DEVELOPMENT OF A SMALL AND LOW-TEMPERATURE GEOTHERMAL POWER GENERATION SYSTEM AND ITS MARKETABILITY IN ASIA

Hirofumi MURAOKA[1], Munetake SASAKI[1], Norio YANAGISAWA[1] and Kazumi OSATO[2]
[1]Institute for Geo-Resources and Environment, AIST, Central 7, 1-1-3 Higashi, Tsukuba, Ibaraki 305-8567, Japan
[2]Geothermal Energy Research & Development Co., Ltd., Shinkawa Nittei Annex Bldg., 1-22-4 Shinkawa, Chuo-ku, Tokyo 104-0033, Japan
e-mail: hiro-muraoka@aist.go.jp

ABSTRACT

Innovation of a smaller-scale geothermal power generation system will expand the geothermal power market to rural areas where each electricity demand is relatively limited. Innovation of a lower-temperature geothermal power generation system will directly enlarge the geothermal power market because abundance of hydrothermal resource dramatically increases with decreasing resource temperature. For the dual purposes, a development project of a 50 kW class Kalina cycle geothermal power generation system is conducted. Key subjects for the project are down sizing of the hardware with keeping its original energy conversion efficiency and protection of the heat exchanger from mineral precipitates. 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 and remote volcanic islands.

Keywords: geothermal power generation, small system, low-temperature system, Kalina-cycle, applicability, marketability, hot spring power generation, Japan, rural electrification, Asia, Pacific

1. INTRODUCTION

Among the renewable power energy sources, geothermal power generation has a variety of advantages such as a stable, clean, almost cost-competitive and relatively large-scale power source. The geothermal power generation, however, has typical two weak points: one is that the conventional geothermal power generation can only be used in the high-temperature hydrothermal fields near active volcanoes and the other is that the small-scale geothermal power generation systems are rarely available until the present. For example, there is no geothermal power plant in the Kinki, Chugoku and Shikoku Provinces in Japan due to the less volcanic regions and the smallest operating geothermal power plant in Japan is a 220 kW binary plant at Kirishima Kokusai Hotel. The former weak point hampers geothermal developments in non-volcanic fields and the latter hinders geothermal developments in small electricity demand areas such as the rural areas. Even if photovoltaic power is neither stable nor cost-competitive, this can be widely used in most regions and its 3 kW power generation system can be easily disseminated even in rural areas.

If a small and low-temperature geothermal power generation system can be developed, both weak points could easily be cancelled. This sort of the system is not only needed in Japan for a business model of hot spring power generation (Muraoka, 2007), but also needed in Asia and Pacific regions for the rural electrification and geothermal power development in the non-volcanic fields. To establish the hot spring power generation business model, we, the Geothermal Energy Research & Development Co., Ltd. (GERD) and Institute for Geo-Resources and Environment (GREEN), AIST, cooperatively applied the “Development of the Hot Spring Ecogene (ecology + co-generation) System” project to a RD&D grant competition for new energy ventures in the New Energy and Industrial Technology Development Organization (NEDO) and this proposal was adopted in 2007. This project will provide one of the smallest and lowest-temperature geothermal power generation systems and will open a new geothermal power market.

This paper describes an outline of our ongoing project for the development of a small and low-temperature geothermal power generation system, and emphasizes how much the system can be widely applied in Asia-Pacific regions.

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

Fig. 1 A turbine and generator in the Unterhaching geothermal power plant, Germany, 8 August 2008 (Photo by Muraoka).

Fig. 2 A 3.4 km deep production well in the Unterhaching geothermal power plant, Germany, 8 August 2008 (Photo by Muraoka).

