GEOCHEMICAL PROPERTY OF GEO-PRESSURED RESERVOIR FOR BINARY SYSTEM

Norio Yanagisawa[1], Hirofumi Muraoka[2], Munetake Sasaki[1], Hajime Sugita[1], Masatake Sato[3] and Kazumi Osato[3]

[1]Institute for Geo-Resources and Environment, AIST, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan

[2]Hirosaki University, 2-1-3 Matsubara, Aomori 030-0813, Japan

[3]Geothermal Energy Research & Development Co., Ltd., 1-22-4 Shinkawa, Chuo-ku, Tokyo 104-0033, Japan

n-yanagisawa@aist.go.jp

Keywords: *Hot spring, binary power generation, geo-pressured reservoir, geochemistry, isotope*

ABSTRACT

In central Japan near Matsunoyama the hot spring field in Niigata Prefecture is pressured by the Izu Peninsula, which is defined by the presence of syntaxis. In the Matsunoyama geo-pressured region, the large Matsunoyama dome structure exists, where the natural gas field is characterized by Tertiary sediments.

Generation testing of the 50kW Kalina cycle plant using the fluids fromTakanoyu#3 well, at a fluid temperature of 97 ºC and a flow rate of 300 L/min, has been progressing since 2010. An estimate of the power generation potential and sustainability of the hot spring reservoir in the geo-pressured field is based on the assessment of the geochemistry and historical production data from the Takanoyu#3 well.

The Takanoyu#3 was drilled to a total depth of 1,300 meters in 2007 and its initial production rate was 623L/min. The fluid chemistry from Takanoyu#3 indicated the following concentrations: Cl of 10,000 mg/l, Na of 3,700 mg/l, K of 200mg/l, Ca of 2,100 mg/l and HCO_3 of 36 mg/l, which are similar to those for Takanoyu#2, which was drilled to a depth of 280 meters. The gas composition of the fluid is about 95% CH_4, 1.8% N_2 and 0.5% CO_2. The O-18 and Deuterium isotopes suggest that the fluid is enriched in both isotopes, with data points plotting to the right of the Japan meteoric line and the below that of the sea water.

In the Matsunoyama field, the hot spring Takanoyu#2 well was drilled in 1964 with an initial flow rate measured at about 160 L/min. After 30 years, the production rate of Takanoyu#2 dropped to a constant rate of 100 L/min, about 65 % of the initial flow rate. . Similarly, the production rate of Takanoyu#3 has dropped to about 400L/min, which is likewise about 65% of the initial flow rate.

1. INTRODUCTION

In Japan, several hot springs owners and power generation companies have recently expressed interest in developing small binary power systems using hot spring fluids (Muraoka et al., 2008) as shown in Figure 1.

After the recent nuclear power plant accident (caused by earthquake/tsunami), the Feed-in Tariff (FIT) for small geothermal power plant was set at 42 JPY/kW, which is sufficient to support the development of a small binary system using fluids from hot springs.

Starting in 2010, the Ministry of the Environment (MOE) of Japan gave its support for a hot spring generation project, titled "Development and Demonstration of Small-Grid Power Generation System using Hot Spring Heat Source". 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.

Under this project, power generation testing of the 50kW Kalina cycle system was conducted using 100 °C fluid from the Matsunoyama hot spring field in the Nigata prefecture, in central Japan. The project consists of several components: (1) estimation of long term sustainability and maximum power generation with the existing hot spring flowrate, (2) monitoring the impact of production on the surrounding hot spring system. The major concern of hot spring owners is the sustainability of production if it turns out that a larger volume of fluids is needed to generate the target power output.

To be able to estimate the potential and sustainability of the hot spring reservoir in the geo-pressured field at Matsunoyama, it is necessary to assess the geochemistry and historical production data for the wells drilled in the hot springs area.

