

# Geothermal Steam Turbines for Various Purposes

Shigeto Yamada

## 1. Introduction

Geothermal power generation was first experimentally developed in Italy in 1904, and commercial power generation also commenced in Italy in 1913. At first, geothermal power generation utilized natural steam from production wells. The first flash system was went online in 1958 in New Zealand, and the subsequent installation of geothermal power plants spread throughout the world.

As of 2000, the total installed capacity of geothermal power generation units worldwide is about 8,000MW (Fig. 1). Most plants utilize flash cycle technology and are constructed only for power generation.

In cases where the resource temperature is not high enough to generate steam efficiently above atmospheric pressure, binary cycle technology has been utilized. Even for such low temperature geothermal resources, it is possible to plan for steam turbines that utilize flash cycle technology. Although binary cycle technology offers the greatest benefit, that is, it does not emit non-condensable gases including hydrogen sulfide gas into the atmosphere, it uses working fluids other than water, which makes system operation and maintenance more sensitive and costly compared to flash cycle technology.

Here, two samples of geothermal power plants having other functions in addition to power generation are introduced. One is the Svartsengi Unit 5 in Iceland, which has two extractions pipes for the heating steam used in district heating. The other is Salton Sea Unit 5, which has two intake pipes from a mineral recovery plant. Also a plan for a geothermal steam turbine for use with a very low pressure (VLP) flash system is introduced.

The proprietary technology Fuji Electric employs in its geothermal steam turbines will contribute to satisfying the various requirements for the efficient utilization of geothermal energy.

## 2. Svartsengi Unit 5 (30MW)

Iceland has been utilizing the geothermal resource-

es for district heating. Sudurnes Regional Heating Corp. (SRH), a company that supplies hot water to its local community, operates the Svartsengi Geothermal Power Plant consisting of the back pressure turbine unit, binary units and a condensing turbine unit. Unit 5 is of the condensing type, and has two output ports to supply the heating steam for the district heating water. Unit 5 was delivered to the plant in 1998 and

Fig.1 Installed capacity of geothermal power plants

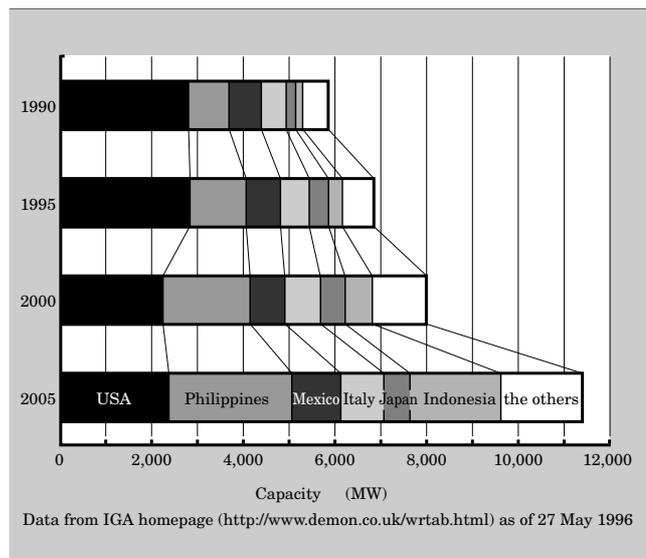
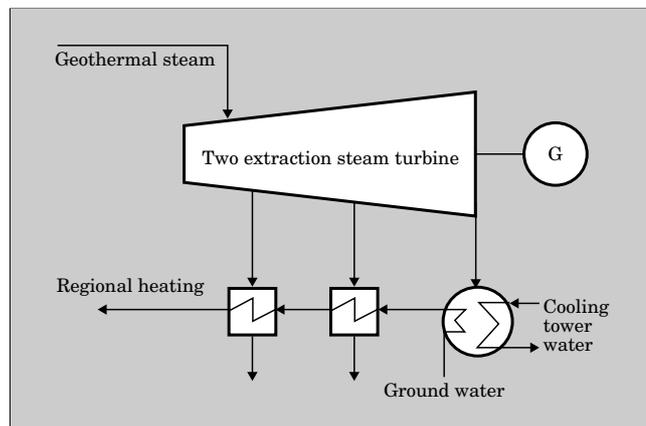


Fig.2 Svartsengi Unit 5 system



went online in 1999. Figure 2 shows a schematic of the Unit 5 system.