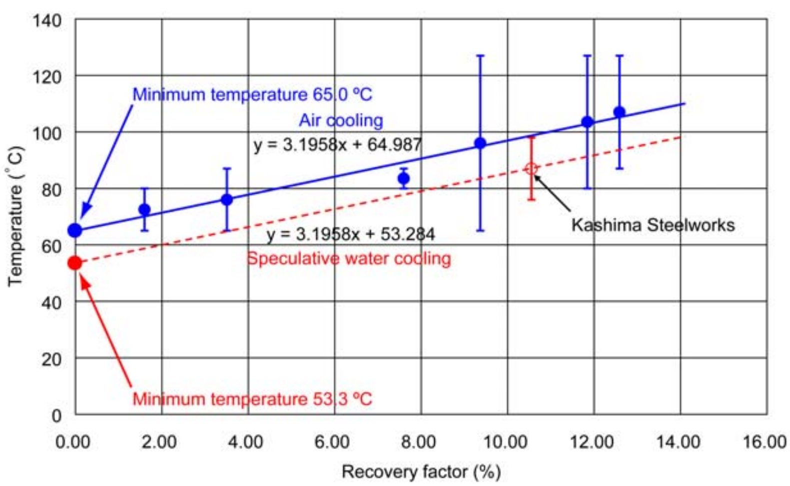

Fig. 3 Relation between the inlet water temperature and recovery factor in the net electricity output ratio to the thermal energy input in the Kalina cycle (Muraoka, 2007; Osato, 2003).

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. An Uehara cycle using the same ammonia-water mixture is invented by Prof. Haruo Uehara in 1994, improving the applicable temperature down to the ocean thermal energy conversion. However, the Uehara cycle uses two turbines and seems inadequate for a small-end and maintenance-free system.

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 (Fig. 1), 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 (Fig. 2). Several geothermal Kalina cycle power plants from 10 to 37 MW are now under construction in the western USA.

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

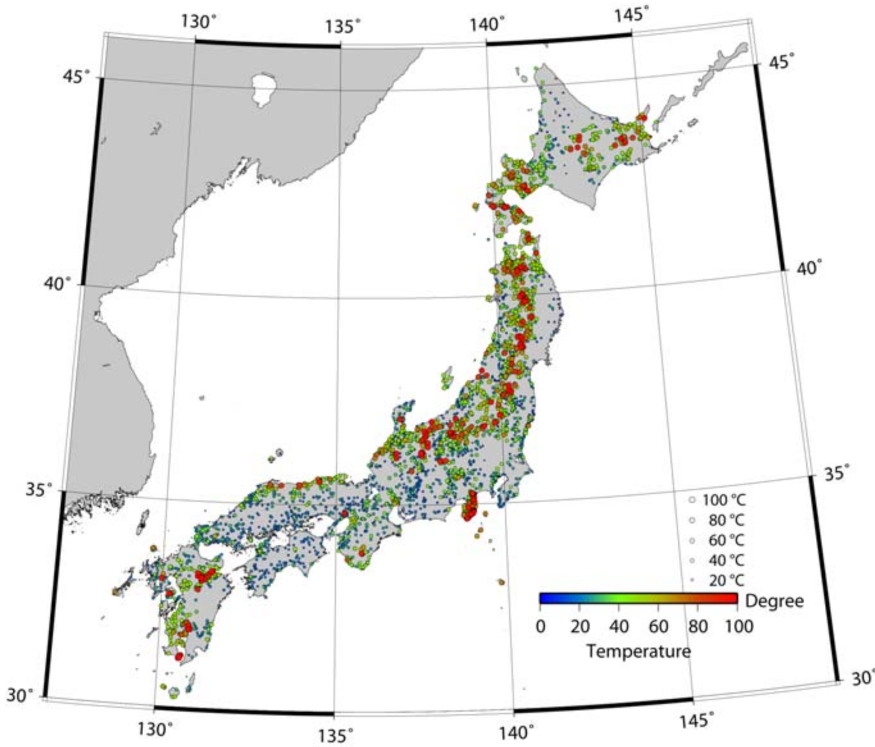

Fig. 4 Distribution of 3,686 hot spring sources in Japan (Muraoka et al., 2006), part of the entire sources 28,154.

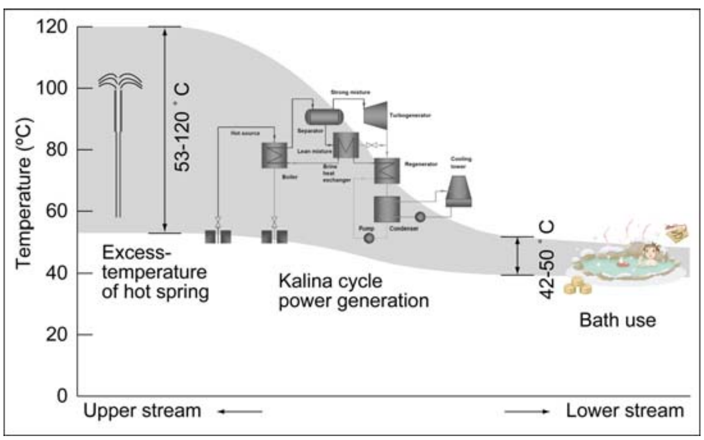

Fig. 5 A business model of hot spring power generation (Muraoka, 2007).