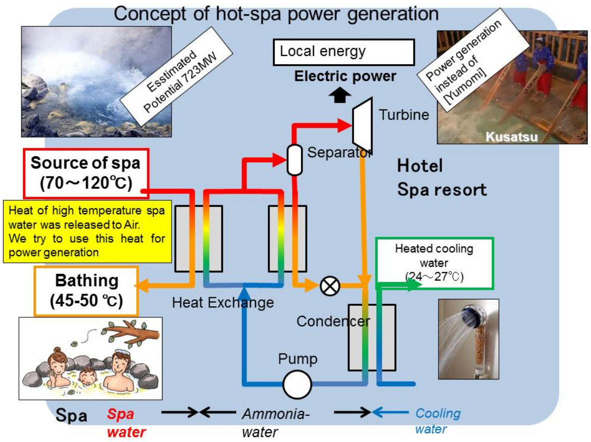

Figure 1: The concept of power generation using hot spring fluids.

2. BINARY SYSTEMS IN JAPAN

The recent nuclear power plant accident influenced the rapid progress in research and development into the use of hot springs fluids for power generation. However, several hot springs owners resisted the introduction of large geothermal power plants due to their possible impact on decreasing the discharge from the hot springs. Their preference is for small binary systems that utilize waste high temperature hot spring fluids without the need for drilling new wells.

Several Japanese companies have ventured into production of new small binary systems. For example, KOBELCO (Kobe Steel, Ltd) developed a 72kW binary system that was made available in October, 2011. This system was installed at Beppu hot spring field in the Oita prefecture and at the Obama field in the Nagasaki prefecture, all in Kyushu Island near a volcanic area. IHI Co. Ltd. likewise developed a 20kW class binary system which was released in August, 2013 while ULVAC-RIKO. Inc. developed a 3kW binary system.

These binary systems use Hydro Fluoro Carbon (HFC) as the heating medium. Since HFC is non-toxic and has low flammability, owners of the HFC binary systems below 300kW size are not required to employ a special licensed engineer usually compulsory for boiler and turbine operation in Japan. On the other hand, owners of Hydrocarbon binary and Kalina (water-ammonia) cycle systems have to employ a special licensed engineer. Even with this requirement, the personnel expense cost for the HFC binary system is a lot cheaper than for large ORC plants, which has greatly influenced the decision of several hot spring owners in choosing a HFC binary system.

However, the HFC binary system has several issues. One is that the Global Warming Potential (GWP) of HFC is very high, at about 1,000 times that of the Carbon Dioxide gas (CO_2). Second, the cost of HFC gas may become higher in future due to an increase in demand. And third, the electrical efficiency of an ORC using HFC gas or Hydrocarbon is lower compared to that of a Kalina system, especially at temperatures lower than 100^{o}C, as shown in Figure 2.

The Kalina cycle system has a relatively high electrical efficiency with a hot spring fluid, and no impact on global warming. However, running cost of a Kalina cycle system is high due to the need for a special licensed engineer. This may be reduced if the safety and stability of the Kalina cycle system can be established. In Japan, a Kalina cycle system has already been utilized at the Kashima works of Nippon Steel and Sumitomo Metal Co. Ltd. (3,400kW) since 1999, and at the Sodegaura works of Fuji Oil Co. Ltd. (3,300kW) since 2007. These systems have been operational for several years now without any issues. Currently, the ongoing production test of a 50kW Kalina cycle system at the Matsunoyama hot spring field using a small generator (Welch et al., 2011) aims to evaluate the safety and stability of the Kalina cycle system and the sustainability of production from the hot spring.

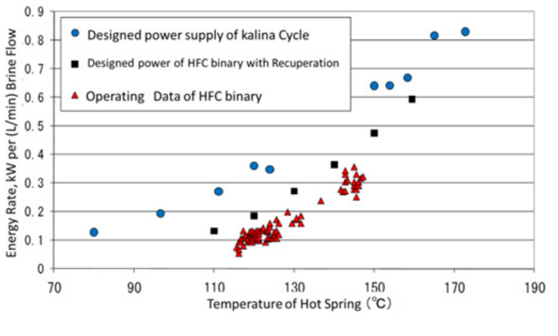

Figure 2: Comparison between the inlet temperature and net electricity output of Kalina and organic Rankine cycles (Osato, 2005).