Geothermal steam is supplied to the turbine for generating 30MW and for heating fresh water. The turbine has an exhaust pipe leading to the condenser as well as two extraction pipes. Exhaust steam is condensed in the condenser by the cooling tower water. The condenser is divided into two sections, one is a normal condensing zone, and the other is a condensing zone that functions also as a pre-heater for the district heating water. Ground water is first fed to the condenser. Two steam pipes are used for heating the ground water. Then the heated water is supplied to the particular region. Table 1 lists major technical specifications of the Unit 5 turbine.

The extracted steam pressure is externally controlled to maintain the heated water temperature. By changing the ground water flow and by controlling the extraction pressure, four season operation patterns are planned as shown in Table 2.

Figure 3 shows the section of the Svartsengi Unit 5

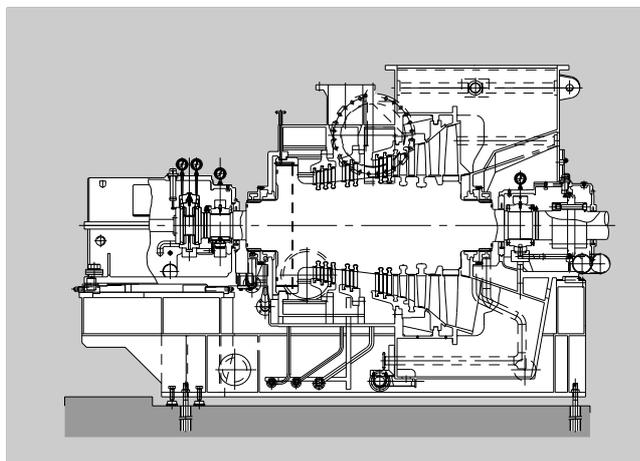
Table 1 Features of Svartsengi Unit 5 turbine

| Output          | 30,000 kW    |              |
|-----------------|--------------|--------------|
| Main steam      | 0.65 MPa abs | 262,800 kg/h |
| No.1 extraction | 0.29 MPa abs | 14,400 kg/h  |
| No.2 extraction | 0.16 MPa abs | 97,200 kg/h  |
| Exhaust         | 0.01 MPa abs |              |
| Speed           | 3,000 r/min  |              |

Table 2 Four season operation patterns

| Item                    | Summer normal | Spring Autumn | Winter  | Winter peak |
|-------------------------|---------------|---------------|---------|-------------|
| No.1 Extraction (kg/h)  | 0             | 18,000        | 14,400  | 39,600      |
| No.2 Extraction (kg/h)  | 54,000        | 57,600        | 97,200  | 108,000     |
| Hot water supply (kg/h) | 432,000       | 432,000       | 864,000 | 864,000     |

Fig.3 Section of Unit 5 turbine



turbine.

### 3. Salton Sea Unit 5

Salton Sea is located in Imperial Valley California, and it is one of the largest geothermal power generation area in the world. Table 3 lists the power generating units currently in operation.

Unit 5, introduced here, is located in the Region 1, where four level of steam pressure are utilized: high pressure (HP), standard pressure (SP), low pressure (LP) and very low pressure (VLP). Unit 1 is a simple straight condensing unit and Unit 2 is a turbo expander from HP to SP. Unit 3 intakes SP and LP steam, and Unit 4 intakes SP steam and extracts LP steam. Unit 5 intakes SP, LP and VLP steam. Usage these four levels of steam pressure is coordinated in the Region 1 area to optimize the steam usage and power generation.

