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Summary of Geothermal Power Generation Engineering Technology in China

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ABSTRACT

A brief review was given about the development of geothermal power generation in China. Focusing on Yangbajing and Naqu geothermal power plants in Tibet, the details were given including thermal system, pipeline system, operation and maintenance, scaling and corrosion, reinjection, field monitoring system, environment and prospects.

1. INTRODUCTION

China owns rich geothermal resource. Most of geothermal resource is explored and utilized by direct heat due to low temperature. High-intermediate temperature resource is just found in Tibet, Yunnan and Taiwan. Only in Tibet, geothermal energy is converted to electricity in large scale. Several geothermal power plants have been built there, and the total installed capacity reaches 25.18MW. In Taiwan, a 3000kW pilot geothermal plant was built in 1981 and shut down around 1995. However, a 300kW binary geothermal power plant has been operating since 1986. Yunnan Geothermal resource has not been developed. In Yunan Tengchong geothermal field, it is found that well temperature is over 260℃.

In China, geothermal generation research began in 1970's. It was simply thought that geothermal energy is no cost and green energy at that time. A few pilot plants with small capacities were built and operated inland soon, using low temperature resource. After that, almost all of the power plants met the same problems about economic effect and durable and reliable operation. People started to realize the reasons. Firstly, because of low temperature, thermal cycle efficiency is too low. Secondly inland areas have been covered by electric grid which connected with large fossil-fuel power plants. Geothermal power plants can not grow-up inland. So those pilot plants were waived soon. Chinese engineers learned a lot of experiences and knowledge from this unsuccessful time. It is very helpful to build geothermal power plants in Tibet.

Tibet lacks fossil fuel resource but has hydraulic resource and geothermal resource. This area faced the severe shortage of electricity in 1970's. In order to solve the problem, three geothermal power plants were built in sequence in Yangbajing, Naqu and Langjiu. Up to 2003, the total output is 1.6 billion KWh from Yangbajing power plant, and average annual output is roughly about 0.1 billion KWh in recent years. Since 1991, the geothermal power plant has taken 40% of the total output of Lhasa grid and over 50% in winter. Although the number of the geothermal power capacity is relatively small, geothermal generation has been a main supplier for Lhasa grid for a long time.

Generally, the history of geothermal exploration and utilization in Tibet represents geothermal development of China, and is also a part of world geothermal history. It is necessary to make a summary

2. THERMAL SYSTEM

Yangbajing geothermal field lies in the northwest of Lhasa about 89km away. Lhasa is the capital of Tibet. The altitude of Yangbajing is about 4300m. The atmosphere pressure is about 59.8kPa. Zangbu River passes by south of the field. China-Nepal highway is just cross the center of the field. Yangbajing geothermal power plant has two parts. South plant has one 1000kW unit and three 3000kW units while north plant has one 3180 kW unit and four 3000kW units.

Naqu geothermal field lies in the outskirts of Naqu town. The area is about 1km^2. The field is about 330km away from Lhasa and nearby the Qinghai-Tibet highway. There are three production wells .Two wells are used for power generation and one well is used to supply heat to the town. Due to the high concentration of dissolved carbon dioxide the geofluids with low enthalpy cause severe scaling of $CaCO_3$ and $MgCO_3$. Wellhead temperature is about 110℃ and the pressure is about 0.3MPa.