3. GEO-PRESSURED HOT SPRING

In Japan, high temperature hot springs (about 100^{o}C) are normally located near a volcanic area. However, the Matsunoyama hot spring field, located in Tokamachi city in the middle part of the Niigata prefecture (about 200km NNW from Tokyo), is far from a volcanic area. Further study suggests that the origin of Matsunoyama is a geo-pressured reservoir type.

The geological map of central Japan which includes the Matsunoyama region (Takeuchi et al., 2000) is shown in Figure 3. The central Japan area near the Matsunoyama hot spring field in the Niigata Prefecture is pressured by the Izu Peninsula, which is defined by the presence of syntaxis. In the Matsunoyama geo-pressured region, the large Matsunoyama dome structure exists, where the natural gas field is characterized by Tertiary sediments.

The geo-pressured reservoir is characterized by the following; 1) the source of hot fluid is sea water, captured in the sedimentary basin formation at depth; 2) the hot fluid is present at depths of 2 to 7 km; 3) the pressure of the formation is much higher than the hydrostatic pressure; 4) the hot fluid has methane gas (CH_4); and 5) the heat source is through conduction from the deep crust, with fluid temperatures of over 100^{o}C depending on the heat source and reservoir depth.

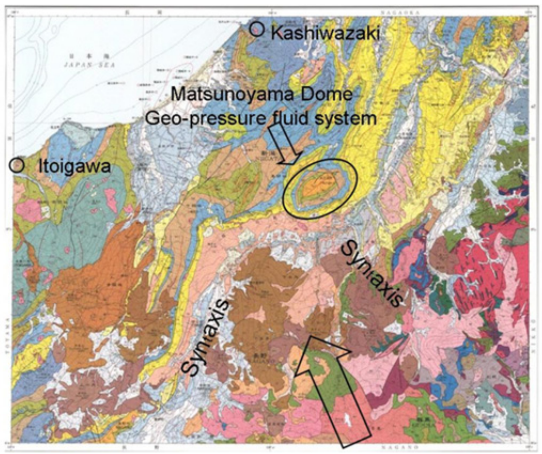

Figure 3: Geological map of central Japan including Matsunoyama region (modified Takeuchi et al., 2000).

4. MATSUNOYAMA HOT SPRING FIELD

There are about 20 hotels and several hot spring wells in the Matsunoyama hot spring field as shown in Figure 4. The oldest well, Takanoyu#1, was drilled in 1938 to a depth of 170 meters, and has a flow rate of 60 L/min and a fluid temperature of about 90 ^{o}C . The second well, Takanoyu#2, was drilled in 1964 to a depth of 284 meters, with an initial flow rate of 160 L/min, of 90 ^{o}C fluid. After 1973, the flow rate dropped to 100 L/min as shown in Figure 5.

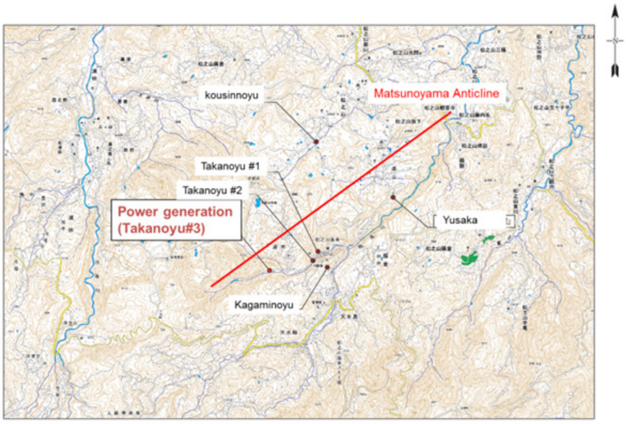

Figure 4: Location of Takanoyu#3 and the surrounding hot spring monitoring wells.

