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The Case Studies of Mid-low Temperature Geothermal Power Plant in China

Lichang HUANG

The Standing Committee of the People's Congress of Boluo County of Huizhou Municipality, Huizhou, 516100, Guangdong, China

huanglc945@163.com

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ABSTRACT

Geothermal energy has the potential to play an important role in the future energy supply of China. Based on mid-low-temperature geothermal resource and waste heat resource, the paper introduces the energy efficiency of single-flash and binary cycle geothermal power plant. The result shows that binary cycle plant is favorable for power generation when water temperature is below 130℃, otherwise, flash steam power plant is a better choice. Furthermore, two project cases were analyzed in the end, focusing on the operating parameters and thermal efficiency. The two types could be improved energy efficiency of low-grade resources and both widely utilized in China.

1. INTRODUCTION

Geothermal energy can be applied for different purposes according to temperature range. Low-temperature geothermal energy would generally utilized for greenhouse heating and aquaculture, high-temperature applications, including absorption chillers for refrigeration and air conditioning and power generation – the highest grade and most useful form of energy known to humankind, Cerci.Y (2003). In China, the high-temperature geothermal resources are mainly distributed in southern Tibet, western Sichuan, western Yunnan; Mid-low temperature geothermal resources are mainly distributed in coastal areas of southeastern China, including Guangdong, Hainan, Jiangxi, Hunan and Fujian, Zheng K. Y (2013).

Geothermal energy, one of the most promising among renewable energy sources, has proven to be reliable, clean, and safe, and therefore, it is increasingly explored for power production, heating and cooling, Bertani R (2010). Geothermal energy produces electricity with minimal environmental impact, and very little nitrous oxide and sulphur-bearing gases.

The objective of this research is to highlight the use of geothermal energy in power generation in China, which has the largest geothermal energy potential for power generation. A single-flash geothermal power plant was designed in Fengshun geothermal field; an experimental binary cycle power plant was built in Sanshui. The potential of power generation by single-flash and binary cycle were researched and preliminary feasibility studies were conducted in this paper.

2. THERMODYNAMIC CALCULATIONS AND PERFORMANCE OF GEOTHERMAL POWER PLANT

The basic types of geothermal power plants in use today are steam condensing turbines and binary cycle units. Steam condensing turbines can be used in flash or dry-steam plants operating at sites with intermediate- and high-temperature resources (≥150°C). The power plant generally consists of pipe lines, water-steam separators, vaporizers, de-misters, heat exchangers, turbine generators, cooling systems, and a step-up transformer for transmission into the electrical grid. The only difference between a flash plant and a dry-steam plant is that the latter does not require brine separation, resulting in simpler and cheaper design.

Binary-cycle plants, typically organic Rankine cycle (ORC) units, are commonly installed to extract heat from low- and intermediate-temperature geothermal fluids (generally from 70°C to 170°C). Binary plants are more complex than condensing ones as the geothermal fluid (water, steam or both) passes through a heat exchanger heating another working fluid. The working fluid, such as isopentane or isobutene with low boiling point drives the turbine after vaporizing, and then is air cooled or condensed with water. Based on the temperature and property of the water-dominate geothermal resource, different energy conversion system can be utilized to maximize the extraction of energy from the geothermal fluid, Kose R (2005), Franco. A (2009), Yan J.J (2010), Zhang S. J (2011), Kanoglu M (2008) and Rosyid H (2010).

2.1 Single-Flash Steam Power Plant

The terminology single-flash system indicates that the geofluid has undergone a single flashing process, a process of transitioning from a pressurized liquid to a mixture of liquid and vapor, as a result of lowering the geothermal pressure below the saturation pressure corresponding to the fluid temperature.

The geofluid starts off as a compressed somewhere in the reservoir, then it experiences a flashing process in the separator, where the two-phase are separated. The steam is then used to drive the turbine which in turn drives the electric generator. The schematic diagram of single-flash system is given in Fig. 1.

