Small Capacity Geothermal Binary Power Generation System

Shigeto Yamada
Hiroshi Oyama

1. Introduction

Japan is a volcanic country having abundant geothermal resources. To date, Japan has 20 geothermal power generation facilities, with a total installed capacity of 550 MW. Most of these facilities are large capacity geothermal power plants constructed by utility power companies, but due to various circumstances, there are no further plans to build large capacity plants in the near future. The New Energy and Industrial Technology Development Organization (NEDO) is continuing its program of Geothermal Development Promotion Surveys, which since 2003 have targeted the development of small and medium capacity resources. There are many high temperature wells and steam discharge sites in Japan which are not utilized. Various studies are being carried out to expand the usage of such geothermal energy sources that are not currently utilized for domestic energy generation. Efforts are underway to promote the use of natural resource-based energy systems, including geothermal energy, and this initiative is known as EIMY (energy in my yard).

In addition, RPS (renewable portfolio standard) legislation mandating the utilization of electricity generated from renewable energy has been enacted in many countries. In Japan, the RPS became effective in April 2003. The renewable energy required for use in accordance with the RPS includes geothermal energy. Consequently, utilization of low temperature geothermal resources for electricity generation, which was not considered previously, is now being planned.

For small scale or low temperature geothermal resources, it is sometimes more economical to use a binary power generation system having a lower boiling point medium than that of conventional geothermal steam turbines.

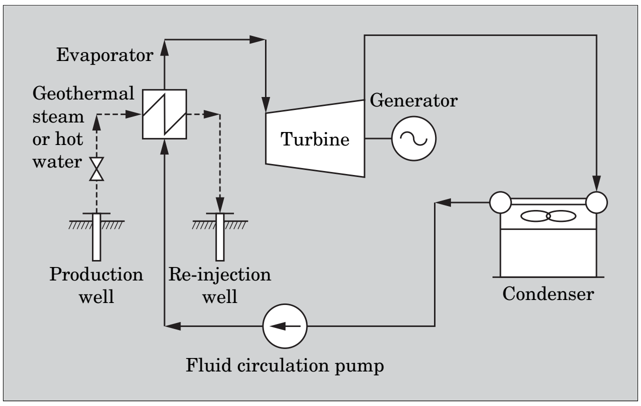
In consideration of these circumstances, Fuji Electric is developing a small capacity geothermal binary power generation system.

2. Binary Power Generation System

Geothermal binary power generation systems utilize a geothermal resource (steam or hot water) as a heating source to evaporate a low boiling point fluid, which drives a turbine. Such a system is called a "binary power generation system" because it uses two different kinds of fluids, geothermal fluid and low boiling point fluid. Figure 1 shows a conceptual schematic diagram of a geothermal binary power generation system. In Japan, binary systems were experimentally operated for 5 years beginning in 1993 by NEDO (new energy and industrial technology development organization). During that experimental operation, hydrochlorofluorocarbon (HCFC) was used as the low boiling point fluid, however, HCFC use must be abolished by 2020. There is a manufacturer abroad who has commercialized a binary power generation system that uses hydrocarbons such as butane or pentane. Another system is the so-called "Kalina cycle" which uses a mixture of ammonia and water.

In countries such as the USA, Philippines, New Zealand and Iceland, binary power generation systems are widely utilized for geothermal power generation at facilities ranging in capacity from several hundreds of kW to tens of thousands of kW. The binary power generation system by Ormat Industry, Inc. that uses pentane is especially well known and has been delivered to many geothermal countries. One of those systems has been delivered to Japan at the Hachobaru Geothermal Power Station of Kyushu Electric Power Co., Inc. as a pilot machine. Several published papers

Fig.1 Schematic diagram of binary power generation system



describe small capacity geothermal binary power generation systems of other manufacturers that are being operated in Europe. In Japan, there are no manufacturers supplying geothermal binary power generating systems as commercial products, although there have been instances of experimental operation. When importing a power generation system from overseas, the owners of the small capacity geothermal binary power generation system may require technical support from Japanese engineers to comply with Japan's various requirements such as documentation and inspections in accordance with the Electricity Utilities Industry Law. There might also be some concerns regarding the after sales service of the imported system. In this regard, we consider it quite important that small scale geothermal binary power generation systems be supplied by Japanese manufacturers.