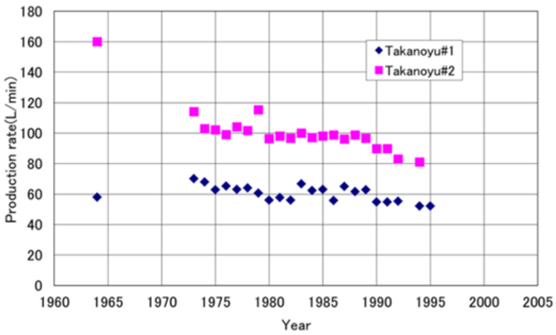

Figure 5: Historical flow rate of Takanoyu#1 and #2 between 1964 and 1995.

In 2007, a new hot spring well, Takanoyu#3,was drilled to a depth of 1,300 meters. During the initial production test, the well had a flow rate of 623 L/min (98°C fluid) which is the largest in the Matsunoyama hot spring field. After the test, the production rate from Takanoyu#3 was controlled to 230 L/min by valve at the wellhead, with a fraction of the fluid (about 120 L/min) released to the river as it was surplus to the demand from the hotels.

Figure 6: The Kalina power generation system using hot spring fluid at Matsunoyama.

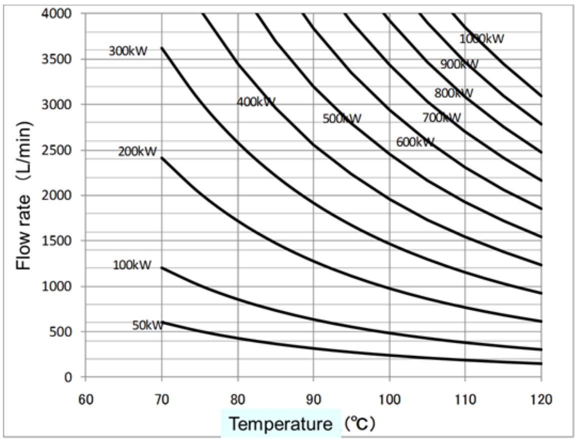

Figure 7: Estimated power generation using the Kalina power generation system based on flow rate and temperature.

In December 2011, a 50kW Kalina cycle power plant was installed with fluid supplied from Takanoyu#3. The plant consisted of a power generator, a heat exchanger with ammonia/water mixture, a separator to separate ammonia gas from water, and an ammonia tank and pumping system. The total plant size is about 5 cubic meters (Figure 6) with the control system inside the building to protect it from a 3 meter depth of snow.

The estimated power generation from the Kalina cycle system, ss shown in Figure 7, depends on the fluid temperature and flow rate. At the Matsunoyama hot spring field, with a fluid temperature of 98°C from the Takanoyu#3 well only about 300L/min of fluid is needed to operate at the full capacity of the 50kW Kalina cycle system.

5. GEOLOGY OF MATSUNOYAMA HOT SPRING FIELD

Figure 8 shows the reverse fault near the top of the Matsunoyama dome including the Takanoyu#3 well. The reverse fault was found by Muraoka *et al.*, (2011). In the Matsunoyama region, the reverse fault exists at the center of an anticline which runs from north to south and leans to the west at depth.