The processes undergone by the geofluid are best viewed in a thermodynamic state diagram in which the fluid temperature is plotted on the ordinate and the fluid specific entropy is plotted on the abscissa. A temperature-entropy (*T-s*) diagram for the single flash plant is shown in Fig. 2. The sequence of processes begins with geofluid under pressure at state h, close to the saturation curve.

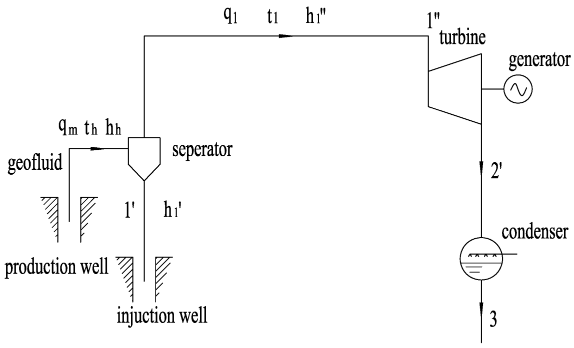

Figure 1: Schematic Diagram of Single Flash System

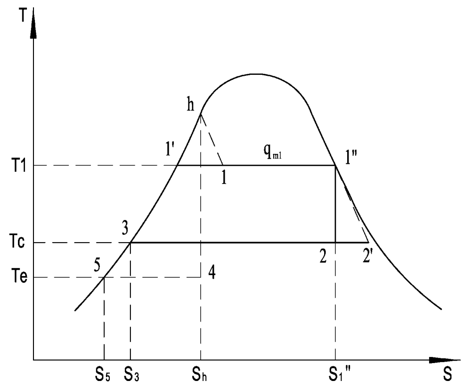

Figure 2: Temperature-entropy (T-s) Diagram of Single Flash System

Thermodynamic process can be calculated as follow:

Net power output of signal flash system:

$$P_{net} = \frac{q_{m1}(h_1"-h_2)(1-X)}{3.6}\eta_{oi}\eta_m\eta_g \quad (1)$$

Net power output per ton geothermal water:

$$Ne = \frac{P_{net}}{q_m} = \frac{m_1(h_1"-h_2)(1-X)}{3.6}\eta_{oi}\eta_m\eta_g \quad (2)$$

The energy efficiency of signal flash system:

$$\eta_{net} = \frac{3.6P_{net}}{q_m(h_h-h_3)} = \frac{3.6Ne}{h_h-h_3} \quad (3)$$

The efficiency geothermal resource utilization of single flash system:

$$\eta_u = \frac{3600P_{net}}{q_m w_{\max}\times 10^3} = \frac{3.6Ne}{w_{\max}} \quad (4)$$

The maximum available energy $w_{\max}$ is defined as the maximum energy extracted from the geothermal water isentropic expansion from the initial state to environment temperature in an idea condition. It can be calculated by the following formula:

$$w_{\max} = h_h - h_5 - T_e(s_h - s_5) \quad (5)$$

2.2 Binary Cycle Power Plant

Binary cycle geothermal power plants are the closest in thermodynamic principle to conventional fossil or nuclear plants in that the working fluid undergoes an actual closed cycle. The working fluid, chosen for its appropriate thermodynamic properties, receives heat from the geofluid, evaporates, expands through a prime-mover, condenses, and is finally returned to the evaporator by means of a feedpump. In its simplest form, a binary plant follows the schematic flow diagram given in Fig.3. Binary cycle plants use the geothermal water from liquid-dominated resource. These plants operate with a binary working fluid (R245fa, R123a, etc.) that has a low boiling temperature in a Rankine cycle. The working fluid is completely vaporized by the geothermal heat in the evaporator. The vapor expands in the turbine, and then condensed in a water-cooled condenser before being pumped back to the evaporator to complete the cycle (1-2’-3-4-5-6-1).