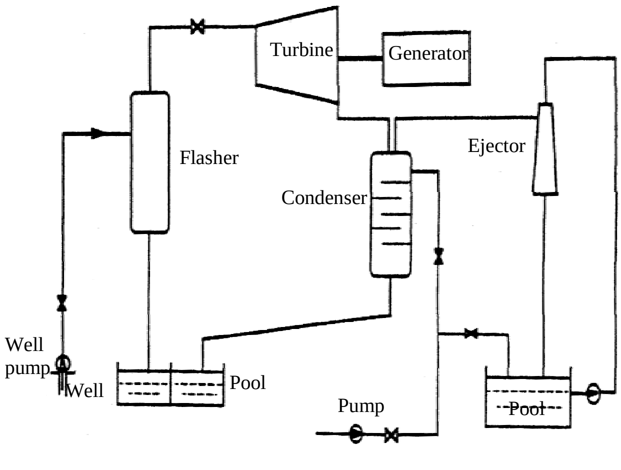

Figure 1: Single flash system diagram

2.1 Single flash system

No.1 pilot unit of Yangbajing power plant was designed as a single flash system. It started to generate successfully in October 1st, 1977. Thermal system diagram is seen in Fig 1. The turbine was from a second-hand coal-fired steam turbine. A single flash system was adopted due to high reliability and simple control system. This unit was used to supply electricity for construction, and it became the only place to train local operators and administrators at that time.

2.2 Double flash system

From 1981 to 1991, eight 3MW units were installed in Yangbajing power plant. South part has 3 units and north part has 5 ones. Seven turbines were made in Qingdao of China, and one was made by Fuji. Thermal system diagram is seen in Fig 2. These turbines are mixed pressure turbines. Separated steam and water are conveyed to 1st flasher by two pipes. Steam from two flashers goes into two steam inlets separately. The designed inlet pressures were 167±20kPa and 49±5kPa, and the exhaust pressure was 5kPa in south part and 8.8kPa in north part. Cooling water is used from Zangbu River in south part while mechanical cooling tower is adopted in north part.

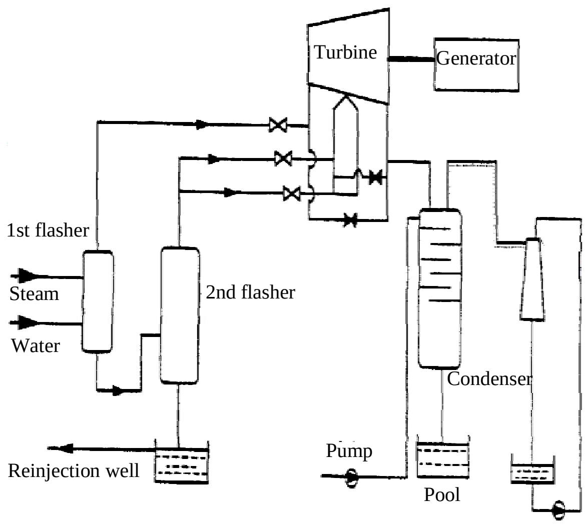

Figure 2: Double flash system diagram

2.3 Binary cycle system

1 MW binary cycle geothermal power plant was operated in Naqu in 1992. However, downhole pumps had to shut down soon due to failures. In 1995, dosing systems was applied to replace the downhole pumps. The system diagram is seen in Fig 3.

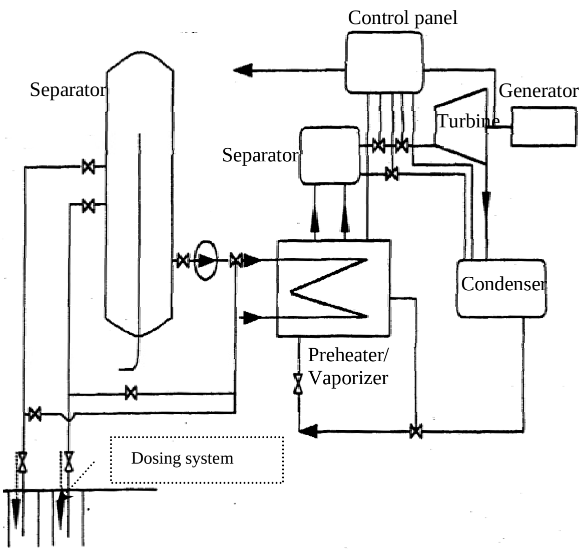

Figure 3: Binary cycle system diagram

2.3.1 Dosing system

The content of CO_3^{2-} was about 5240mg/kg and HCO_3^- is about 2000mg/kg. The growth rate of calcite was about 3mm/day. Some trial tests were carried on a well quite near the production wells. DR-1 type of complex phosphor inhibitor showed the best effect in five different types in the tests. The concentration reached 5mg/l to prevent scaling by directly passing the heat exchanger, but 7mg/l by passing the separator.