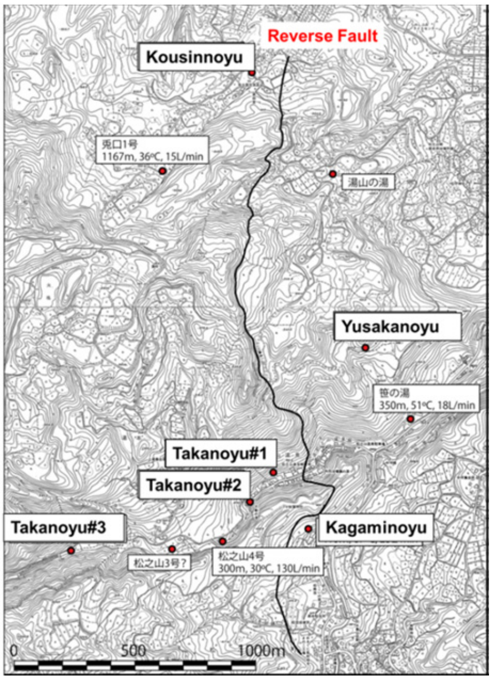

Figure 8: Reverse fault at the top of the Matsunoyama dome.

Figure 9 shows the location of the reverse fault and hot spring wells in Matsunoyama. Wells Takanoyu #1, #2 and #3 are located on the western side of the reverse fault. Takanoyu#1 is 170 meters deep, Takanoyu#2 is 280 meters deep and Takanoyu#3 is 1300 meters deep, with the wells depths proportional to the distance from the fault. The reservoir is spread in a high permeability layer and the layer thickness around Takanoyu#3 is estimated to be more than 300 meter from the geological column. The layers between the reservoirs for Takanoyu#2 and Takanoyu#3 are low permeability sediments, withTakanoyu#2 believed to be connected to Takanoyu#3 through the reverse fault. The source of the hot spring fluid tapped by Takanoyu#1, #2 and #3 come from the deeper reservoir through the reverse fault, and spreads out horizontally along a high permeability sediment layer.

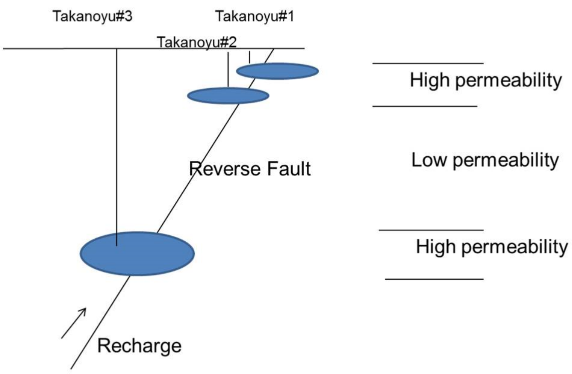

Figure 9: Reservoirs connection around Takanoyu #1, #2 and #3 and the reverse fault

6. GEOCHEMISTRY OF MATSUNOYAMA HOT SPRING FIELD

Table 1 shows the fluid composition of the Matsunoyama wells Takanoyu#3, Takanoyu#2, Yusaka, Kagaminoyu and Kousinnnoyu measured in November 2012, which are all located within a 2 km distance from each other as shown in Figure 8. These wells are considered during the power generation test. All wells have high Cl concentration of about 10,000 mg/l. The close similarity in fluid chemistry between Takanoyu#2 and Takanoyu#3 despite the depth difference supports the concept of the connection between these wells.

Table 1: Hot spring fluid chemistry of Takanoyu#3 and the surrounding wells

	Na	K	Cl	Ca	SO4
Takanoyu#3	3661.0	195.9	10140	2100.0	90.7
Takanoyu#2	3785.0	208.0	9495	2162.0	94.4
Yusaka	3526.0	162.2	10297	1957.0	89.1
Kagaminoyu	3720.0	129.2	9421	1981.0	84.8
Kousinnoyu	5493.0	50.1	9724	222.0	0.0
					(mg/l)

	HCO3	Mg	Si	T_{NaKCa}	Depth
Takanoyu#3	36.1	0.4	50.1	161	1260
Takanoyu#2	39.1	0.6	59.2	162	287
Yusaka	30.5	5.5	40.2	153	1100
Kagaminiyu	39.1	14.4	29.3	141	410
Kousinnoyu	344.7	44.9	9.4	106	356
			(mg/l)	(°C)	(m)

Figure 10 shows the trends in Cl and Na for Takanoyu#2 and Takanoyu#3 which indicate stable trends in both wells. The chemical composition of Takanoyu#3 has remained unchanged since the start of production in September 2007.