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.

3. A BUISINESS MODEL OF HOT SPRING POWER GENERATION IN JAPAN

Geothermal power development was stagnant in Japan for the last ten years (Muraoka, 2007). One of the serious obstacles specified in Japan is the conflict with numerous hot spring spas. The hot spring bath use is one of the most popular leisure in Japan. As of March 2007, there exist 28,154 hot spring sources in Japan (Ministry of the Environment, 2008) that occupy almost entire on-shore territories (Fig. 4). Geothermal power developments used to be often abandoned in hot spring areas, particularly in the large-scale hot spring resort areas.

Thermal energy above a bath use temperature 42 ºC in the high-temperature hot springs is, however, entirely wasting until the present. Moreover, to cool the excess temperature down to the bath use temperature without dilution of balneological constituents, hot spring owners are making various efforts such as cooling by a long channel or stirring by human power.

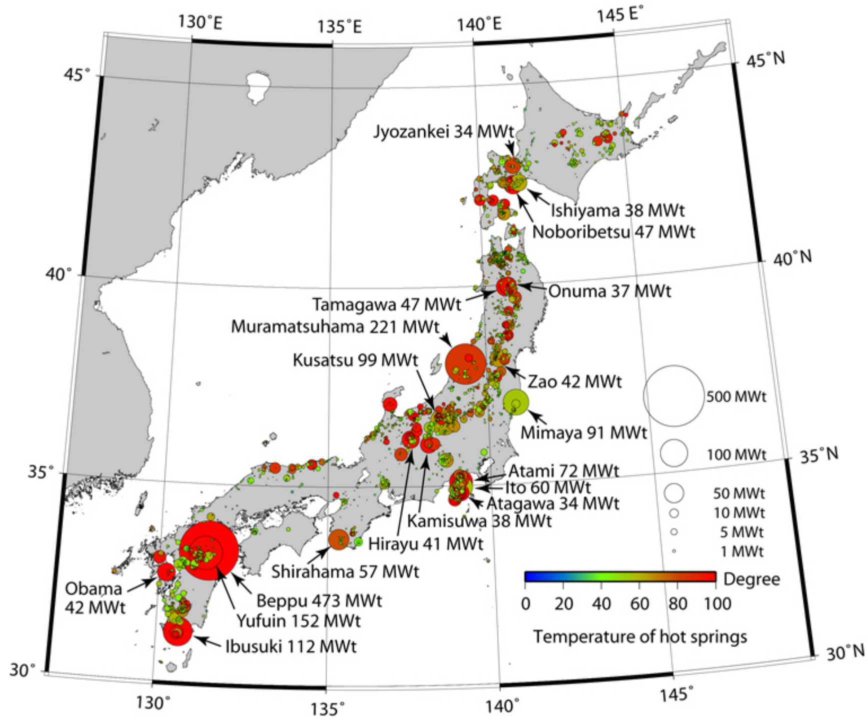

Fig. 6 Distribution of major fields for the hot spring power generation utilizing the currently wasting energy in Japan.

Then, a reversal idea is obtained that the numerous hot springs as a present obstacle should turn to be geothermal power sources as shown in Fig. 5 (Muraoka, 2007).

If we incorporate a small-scale Kalina cycle power generation system into the upper stream of the high-temperature hot springs, we could obtain a double advantage; one is to obtain electricity and the other is to 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 (Fig. 5). This idea can be called a hot spring power generation business model. The third merit of this business model is to mitigate the conflict between geothermal and hot spring sectors.

To realize the hot spring power generation business model, development of a small-scale Kalina cycle power generation system is needed, because a discharge rate of each hot spring source is commonly small. Then, we GERD and GREEN, AIST, cooperatively applied the "Development of the Hot Spring Ecogene (ecology + co-generation) System" project to a NEDO RD&D grant competition for new energy ventures. An objective of this project is to develop a 50 kW class Kalina cycle power generation system.

4. PROJECT FOR DEVELOPMENT OF THE HOT SPRING POWER GENERATION SYSTEM

The project for the "Development of the Hot Spring Ecogene System" was adopted as a feasibility study (phase I) for FY2007 in August 2007. The results of the feasibility studies were positively evaluated by the NEDO Evaluation Committee, March 7, 2008 and our project stepped up to the two years' development stage (phase II) for FY2008-2009. An objective of the phase II is to develop a 50 kW class Kalina cycle power generation system that will be completed in March 2010 (Muraoka and Osato, 2008). Since the phase II has just started, we here describe outline results of the phase I and a future plan for the phase II.