This dosing system developed by TPRI was installed under the aid of UN in Naqu geothermal power plant. All parts of the dosing system were made of 1Cr 18Ni 9Ti steel. There is one injection point near the wellhead and two sampling points in the system. According to two month operation experiences, it was estimated that the power plant would have an extra benefit of over 200,000 $US per year. DR-1 inhibitor not only prevented scaling but also removed previous depositions, so the unit reached the rated power output at the first synchronization after the dosing system was installed.

3. PIPELINE SYSTEM

Yangbajing geothermal field is a liquid-dominated system. The wellhead pressure is about 0.3~0.45MPa and the dryness was about 5%~6% in 1970's. At that time, it is quite hard to design a 1~2km long pipeline to carry geofluids. Chinese engineers had figured out this problem finally.

The original method was to install wellhead separators. Separated steam was directly discharged to atmosphere and separated water was pumped to a flash tank to produce steam. Thus, it caused great energy loss and brought pump failures because of scaling and cavitations.

Then the design was improved. Separated steam and water were carried into two main pipelines separately. It increased 50% of power output. However, because of the significant difference of wellhead parameters, geofluids were injected into the wells with lower parameters.

After that it was redesigned in 1984. After a lot of experiments, the production wells were divided into two groups according to wellhead parameters. It designed two pipelines, high pressure pipeline and low pressure pipeline. This system has been operating up to now.

4. OPERATION AND MAINTENANCE

In the early stage, the following problems happened:

1) Production well $CaCO_3$ scaling (removing it by mechanical cleaning) ;

2) Serious turbine scaling ;

3) Pipeline without insulation;

4) Too much sands into the cooling system due to the extraction from riverbank;

5) Turbine parts corroded.

In 1990's, the following problems existed:

1) Lack of enough data from geothermal field;

2) All the stage 3 blades broken (turbine made in Qingdao);

3) Last stage blades broken (turbine made by Fuji);

4) Turbine path scaled severely;

5) Instrument inaccuracy and failures;

6) Turbines could not reach rated power output;

7) Not enough cooling water in winter;

8) Not enough maintenance of wellhead equipment.

At present, the following problems are found:

1) All parts of power plants aged;

2) Very low turbine inlet pressure;

3) Ineffective field monitoring.

4) No enough funds to support the further expansion.

From the above, it is seen that the current problems are caused by aging and lower parameters, instead of design and material. Any update will bring the high risk in capital return. It is important to keep the power plant going reasonably without update now.

5. SCALING AND CORROSION

Although Yangbajing has high temperature geothermal resource, only the shallow reservoir is developed now and the deep reservoir is still in silence. So it is likely to form the serious calcium deposition when geofluids flow out from production well. Mechanical hammering has been used to get rid of the scaling and has been effective in Yangbajing and Longjiu power plants. A regular cleaning wellbore technique has also been adopted. The scaling in turbine blades can reach 2~5mm per year. Thus, it reduces the power output and affects turbine dynamic balance.

Corrosion could potentially threaten to damage the components of power plants. That is because of the relatively high wetness of the steam that contains an amount of chloride and sulfur. When the components are in standby, air could enter by drains and glands. Then it could result in serious corrosion in such as stators, rotors and blades. It is also called "standby" corrosion.

The 3rd stage blades of 3MW units made in Qingdao were all broken. After the analysis on the cracking features of the blades, silica deposition was found on the blades while transgranular and intergranular corrosions were found. Silica deposition contains small quantities of ions such as Cl^-, S^{2-}, Al^{3+}, Ca^{2+}, K^+ and Fe^{3+}. The broken blades were caused by corrosion fatigue. So when the unit is in standby in a long time, it is suggested that nitrogen protection should be used to prevent air leak. In operation, it should avoid overpressure in order to decrease fatigue degree. It also increases the corrosion resistance of turbine blades by using better material.