The thermodynamic process undergone by the R245fa is shown in Fig. 4, a temperature-entropy, *T-s* diagram. This type of diagram is most often used for refrigeration and air condition cycles, but lends itself very well to geothermal binary plant. The diagonal A-B-C displays the geothermal water temperature change when heating the working fluid.

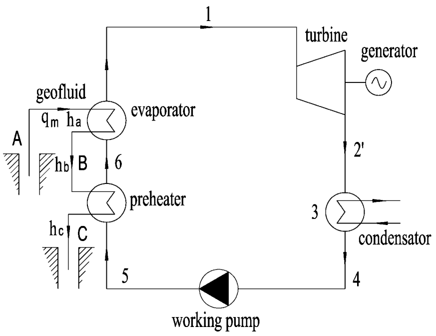

Figure 3: Schematic Diagram of Saturated Steam Binary Cycle

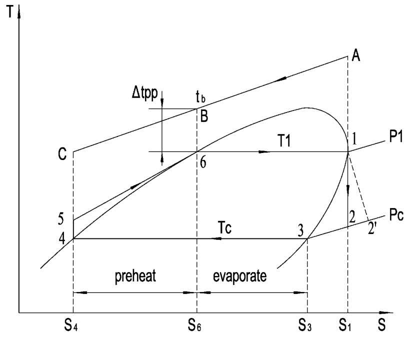

Figure 4: Temperature-entropy (T-S) Diagram of Binary Rankine Cycle

Thermodynamic process can be calculated as follow:

Net power output of binary cycle：

$$P_{net} = \frac{q_{mo}[(h_1 - h_2) - (h_5 - h_4)](1 - X)}{3.6}\eta_{oi}\eta_m\eta_g \tag{6}$$

Net power output per ton geothermal water:

$$Ne = \frac{P_{net}}{q_m} = \frac{m_o[(h_1 - h_2) - (h_5 - h_4)](1 - X)}{3.6}\eta_{oi}\eta_m\eta_g \tag{7}$$

The energy efficiency of binary cycle:

$$\eta_{net} = \frac{3.6P_{net}}{q_{mo}(h_1 - h_5)} \tag{8}$$

The maximum available energy of the geothermal water $w_{\max}$ can be calculated by the following formula:

$$w_{\max} = c(T_h - T_e) - T_e c \ln\frac{T_h}{T_e} \tag{10}$$

2.3 The Comparison of Different Power System

At the condition of same hot geofluid, condensation and environment temperature, the thermodynamic calculation of the two systems is show in table 1. The comparison of the two power system will be referred for the choice of different energy conversion system.

Table 1 The Thermodynamic Calculation of Two Geothermal Power Systems

Type of plant	Working fluid	Geofluid inlet temperature (℃)	Geofluid outlet temperature (℃)	Mass flow rate of geofluid (t/h)	Cooling water inlet temperature (℃)	Cooling water outlet temperature (℃)	Turbine efficiency (%)	Energy efficiency of power plant (%)	Power output of per ton geofluid (kWh/t)
Binary	R245fa	95	66	1	25	35	72	4.15	1.4
Single flash	Geothermal water	95	66	1	25	35	72	2.45	1.57

Table 2 shows the comparison of different power system using different working fluids. It could be clearly seen that the power output of per geofluid for single flash system is higher than binary cycle when the temperature is below 130℃; otherwise, the result is just opposite. Compared with binary cycle, single flash has its merits such as large power output per ton geothermal water, safety, mature technology, low investment and easy operation. However, when the geofluid temperature is 100℃ or lower, the specific volume of flash steam is 80 times larger than organic fluid. Therefore, it is important for single-flash system to separate the two phases before the steam is admitted to the turbine. Liquid entrained in the steam can cause scaling and/or erosion of piping and turbine components. In contrast, turbine using organic fluid has its advantages such as smaller volume and higher energy efficiency.