This project mainly consists of three subjects: (1) market evaluation, (2) development of a method to inhibit mineral precipitates, and (3) development of hardware. GREEN, AIST is in charge of the subjects (1) and (2), and GERD is in charge of the subject (3).

When we apply a 50 kW class Kalina cycle power generation system to currently wasting energy from high-temperature hot springs (Fig. 6), available electricity is statistically estimated to be 723 MW where hot springs with their output electricity

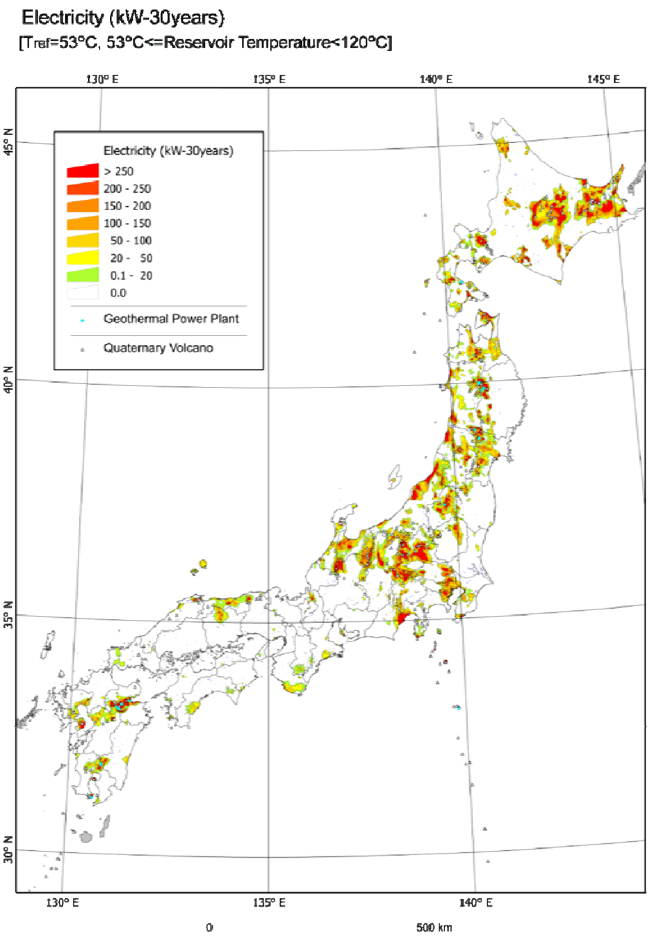

Fig. 7 Distribution of hydrothermal resources at a temperature from 53 ºC to 120 ºC above the pre-Paleogene basement units.

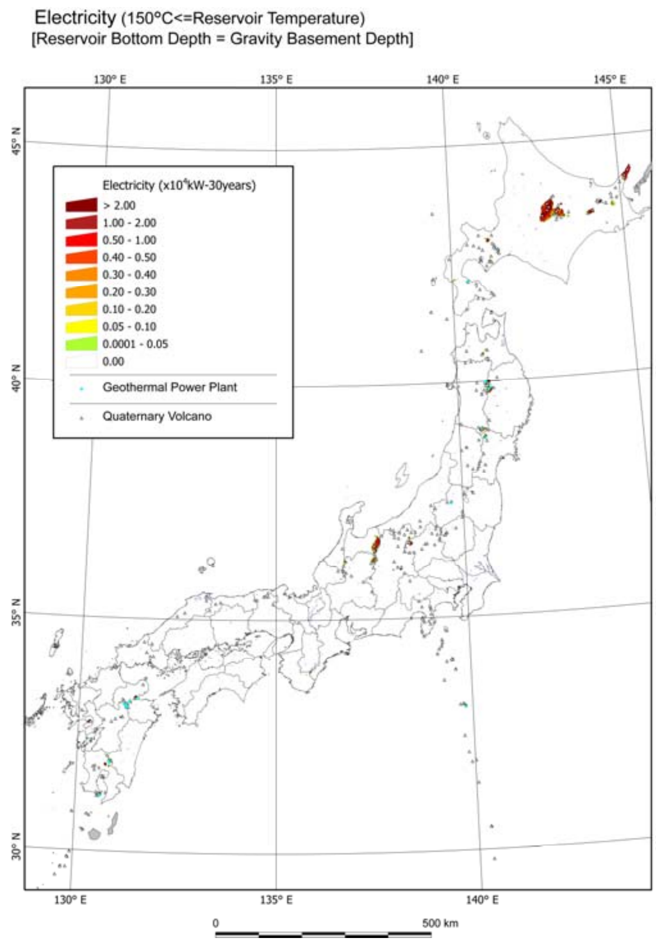

Fig. 8 Distribution of hydrothermal resources at a temperature higher than 150 ºC above the pre-Paleogene basement units (Muraoka et al., 2008).