6. REINJECTION

Reinjection technology was not applied until 1990. As the shallow reservoir was developed, wellhead parameters decreased significantly in almost all the production wells. Some of the wells had to operate in the unsteady conditions, so these wells were shut down and waived. Sedimentation and environment pollution began to happen.

Reinjection has already been adopted in geothermal power plant in the world. Reinjection is an important part of a geothermal power plant. It is effective to slow the decrease of wellhead pressure and sedimentation speed and protect natural environment. For Yangbajing, it was a bit late to install reinjection system.

The first part of the reinjection project was finished in 1990. Its capacity was about 25% of the total brine. In 1994, the second part of the project was finished. This project realized the aim that 100% of wastewater was reinjected. The system diagram is seen in Fig. 4. There were 8 reinjection wells, 2 pump houses and 7.5km pipelines. The capacity of each well is about 220~250t/h. Wastewater temperature is about 55 ℃. Monitoring instruments were installed on the wellhead. Reinjection wells are distributed in southwest boundary. Well depth is the same as that of south shallow reservoir. The temperature of reinjection water is just over the temperature inside the well. Any short circuit was not found by tracer between production wells and reinjection wells. At present, a number of waived wells at south field have been used as new reinjection wells.

Yangbajing geothermal resource was developed from south to north step by step. Power plant #1 locates at south part geothermal field and power plant #2 is at north part geothermal field. However, south part and north part belong to a whole liquid-dominated system. Hence, the two parts could influence each other. Reinjection affects south part more because reinjection wells were drilled in south part and reinjected mainly brine flows to south part. Power plant #2 was installed completely in 1991. Thus, field changes were recorded in only south part before reinjection. It will be discussed around south part below.

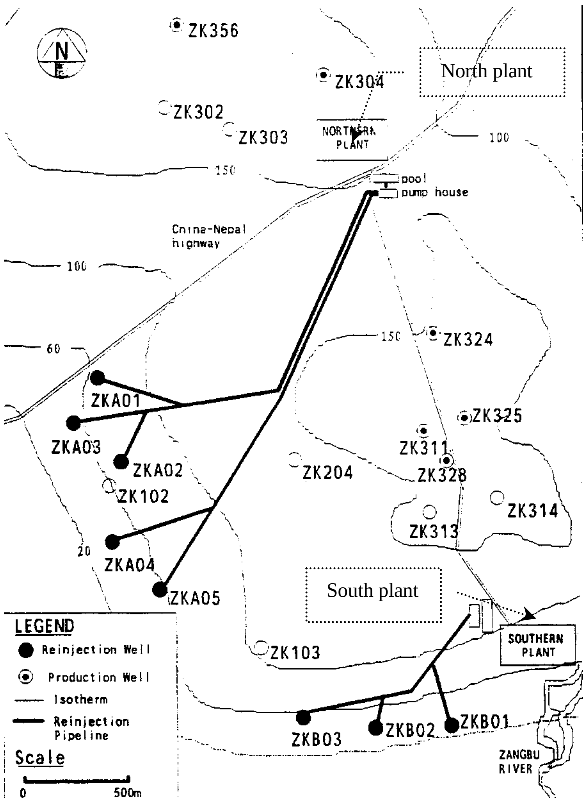

Figure 4: Reinjection system diagram

6.1 Before reinjection (1981~1991)

6.1.1 Temperature field

Reservoir temperature mainly decreased in south part, but almost no variation in north part. It said that more cool makeup water flowed into south part so that the temperature of the shallow reservoir decreases.

6.1.2 Pressure field

Pressure reduced significantly in south part, but it could obtain heat transferred from north part. As north part was exploited further and too much geofluids were extracted, heat was transferred less and less from north part to south part. Because three reinjection wells were drilled at the boundary of the reservoir, more cool water flowed into the reservoir as well pressure dropped.