Table 2 The Comparison of Different Power System Using Different Working Fluids

Geothermal temperature (℃)	Working fluid	Type of plant	Ne (kW·h/t)	η_t (%)	η_u (%)
80	R123a	Binary	1.29	4.6	20.4
80	R600a	Binary	1.34	4.6	21.2
80	R152a	Binary	1.29	4.0	20.4
80	Geothermal water	Single flash	1.81	2.8	28.6
100	R123a	Binary	2.75	6.0	25.4
100	R600a	Binary	2.89	6.0	26.7
100	R152a	Binary	2.75	5.8	25.4
100	Geothermal water	Single flash	3.30	3.8	30.4
120	R123a	Binary	4.77	7.3	29.3
120	R600a	Binary	5.09	7.2	31.2
120	R152a	Binary	4.84	6.9	29.7
120	Geothermal water	Single flash	5.20	4.7	31.7
140	R123a	Binary	7.40	8.4	32.7
140	R600a	Binary	8.05	8.2	35.5
140	R152a	Binary	7.72	7.9	34.1
140	Geothermal water	Single flash	7.55	5.6	32.9
160	R123a	Binary	10.69	9.5	35.8
160	R600a	Binary	11.92	9.1	40.0
160	R152a	Binary	11.65	8.7	39.1
160	Geothermal water	Single flash	10.17	6.4	33.5

180	R123a	Binary	14.74	10.4	39.1
180	R600a	Binary	16.95	9.9	44.9
180	R152a	Binary	17.29	9.3	45.8
180	Geothermal water	Single flash	13.42	7.3	34.7

3 GEOTHERMAL POWER PLANT APPLICATIONS IN CHINA

3.1 Single-Flash Geothermal Power Plant in Fengshun

The first single-flash geothermal power plant with capacity of 300kW in China was built in Dengwu, Fengshun, Guangdong province in 1982. This power plant with one 800m projection well generates an average of 210kW electricity and runs 8000 hours annually at present. 2 technicians are in charge of on-grid operation of the plant. The net output power and geothermal water capacity are reducing due to disorderly exploitation of the local geothermal resource. Fortunately, positive measures are taken by local government to ensure rational resource utilization.

Figure 5 shows the design of the plant drawn up in the computer program. As shown in figure 5, the design of the plant starts from the production pump which used to deliver the geofluid to the separator. The geofluid at the liquid state enters the separator and flashes into the saturated vapor and liquid. The saturated liquid is directed into the drainage weir without using a pump because the separator is in high position. The saturated vapor enters the turbine where it expands and rotates the shaft. The exhaust steam from the turbine enters the condenser and is condensed directly by the cooling water from the river. The exhaust steam contains a non-condensable gas which is deflated by the air ejector to maintain the condenser in vacuum state. The geothermal water temperature is 91℃ in Fengshun, Guangdong province. The thermal energy efficiency is about 2.73% and net power output per ton geothermal water is 1.4kWh/t.