less than 30 kW are ignored. The number of objective hot spring sources is statistically estimated to be 1,591. This electricity can be easily obtained without any new drilling. 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. 7), where hydrothermal resources higher than 120 ºC are ignored. Compared with the potential areas of the hydrothermal resource higher than 150 ºC (Fig. 8; 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).

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). The most serious mineral precipitates in the hot spring temperature range is thus calcium carbonates such as calcite and aragonite. Then, a precipitation test was conducted in the Otari geothermal field, Nagano prefecture, Japan from January to February 2008 for 19 days (Figs. 9 and 10). The very thin precipitation of aragonite is observed on the surface of a thermal water side blade of a heat exchanger, whereas very thick precipitation of aragonite is observed on the surface of a cooling water side blade of a heat exchanger (Fig. 11). The weight gain of the blade is 20 times larger in the latter than in the former (Yanagisawa et al., 2008). This is basically explained by the special habit of calcium carbonate minerals where the solubility of them decreases with increasing temperature. Their solubility behaviors are basically explained by the chemical equilibrium so that a method to inhibit mineral precipitates seems not very difficult. We have a plan to investigate the effect of the physical separation by the Cyclone separator, solubility control by CO_2 injection and electrochemical separation by the electrode during the phase II (Fig. 12).

Fig. 9 A precipitation test in the Otari geothermal field, Nagano Prefecture, Japan, 19 January 2008 (Photo by Muraoka).

Fig. 10 A precipitation test facilities in the Otari geothermal field, 20 January 2008 (Photo by Muraoka).

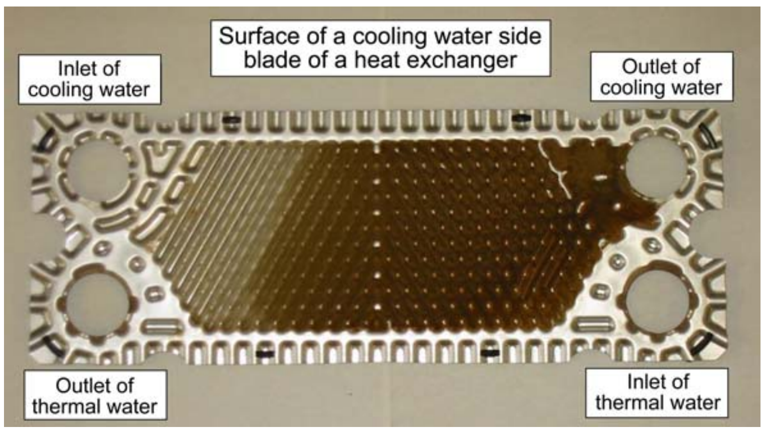

Fig. 11 Surface aragonite precipitation of a cooling water side blade of a heat exchanger (Photo by Yanagisawa).

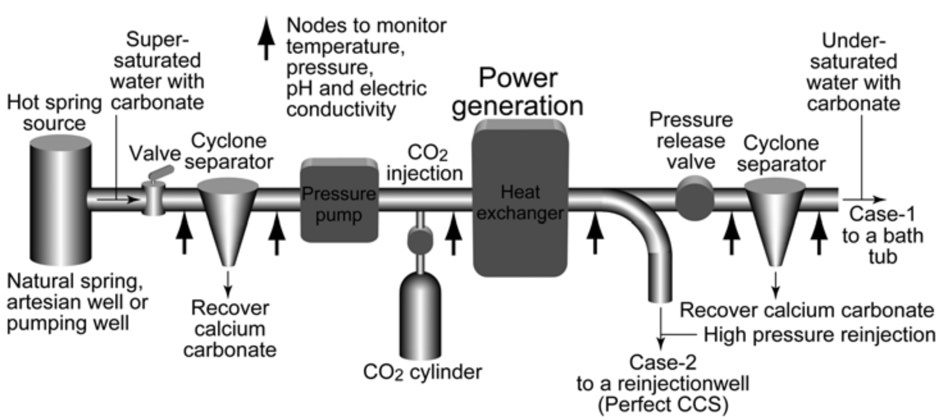

Fig. 12 A concept of methods to inhibit mineral precipitates.