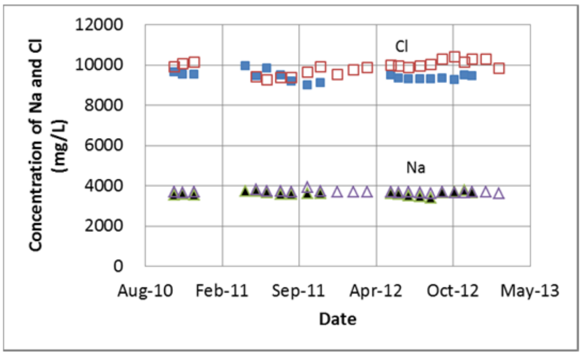

Figure 10: Cl and Na trends from October 2010 to February 2013. The open squares and triangles refer to Takanoyu#3, while the close squares and triangles refer toTakanoyu#2.

Table 2 shows the steam/gas flow rates and gas composition from Takanoyu#3 relative to wellhead pressure change measured in November 2012. The steam/gas flow rates have increased as the well is opened further and the wellhead pressure decreases. The ratio of gas composition remained constant, with about 95 % methane, 1.8% N_2 and 0.5 % CO_2. The methane rich condition is one of properties of a geo-pressured field.

Figure 11 shows the isotopic composition of hot spring fluid of Takanoyu#3 and Kousinnoyu, and sea water and river water, plotted in O-18 and Deuterium isotopes diagram. The data point for the river water plotted along Japanese mean meteoric water line. Fluids from Takanoyu#3 and Kousinnoyu are enriched in both O-18 and Deuterium isotopes, and plotted to the right of the meteoric water line and the below that for sea water. This means that the origin of the hot spring fluid is not the meteoric water but the captured sea water, as is characteristic of a geo-pressured reservoir.

Table 2: Gas ratios and flow rates relative to wellhead pressures at Takanoyu#3.

Wellhead Pressure (MPa)	Steam Flow (ton/h)	Gas Flow (ton/h)	Ratio of gas from Takanoyu#3 (Vol%)					
			CH4	CO2	H2S	H2	N2	O2
0.6	1.24	0.06	94.9	0.38	0.05	0.02	1.82	0.31
0.55	1.40	0.10	94.4	0.53	0.05	0.02	1.86	0.29
0.35	1.63	0.17	94.6	0.39	0.06	0.02	1.48	0.21

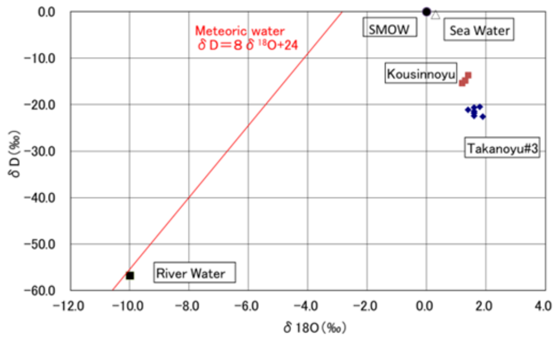

Figure 11: Isotope diagram of hot spring fluid in Matsunoyama field.

7. ESTIMATION OF STABLE FLOW RATE OF TAKANOYU#3

Figure 5 shows the historical flow rates for Takanoyu#1 and #2 from 1964 to 1995. Takanoyu#1 was drilled in 1938, and as shown in the graph its flow rate remained relatively constant at 60 L/min between 1965-1995.Takanoyu#2 was drilled in 1964 with an initial flow rate of 160 L/min, and after 10 years, by 1974, the flow rate had dropped to 100 L/min, and then remained constant from 1974 to 1990 before dropping again to 80 L/min. The observed trend is consistent with the result of the simulation conducted on the Gulf Coast geo-pressured geothermal reservoirs (Esposito *et al*., 2012).