Unit 5 was delivered to the plant in 1999 and went online in 2000. Table 4 lists major technical specifications of Unit 5.

Unit 5 contains not only a power generation unit but also a mineral recovery plant. The LP and the VLP steam for Unit 5 are generated in the mineral recovery plant. Figure 4 shows the rough schematic of the Unit 5 system.

The SP steam supplied to Unit 5 is delivered from Unit 3 and 4 located next to Unit 5. SP brine is also fed from Units 3 and 4 areas to the mineral recovery plant., LP and VLP steam is generated in the mineral recovery plant, and fed to the Unit 5 turbine.

Figures 5 and 6 show the Unit 5 turbine.

Table 3 Power generating units in Salton Sea Area

|          |             |        |
|----------|-------------|--------|
| Region 1 | Unit 1      | 10 MW  |
|          | Unit 2      | 4 MW   |
|          | Unit 3      | 54 MW  |
|          | Unit 4      | 49 MW  |
|          | Unit 5      | 58 MW  |
| Region 2 | Vulcan (HP) | 27 MW  |
|          | Vulcan (LP) | 9 MW   |
|          | Hoch        | 36 MW  |
| Region 3 | Elmore      | 36 MW  |
|          | Leathers    | 36 MW  |
| Total    |             | 319 MW |

Table 4 Features of Salton Sea Unit 5 turbine

| Output          | 58,320 kW              |         |
|-----------------|------------------------|---------|
| SP steam inlet  | 0.86 MPa abs           | 16 kg/s |
| LP steam inlet  | 0.37 MPa abs           | 73 kg/s |
| VLP steam inlet | 0.14 MPa abs           | 65 kg/s |
| Exhaust         | 0.0096 / 0.013 MPa abs |         |
| Speed           | 3,600 r/min            |         |

Fig.4 Salton Sea Unit 5 system

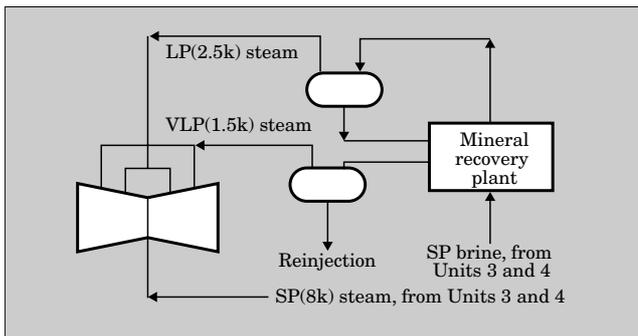


Fig.5 Section of Salton Sea Unit 5 turbine

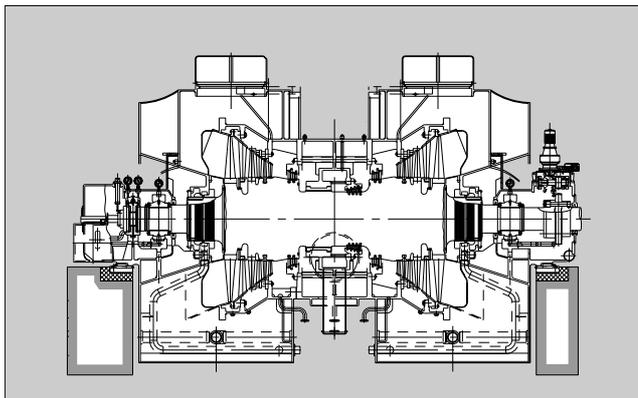
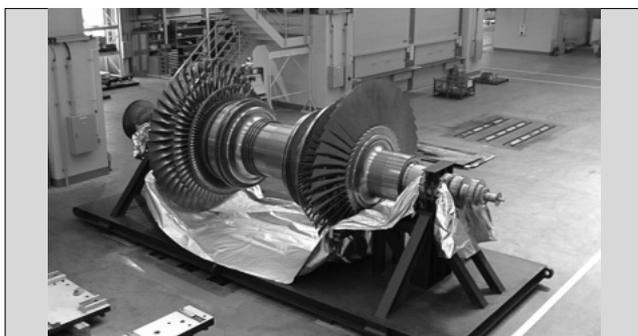