The first geothermal power generation experiment was successfully carried out in Italy in 1904(1), and the experimental system reportedly used a steam engine driven by steam obtained from pure water evaporated by the geothermal steam. This system is one type of a binary power generation system.

A binary power generation system is driven by the vapor of fluid different from the heat source, and such heat source is not necessarily a geothermal resource. In Minakami, Gunma, a binary power generation system has been constructed and operated utilizing steam generated by an RDF (refuse derived fuel) boiler. A binary power generation system can be used to generate electricity from various heat sources such as industrial waste heat.

3. Development Through Experimental Operation

Fuji Electric is proceeding with the development of a geothermal binary power generation system, aiming at the Japanese market of small scale low temperature geothermal resources as well as geothermal resources throughout the world which may be suitable for a binary system.

Binary power generation systems use the Rankine cycle and basically apply the technologies associated with thermal power generation systems. One of the most important issues is the selection of the most appropriate and economical low boiling fluid, which effectively functions between the high heat source (geothermal resource) and the low heat source (atmosphere). Once a fluid is selected, the heat cycle can be planned with a simpler heat balance calculation than for a conventional thermal power plant.

The other important issue is the selection of optimum design conditions so that the design is both efficient and economical. It is also important to apply appropriate measures to prevent leakage of the fluid. Economical design is quite important for a small capacity system.

Fuji Electric plans the experimental operation of a prototype binary power generation system and intends to develop a product series based on the results of study and evaluation of the experimental operation.

4. Prototype System

4.1 Overview of prototype system

In consideration of the targeted heat source (low temperature geothermal resources) Fuji Electric decided to use iso-pentane which effectively evaporates with such heat sources and condenses at atmospheric conditions. Although iso-pentane is a flammable gas, it can be safely used with proper design and handling. Moreover, since the similar hydrocarbon of butane is recently being used as a cooling medium for home-use refrigerators, it is likely that the usage of hydrocarbon will be easily accepted by future owners.

In order to facilitate proper evaluation of the results from the experimental operation, the prototype system has been designed in consideration of the geothermal resource temperature at the actual well site. It is expected that a mixture of geothermal steam and hot water will be used, and that the separated hot water will be used for pre-heating and the separated steam will be used for evaporating at the pre-heater and the evaporator respectively. Also, an air-cooled type condenser is used because large amounts of cooling water will not always be available at sites where the binary power generation system will be installed. The prototype system is designed with a simple cycle, that is, the pentane vapor evaporated through the pre-heater and the evaporator drives the turbine, pentane vapor exhausted from the turbine is condensed at the condenser, and the condensed pentane is pumped back to the pre-heater.

Figure 2 shows the main flow diagram of the prototype system, and Fig. 3 shows an overview of the prototype system.

In order to realize an economical system, the prototype system is designed with general products and technologies, and does not require the development of any new equipment or materials.

4.2 Pre-heater and evaporator

Both the pre-heater and evaporator use the geothermal fluid as their heat source. In general, the geothermal fluid contains calcium carbonate or silica which causes scaling, and therefore, the pre-heater and the evaporator should be designed with a construction that enables easy periodic cleaning of the internal works. For the prototype system, shell-and-tube type heat exchangers are utilized, and the geothermal fluid flows on the tube side. Table 1 lists major features of the pre-heater and the evaporator.