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. 13; Osato, 2005). This efficiency should be kept as far as possible

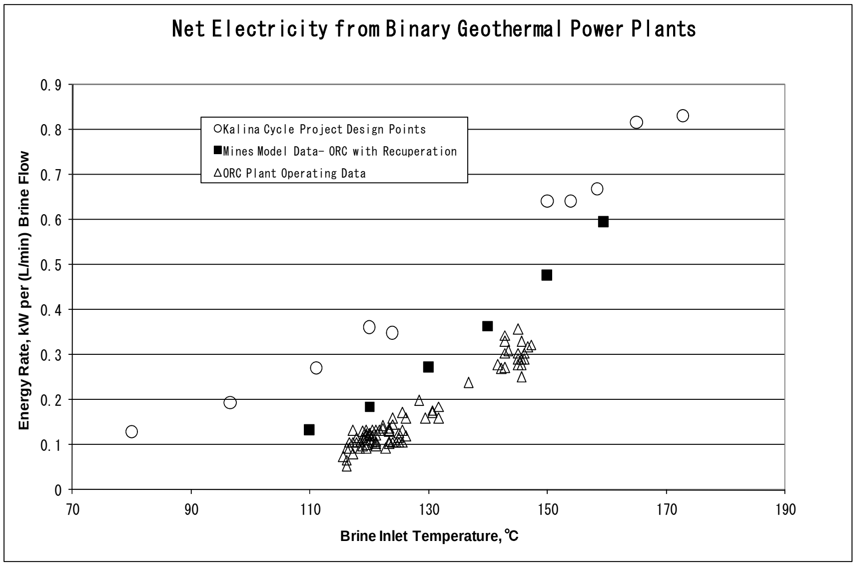

Fig. 13 Comparison between the inlet temperature and net electricity of Kalina and organic Rankine cycles (Osato, 2005).

Fig. 14 The thermal water produced at a temperature of 91 ˚C and at a pumping rate of 3,333 L/minute from the 3000 m depth well at the Xian Athletic School in Xian, China, 12 October 2004 (Photo by Muraoka).

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.

5. DISCUSSION: MARKETABILITY IN ASIA-PACIFIC REGIONS

The development of the 50 kW Kalina cycle power generation system will open a low-temperature geothermal power generation market. This effect can be typically seen in the comparison of Figs. 8 and 7 in Japan. The same effect is also expected in Asia. For example, geothermal power plants in China have been restricted in southern Tibet and southeastern provinces by this time, but the thermal water produced at a temperature of 91 ˚C and at a pumping rate of 3,333 L/minute from the 3000 m depth well at the Xian Athletic School in Xian can be easily utilized for the Kalina cycle power generation (Fig. 14). Likewise, as described by Song (2006), the artesian well overflowing amounts of brine water at a temperature of 70 ˚C in Seokmo-Do near Incheon would have high probability to be developed as a first geothermal power plant in Korea.

Fig. 15 shows heat flow data points in Asia (University of North Dakota, 2008). The data are unevenly distributed and some part seems not reliable such as the Philippines where the data are biased in non-geothermal fields. However, Fig. 16 would provide a broad heat flow pattern in Asia-Pacific regions. If we assume an average atmospheric ground surface