Fig.6 Salton Sea Unit 5 turbine rotor



Because the amount of the SP steam is very small compared to LP and VLP steam as shown in Table 4, the SP steam section is single-flow. After being mixed with LP steam, both LP and VLP sections are double-flow. Some of the SP steam flow is branched to the other side at the LP steam inlet so that the exhaust steam flow on both sides is equal. The turbine exhausts are connected to the condenser, which is divided into two independent condensing zones with different vacuum to increase the unit efficiency compared to a conventional single vacuum condenser.

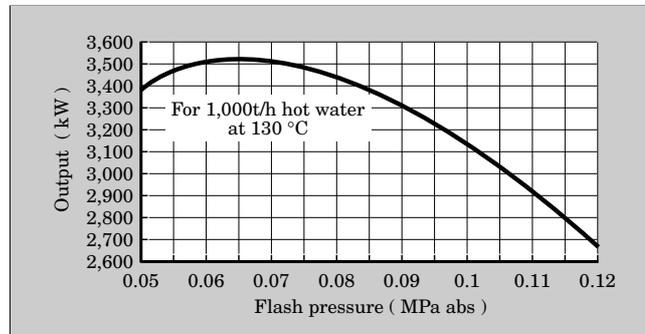
#### 4. Very Low Pressure (VLP) Flash System

When low temperature geothermal resources are used for the power generation, binary cycle technology is normally used. For such geothermal resources,

Table 5 Basis of sample VLP system

|                              |                       |
|------------------------------|-----------------------|
| Hot water temperature        | 130°C saturated water |
| Hot water flow               | 1,000 t/h             |
| Ambient wet bulb temperature | 20°C                  |

Fig.7 Flash pressure vs. output



steam turbines can be utilized by flashing the geothermal brine to very low pressure such as atmospheric or even sub-atmospheric pressure. The binary cycle has a superior to the flash cycle in that the geothermal fluid can be circulated from the production wells to the re-injection wells without emitting gases and impurities from the brine into the atmosphere. However the binary cycle normally requires larger parasitic loads compared to the flash cycle. The working fluid normally used in a binary system is flammable or toxic. The VLP system is planned as one solution that allows utilization of low temperature geothermal resources ranging about 100 to 120°C.

An example of the VLP system plan is show below.

The sample plan is based on the conditions shown in Table 5.

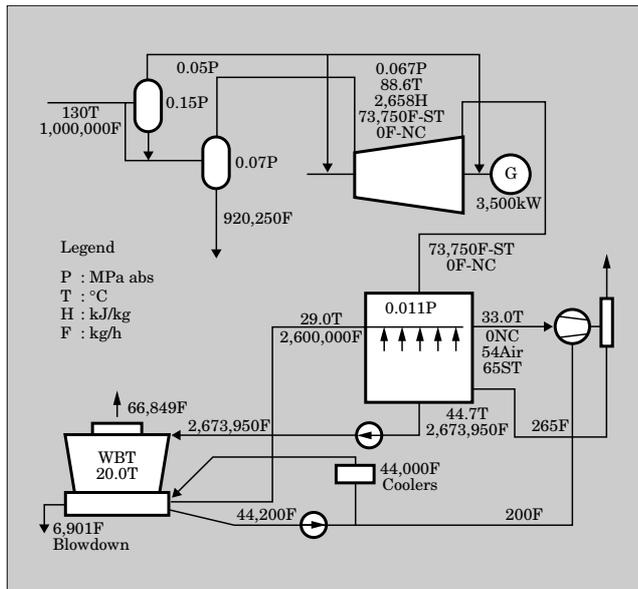
The flash pressure is usually optimized to obtain maximum output. Figure 7 is an example of the optimization for the 130°C saturated hot water. As shown in Fig. 7, maximum output can be achieved at approximately 0.065MPa abs of flash pressure in this example.