4.3 Turbine and generator

Iso-pentane is non-corrosive to metals, and there-

Fig.2 Main flow diagram of prototype system

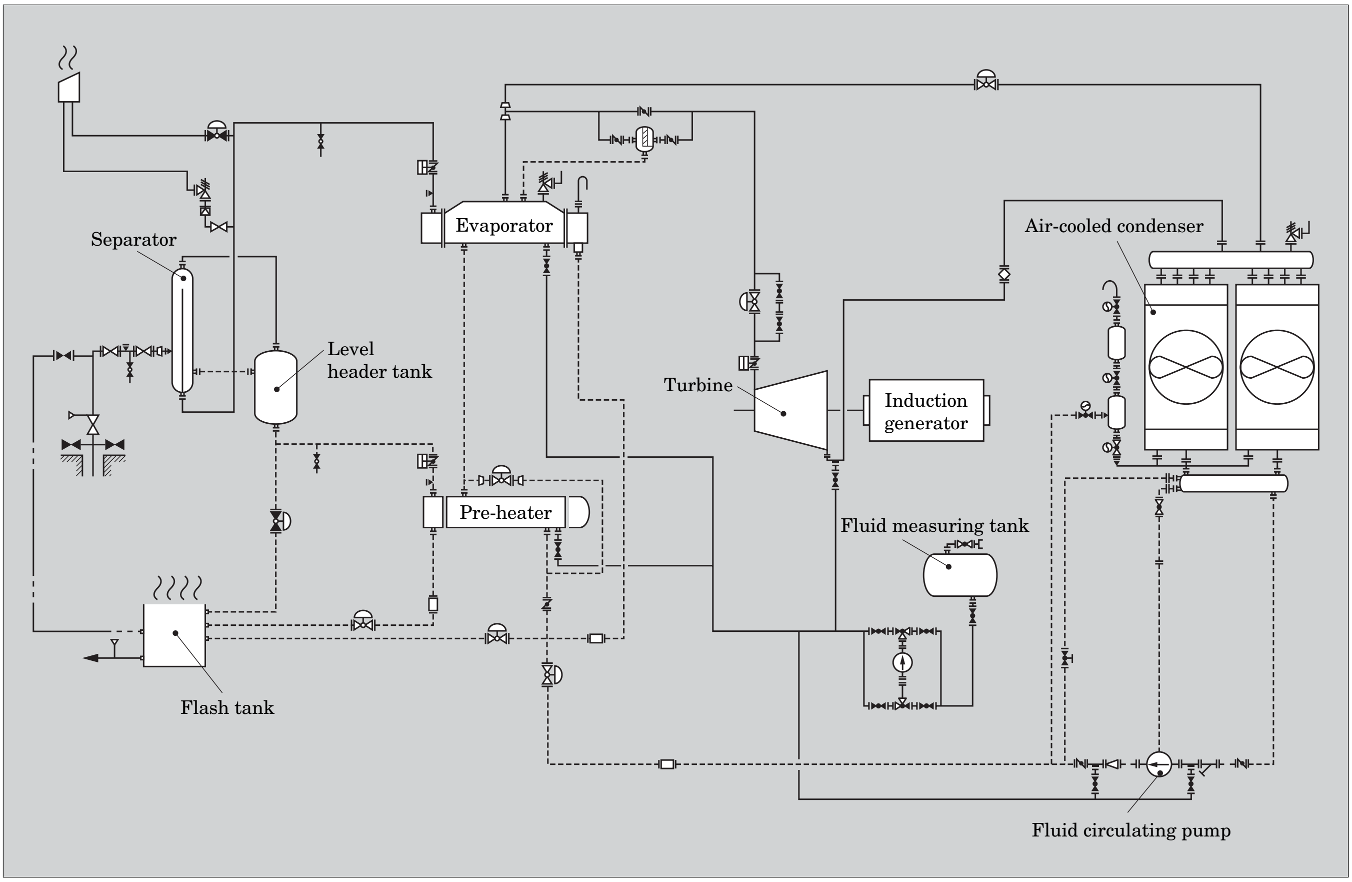


Fig.3 Overview of prototype system

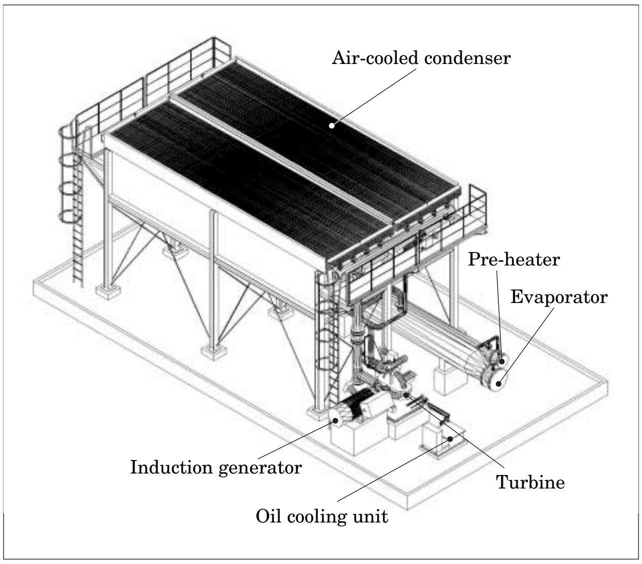


Table 1 Features of pre-heater and evaporator

	Item	Major features
Pre-heater	Type	Horizontal shell-and-tube type
	Capacity	720 kW
	Temperature Inlet / outlet	Iso-pentane : 36 / 84°C
		Geothermal hot water : 130 / 100°C
Evaporator	Type	Horizontal shell-and-tube type
	Capacity	1,990 kW
	Temperature Inlet / outlet	Iso-pentane : 84 / 105°C
		Geothermal hot water : 130 / 130°C

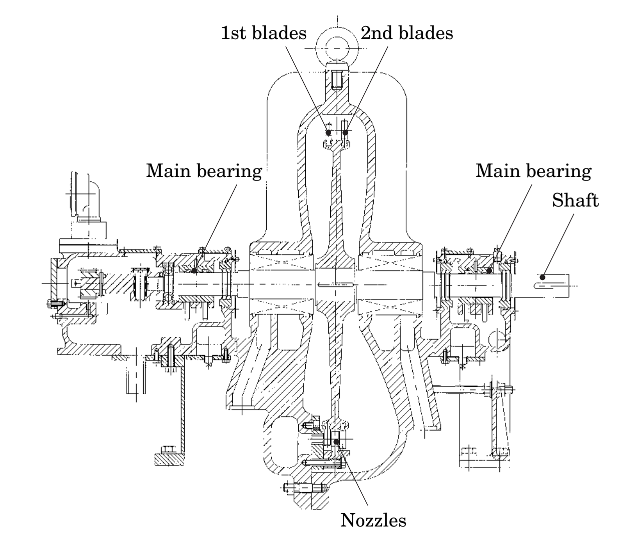
Table 2 Features of turbine and generator

	Item	Major features
Turbine	Type	Horizontal, single stage, impulse type
	Output	220 kW (maximum)
	Speed	1,800 min^{-1}
	Type of shaft seal	Dual mechanical seal
Generator	Type	Three phase induction type
	Output	250 kW
	Speed	1,800 min^{-1}

fore, a standard single-stage steam turbine is utilized. However, a dual mechanical seal system is applied at the shaft seals to eliminate any leakage of iso-pentane from the shaft ends.

Because a standard induction generator is utilized, a speed governor is not provided for the turbine. Therefore, the use of a standard turbine stop valve and governing valve is unnecessary, and instead, a standard process stop valve and control valve which have no fluid leakage can be used. The control valve is used

Fig.4 Section of turbine



to regulate the inlet pressure so as to maintain the evaporator outlet vapor pressure. The stop valve closes immediately at the occurrence of an emergency and stops the turbine and the generator.

Table 2 lists major features of the turbine and the generator. Figure 4 shows a cross-sectional view of the turbine.

4.4 Air-cooled condenser

As described above, the air-cooled condenser is considered as the primary option, and the prototype system also employs air-cooling with fin-tubes. The air-cooled condenser is the largest component in the system and determines the dimensions of the system. When large amounts of water can be used for the purpose of cooling, a water-cooled condenser may be used to achieve a smaller sized system.

5. Conclusion

The prototype system will be constructed within the fiscal year of 2005, and experimental operation will be commenced thereafter. Fuji Electric intends to expand the utilization of low temperature geothermal energy in Japan and throughout the world by providing economical and easy-to-operate binary power generation systems, and anticipates that all forms of renewable energy and natural energy will be recognized as important energy sources. Furthermore, Fuji Electric hopes that the expanded utilization of renewable and clean geothermal energy will contribute to preservation of the global environment and will enable society to leave natural resources for our future generations.

Reference

(1) Geothermal Resources Council: Stories from a Heated Earth. 1999.