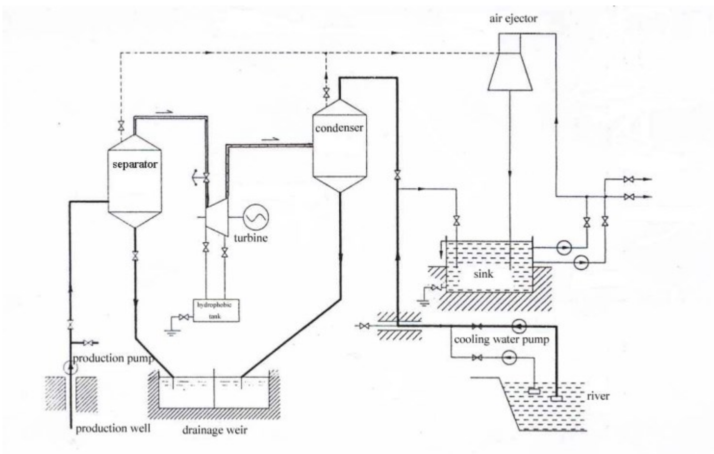

Figure 5: Schematic diagram of single flash system in Fengshun

3.2 Experimental Binary Power Plant in Sanshui

The ammonia-water binary cycle power plant was built in Sanshui, Foshan, Guangdong province, China and completed by Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences (CAS) in 2010. Fig. 6 shows schematic diagram of the binary plant with capacity of 5kW. The plant utilized 60% ammonia water as working fluid. In the experimental plant, the geothermal water is instead of by hot water whose temperature is control at about 82℃. The system is composed of evaporator, absorber, exchanger, screw, electric generator, cooling tower and so on. Ammonia solution with 60% mass concentration is heated by the geothermal water in the evaporator where ammonia vapor is generated. The vapor drives the screw generator to rotate and then is absorbed by the evaporated dilute ammonia solution in the absorber. Flow rotators, pressure gauges and thermometers are installed to monitor the system. The net output of the system could reach to 10 kW calculated from the experimental test data theoretically. The thermal efficiency is 10% theoretically, higher than 8% of traditional energy conversion system. However, the actual net power output of the binary system is only 3kW. For one hand, the unsuitable structure design and installed location of absorber result in higher absorption pressure in the system, therefore, the pressure difference between screw inlet and outlet is less than design value (800kPa). For another, the exchanger has a low heat transfer coefficient, which affects the energy efficiency of the power system.

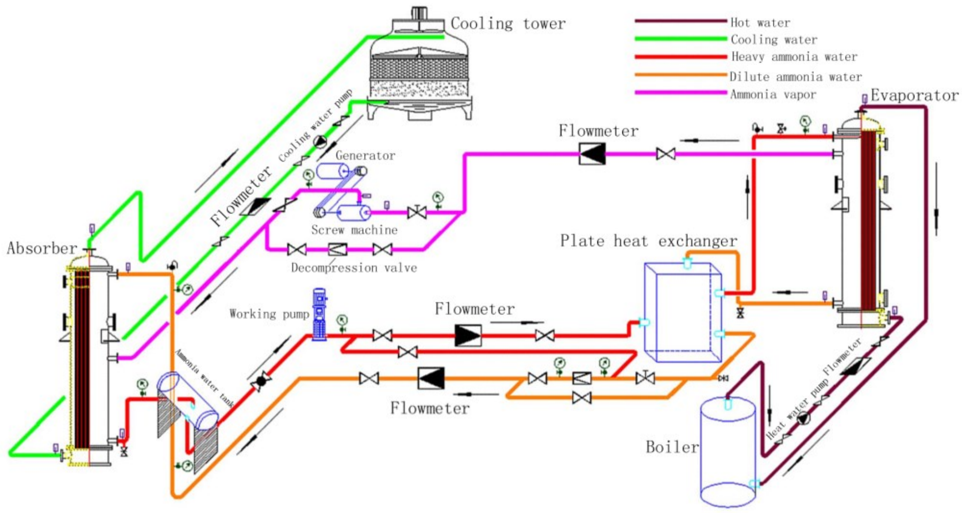

Figure 6: Schematic diagram of binary cycle system in Sanshui

4 CONCLUSION

Geothermal power systems such as flash system and organic Rankine cycle have been proposed for the conversion of low-grade heat source into electricity, which can be widely applied in China. The single-flash geothermal power system is a better choice for energy conversion system as a result of mature technology, safety and higher thermal energy efficiency. If the geofluid temperature is 130℃ (303K) or less, it becomes difficult, although not impossible, to build a flash-steam plant that can efficiently and economically put such a resource into practice. The lower the resource temperature the worse the problem becomes for flash technology. Binary cycle technologies are promising because they permit the utilization of geothermal resources that could not otherwise be used to generate electricity economically. To exploit low- and medium-temperature geothermal sources on a wider scale, it is crucial to use advanced design methods and apply optimization techniques for fine-tuning plant design variables. This is because the results obtained are very sensitive, from both energetic and economic points of view, as well as to variations in design parameters.