Figure 8 shows an example heat and mass balance diagram for this system. Although the maximum output would be achieved at 0.065MPa abs based on Fig. 7, the flash pressure of 0.07MPa abs is selected since the steam flow at 0.065MPa abs does not fit with the selected turbine model for this example. The selected turbine model is a single-flow skid mounted type with 467mm last-stage blades. Figure 9 shows the cross-sectional view of the turbine. As shown in Fig. 9, the turbine is quite similar to a conventional geothermal steam turbine except that the number of stages is only three.

A liquid ring vacuum pump is considered to extract small quantities of leaked air and accompanying steam.

This example has the following parasitic loads; hotwell pump (110kW), auxiliary cooling water pump

Fig.8 Example heat and mass balance of the VLP flash system



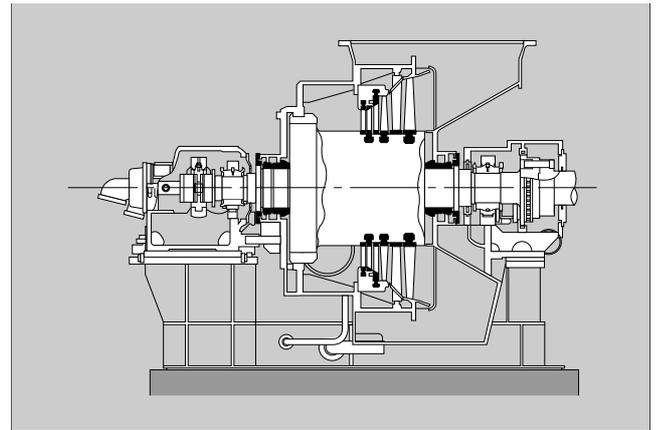
(5.5kW), cooling tower fans (110kW), vacuum pump (15kW) and power for the control system (Ca. 10kW) such as an air compressor; totaling approximately 250kW which is roughly 7% of the gross output.

There may be a various other cases in addition to the example described in the previous section. If geothermal hot water contains some percentage of steam, the turbine inlet pressure can be raised, for example, to 0.09MPa abs, thereby increasing the gross output; however in such cases, more power must be consumed for gas extraction because non-condensable gases are usually contained in steam. Condenser pressure plays a very important role in determining the output since the heat drop across the VLP turbine is quite low compared to that of an ordinary geothermal turbine. With a VLP flash system, compared to ordinary geothermal power generation, it is more effective to lower the design condenser pressure to increase the output under the same brine consumption.

## 5. Conclusion

Geothermal energy is regarded as renewable and

Fig.9 Cross-sectional view of the turbine for very low pressure



domestic energy source, and continuous development is expected in all geothermal countries. In order to utilize geothermal energy more effectively, it is anticipated that geothermal power plants having additional functions, as introduced here, will be planned. Fuji Electric's geothermal steam turbines will contribute as key components to such plans for multi-purpose geothermal plants.

Low temperature geothermal resources are plentiful. In addition to low temperature geothermal resources, hot water that is being re-injected can be a resource for a VLP flash system, if lowering the re-injection temperature is allowed. Nature characteristics of geothermal resources vary area to area, and site conditions also differ. The important consideration is to select the most suitable system under the given conditions. The VLP flash cycle will contribute to expanding the range of selections available for geothermal power generation with low temperature resources.

## References

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- (2) Yamada, S. : Flash Cycle for Low Temperature Geothermal Resources – Very Low Pressure (VLP) Flash Cycle, Proceedings of the World Geothermal Congress 2000



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