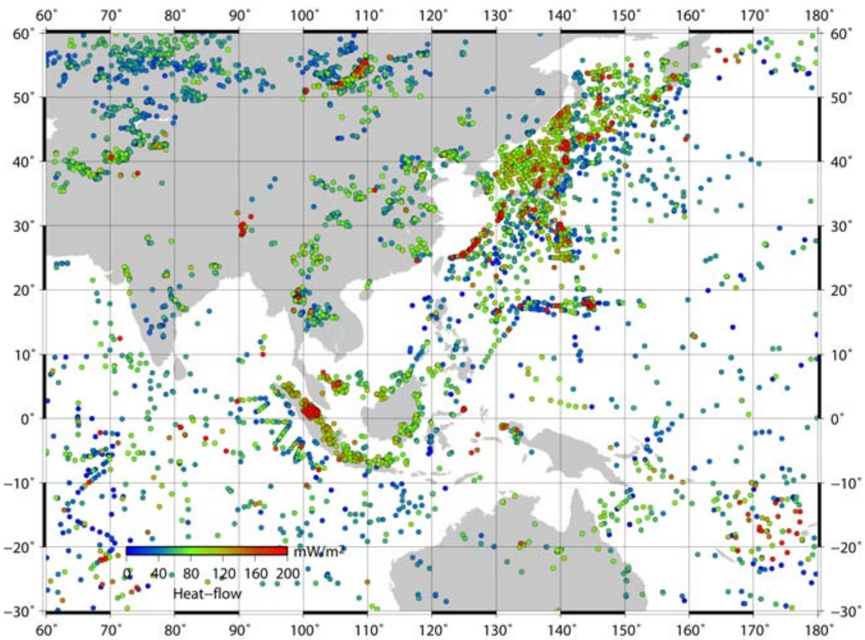

Fig. 15 Heat flow data points in Asia (University of North Dakota, 2008).

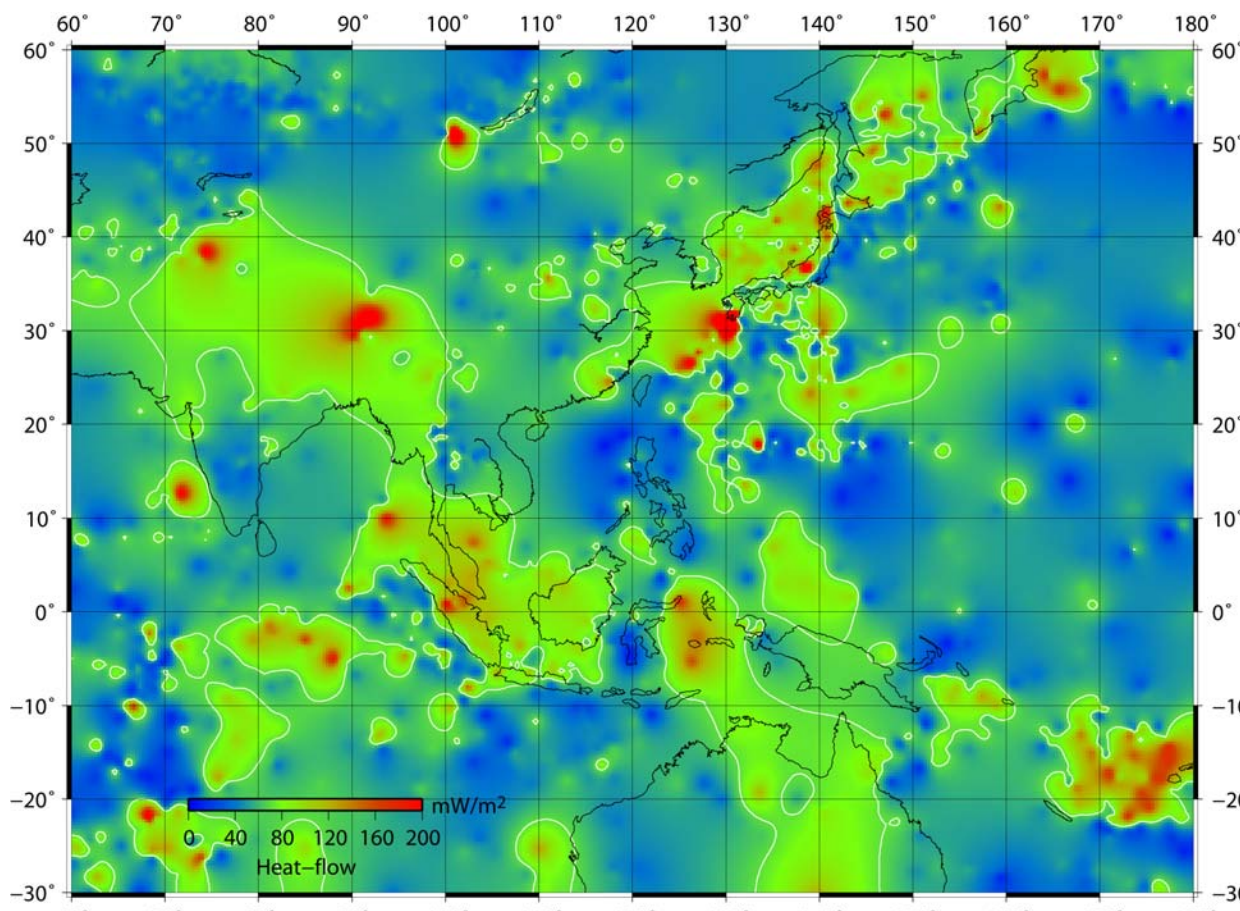

Fig. 16 A heat flow contour map in Asia (University of North Dakota, 2008). A thick white contour shows the heat flow value 70.8 mW/m^2 roughly reaching a temperature 100 ˚C at a depth of 2 km. Although it is a very rough estimate, the inside of the contour may be applicable fields for the Kalina cycle power generation.

