252	80.0	23.0	1980	36.7	7.7
Takanoyu mixture	3316	122	9201	82.4	23.1	2004	41.9	1.3
Kagaminoyu	3392	83	8764	81.1	19.3	1882	20.1	15.7
kousinnoyu	5680	31	8661	2.6	316.6	205	11.5	44.1

(mg/l)

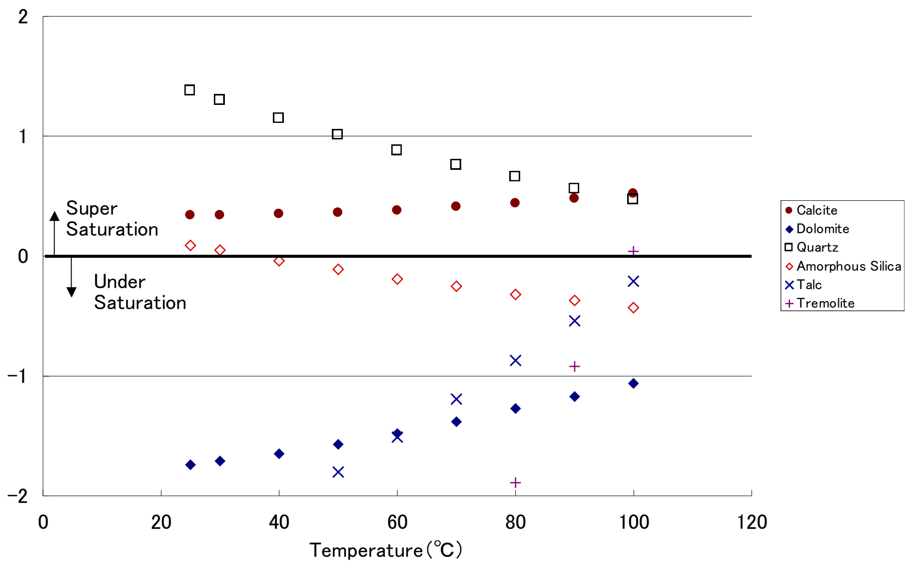

Fig.6 Estimation of equilibrium of scale minerals of Takanoyu#3

6. SUMMARY

We are now preparing a 50 kW class Kalina cycle power generation test at Matsunoyama hot spring field. In this test, we will survey of stability of generation system and environment of hot springs. Recently, several Japanese manufactures are developing small Kalina system for hot spring field. At near future, the system will open a low-temperature geothermal power generation market that enables geothermal power generation including non-volcanic regions in Asia.

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