The single-flash and binary power plants in Fengshun and experimental binary cycle plant in Sanshui indicate that the plants are being operated at a low efficiency. This is certainly due to relatively exergy destruction throughout several processes, such as the discharge of the brine after separation, the discharge of the steam to the river and the conversion of the shaft work to electrical power in the generator, the low conversion efficiency of binary power units and inappropriate installation. However, the successful operation of the two plants would provide basic data for future design of increasing geothermal power plant in China.

Nomenclature
c Specific heat, $kJ\cdot kg^{-1}\cdot K^{-1}$
h Specific enthalpy, $kJ\cdot kg^{-1}$
h'' Saturated steam (vapor) specific enthalpy, $kJ\cdot kg^{-1}$
h' Saturated liquid specific enthalpy, $kJ\cdot kg^{-1}$
m_1 Flash steam mass flow rate per ton geofluid, $t\cdot t^{-1}$
m_o Working fluid vapor mass flow rate per ton geofluid, $t\cdot t^{-1}$
Ne Net power output per ton geothermal water, $kWh\cdot t^{-1}$
P_{net} Net power output of binary cycle, kW
q_m Mass flow rate of geothermal water, $t\cdot h^{-1}$
q_{m1} Mass flow rate of flash steam, $t\cdot h^{-1}$
q_{mo} Mass flow rate of working fluid vapor, $t\cdot h^{-1}$
s Specific entropy, $kJ\cdot kg^{-1}\cdot K^{-1}$
s'' Saturated steam (vapor) specific entropy, $kJ\cdot kg^{-1}\cdot K^{-1}$
s' Saturated liquid specific entropy, $kJ\cdot kg^{-1}\cdot K^{-1}$
t_1 Flash celsius temperature, ℃
t_c Condensation celsius temperature, ℃
t_h Geofluid celsius temperature, ℃
T_1 Flash thermodynamic temperature, K
T_e Environmental thermodynamic temperature, K
T_c Condensation thermodynamic temperature, K
T_h Geothermal thermodynamic temperature, K
X Electricity consumption percentage by self, %
η_{oi} Turbine isentropic efficiency, %
η_m Machinery efficiency, %
η_g Generator efficiency, %
η_u Exergy efficiency, %
η_t Thermal efficiency, %
η_{net} Energy efficiency of power plant, %

REFERENCES

Cerci.Y.: Performance evaluation of a single-flash geothermal power plant in Denizli, Turkey, Energy, **28**, (2003), 27-35.

Zheng K. Y. Dong Y.: A Comparison on Geothermal Development between China and the World, *Proceedings,* European Geothermal Congress 2013, Pisa, Italy (2013).

Bertani R.: Geothermal Power Generation in the World 2005–2010 Update Report, *Proceedings,* World Geothermal Congress 2010, Bali, Indonesia (2010).

Kose R.: Researchon the generation of electricity from the geothermal resources in Simav region, Turkey, Renewable Energy, **30**, (2005), 67-79.

Franco. A, Villani M.: Optimal design of binary cycle power plants for water-dominated, medium-temperature geothermal fields, Geothermics, **38**, (2009), 379-391.

Yan J.J, Zhang D, Chong D. T.: Experimental study on static/circulatory flash evaporation, International Journal of Heat and Mass Transfer, **53**, (2010), 5528-5535.

Zhang S. J, Wang H.X, Guo T.: Performance comparison and parametric optimization of subcritical Organic Rankine Cycle (ORC) and transcritical power cycle system for low-temperature geothermal power generation, Applied Energy, **80**, (2011), 2740-2754.

Kanoglu M, Bolatturk A.: Performance and parametric investigation of a binary geothermal power plant by exergy, Renewable Energy, **33**, (2008), 2366-2374.

Rosyid H, Koestoer R, Putra N.: Sensitivity analysis of steam power plant-binary cycle, Energy, **35**, (2010), 3578-3586