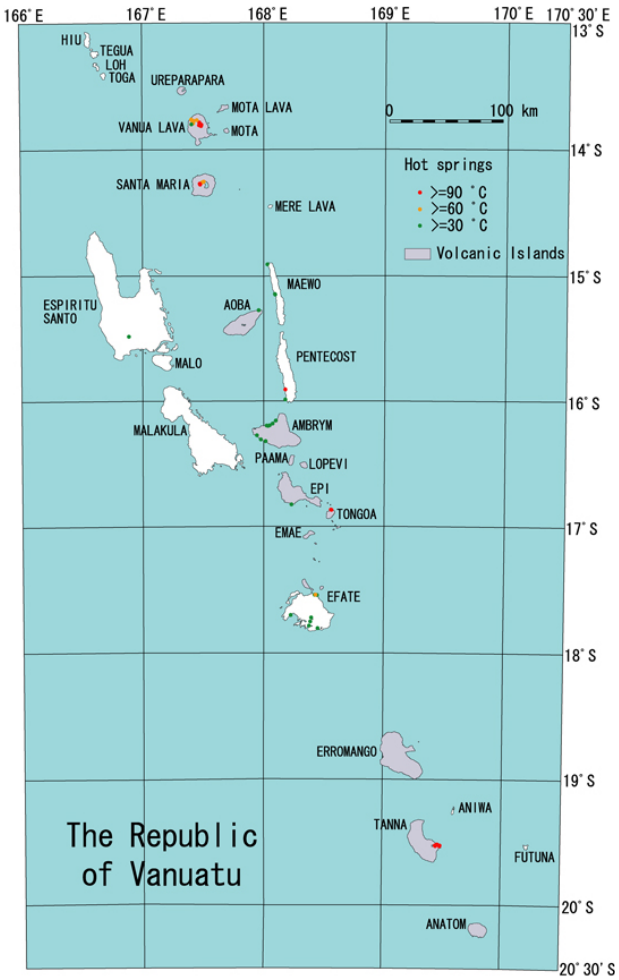

Fig. 17 Volcanic and non-volcanic islands in Vanuatu (Horikoshi et al., 2002).

Fig. 18 Boiling of salt water (seawater) at 100.6 ˚C at the northern shore of Tongoa Island, 16 March 2002 (Photo by Muraoka).

Fig. 19 Boiling of salt water (seawater) at 100.6 ˚C at northern shore of Tongoa Island, 16 March 2002 (Photo by Muraoka).

temperature to be 15 ˚C and an average thermal conductivity of rocks to be 0.004 cal cm^{-1} sec^{-1} ˚C, a thick white contour in Fig. 16 shows a thermal gradient of 42.5 ˚C/km. This contour roughly indicates 100 ˚C at a depth of 2 km, and high-heat flow areas greater than the contour may be prospective fields for the Kalina cycle power generation systems. They are much wider than the volcanic fields.

The development of the 50 kW Kalina cycle power generation system will also open a geothermal power generation market for small demand areas. There are numerous small volcanic islands in Asia-Pacific regions such as in eastern Indonesia, Papua New Guinea, Solomon Islands, Vanuatu, Fiji Islands and Tonga. Fig.17 shows the islands of Vanuatu, most of which are volcanic origin (Horikoshi et al., 2002). Steaming grounds are observed in Tongoa Island, Vanuatu, showing a high geothermal potential (Figs. 18 and 19). However, the island is not electrified at this moment and the demands for electricity is very limited. The same situation is often found in volcanic islands in Asia-Pacific regions where small power generation systems are adequate to use.

6. SUMMARY

We are now developing a 50 kW class Kalina cycle power generation system. The system will open a low-temperature geothermal power generation market that enables geothermal power generation in non-volcanic regions in Asia. The system will also open a geothermal power generation market for small electricity demand areas and will be utilized in numerous volcanic islands in Asia-Pacific regions.

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