6.1.3 Gravity field

Gravity field fluctuated as seasons change because of good permeability in south part, while gravity field increased obviously in north part with poor permeability. However ground sedimentation was not much in north part.

6.1.4 Chemistry field

The content of CO_3^{2-} and CO_2 increased, and maximum change happened in the center of geothermal field. It showed that field center pressure decreased so that more CO_2 was discharged. The content of minerals and SiO_2 reduced largely as well. It showed that cool water was mixed.

6.2 After reinjection (1994~)

Well temperature decreased quickly, and became slower gradually. Well pressure decreased slowly, and became almost steady. Gravity field began to recovery and ground sedimentation became quite slow. The concentration of HCO_3^- increased more. Generally, well pressure has decreased from 0.4MPa to 0.17MPa and well temperature has decreased from 140℃ to 110℃ in south, while well pressure has decreased from 0.45MPa to over 0.2MPa and well temperature has decreased from 145 to 130℃ in north. In south part, 3×3000kW turbines could only produce 5000kW totally. However Yangbajing geothermal field appears to be steady again. It is quite necessary to make the reinjection system working properly in the next years.

7. FIELD MONITORING SYSTEM

Monitoring work is very important to know the changes of the field, instruct the operation and further expansion. Tibet geology team in 1984 and Italy Enel-Aquater Company in 1985 gave a conceptual Yangbajing geothermal field model according to exploration and drilling information. Enel-Aquater Company also worked in the reservoir simulation in detail. It has been proved to be reliable but needs some corrections. However there are not enough monitoring points so that it lacks continual monitoring information, even regular monitoring. Hence, it is difficult to correct the simulation further. Similar situations happened in Naque and Longjiu and even worse.

8. ENVIRONMENT

In the early stage, unreasonable well arrangement resulted in the severe pollution during drilling and power plant construction. Vegetation was polluted around the areas and even died. Waste water was discharged into rivers. It could pollute a 90km long part of Zangbu River seriously. Lhasa River also could be polluted in winter.

After reinjection system was installed, all waste water is reinjected underground. Yabajing power plant has still concerned about the environment and increased the level of environment protection successfully. In 2002, Yangbajing power plant was assessed to reach the requirements of Tibet environment standard.

9. PROSPECTS

This year Yabajing power plant is drilling a new well which will be 2600m deep. Now it is in the depth of 1800m with the pressure of 1.2MPa and the temperature of 200℃. Next year, an old well will be reopened. The well bottom temperature once reached around 300℃. Geofluids will be used to generate during some tests. It is very attractive for the prospects of Tibet geothermal generation.

Yangbajing deep reservoir and Yangyi high temperature geothermal field have not been utilized up to now. Thus Tibet geothermal generation is able to continue to develop further in the future. If new thermal systems like Kalina cycle would be applied, geothermal power plants would generate much more efficiently. As the economy of Tibet develops rapidly and the old geothermal power plants age gradually, new development of geothermal generation will come soon.

Additionally, it is believed that Yunan Tengchong geothermal field is a very valuable geothermal field. In 2004, it passed the assessment by geothermal expert group of China. According to the local conditions, it is suitable to build a large capacity geothermal power plant. It is strongly suggested that state departments should fund this project soon and cooperate with foreign countries. Yunan Tengchong geothermal field could become another new developing area.

10. CONCLUSIONS

From Chinese geothermal generation history, it is seen that geothermal generation utilization depends on the local conditions and geothermal resource conditions. Thus geothermal generation would continue to be applied mainly in Tibet and Yunnan for China. Taiwan geothermal generation may develop further in the future.

It is so hard to build geothermal power plants in such a high area that lacks enough oxygen and good working and living conditions. Chinese scientists and engineers make great efforts to this work while foreign experts also gave a lot of help. China has used intermediate-low temperature geothermal resource from Tibet shallow reservoir to generate for 27 years, especially under such low parameters for a long time. The technology, success, and lessons are precious for Tibet geothermal development in the future. They might be helpful for the other countries and areas as well.

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