For Takanoyu#3, during the Kalina cycle system production test, about 130 L/min waste fluid out of the 230 L/min of total production was used. This flow rate is less than 40% of the initial flow rate due to limitation in production.

However, from the long-term stable production of Takanoyu#2 and similarity in the geological structure, it was estimated that Takanoyu#3 can supply a maximum production rate of 400 L/min (65% of the initial flow rate) to the 50kW Kalina cycle system for power generation.

8. CONCLUSION

In Japan, there is a wide interest, from several high temperature hot spring owners and companies, in using a binary cycle system for power generation. A production test was carried out in December 2011 on a 50 kW class Kalina cycle system using the Takanoyu#3 well from the Matsunoyama hot spring field. The Takanoyu#3 well fluid chemistry is similar to that for the older Takanoyu#2 well, and based on the fact that the same geological structure is tapped by the two wells and the historical production rate of Takanoyu#2, it was established that Takanoyu#3 can supply a maximum 400 L/min fluid to the 50kW Kalina cycle system for power generation.

The Matsunoyama hot spring fluid chemistry indicates highly saline water with a Cl concentration of 10,000mg/l. The gas composition of the fluid from Takanoyu#3 is mainly methane gas with 95% CH_4, 1.8% N_2 and 0.5% CO_2. The O-18 and Deuterium isotopes suggest that the fluid is enriched in both isotopes, with data points plotting to the right of the Japan meteoric water line and the below that of the sea water.

The geo-pressured reservoir is characterized by the following; 1) the source of hot fluid is sea water, captured in the sedimentary basin formation at depth; 2) the hot fluid is present at depth of 2 to 7 km; 3) the pressure of the formation is much higher than the hydrostatic pressure; 4) the hot fluid has methane gas (CH_4); and 5) the heat source is through conduction from the deep crust, with fluid temperatures of over 100°C, depending on the heat source and reservoir depth.

REFERENCES

Esposito A. and Augustine C.: The influence of reservoir heterogeneity on geothermal fluid and methane recovery from a geopressured geothermal reservoir. Proc. 37th Workshop on Geothermal Reservoir Engineering, Stanford University. 1310-1323 (2012)

Muraoka, H., Sasaki, M., Yanagisawa, N. and Osato, K.: Development of small and low-temperature geothermal power generation system and its marketability in Asia. Proc. of 8th Asian Geothermal Symposium (CD-ROM). (2008)

Muraoka, H., Ioka, S., Yanagisawa, N. Sasaki, M., Sato, M. and Osato, K.: *Geo-pressure type Matsunoyama hydrothermal system in Niigata Prefecture and its preliminary geological survey* (in Japanese). Abstracts of 2011 Annual Meeting of Geothermal Research Society of Japan, Ibusuki, B2. (2011)

Osato, K.: *Applicable condition of Kalina cycle for geothermal power plant* (in Japanese). Journal of the Geothermal Energy Research & Development, 30, No.1&2, pp.53-61. (2005)

Takauchi, K., Yoshikawa, T. and Kamai, T.: *Geology on the Matsunoyama onsen district With Geological Sheet Map at 1:50000* (in Japanese). Geol. Surv. Japan, pp.1-76. (2000)

Welch, P., Boyle, P., Murillo, I. and Sells, M.: Construction and Startup of Low Temperature Geothermal Power Plants. Geothermal Resources Council Transaction, 35, 1351-1356. (2011)

Yanagisawa, N., Muraoka, H., Sasaki, M., Sugita, H., Ioka, S., Sato, M. and Osato, K. : Starting field test of Kalina system using hot spring fluid in Japan. Proc. 37th Workshop on Geothermal Reservoir Engineering, Stanford University. 1350-1355 (2012).