WELLHEAD TECHNIQUES AND EQUIPMENT FOR DIRECT APPLICATION OF GEOTHERMAL ENERGY IN CHINA

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ABSTRACT

There is widespread interest in geothermal direct use projects in China. To make the most of these projects, adequate technical measures and equipment are required, the most important of which is the wellhead assembly. The wellhead assembly currently used in geothermal direct use projects in China is described in this paper, along with the problems that require urgent solution and suggestions for international collaboration in developing techniques and equipment.

1. FOREWORD

Geothermal energy resources are widely distributed in China with enormous potential, and are actively developed and used in every part of the country. The total geothermal heat sources in China are estimated to exceed 2000 MW. In recent years, direct applications of geothermal energy have doubled every year. There are at present more than 400 geothermal clinics, over eight million square meters of geothermal heating area, and more than 40 large-scale hot spring holiday centres that have been built all over the country.

In the ninth five-year-plan and program for 2010 in China, the development of new energy sources and regenerative energy sources are listed as important elements of a sustainable strategy. The direct application of geothermal energy is now marching towards its industrialization.

In order to continue the development of geothermal direct applications, it is very important to research and develop the basic equipment required in this sector, the main objectives being to further increase the efficiency of energy conversion, to improve the safety of operations, to lower the cost of heat supply in the thermal utilization process, and to augment its role in the energy resource structure.

2. GEOTHERMAL WELLHEAD EQUIPMENT IN DIRECT APPLICATIONS IN CHINA

Wellhead construction is becoming increasingly more important in geothermal energy uses, because it is the basic condition for safe operation and economic benefit in geothermal projects. Most of the wellhead equipment and techniques used in direct applications in China have achieved some progress.

The equipment that has improved recently includes:

2.1 Submersible Pumps

These are used to extract geothermal water. Submersible pumps for water of less than 100°C have been certified by the relevant government department and are in mass production. A technique has finally been developed to solve the long-standing and crucial problem of pumping high-temperature water, and has been granted a 2nd grade national prize for progress in science and technology and a U.N. star prize for innovation in science and technology. Compared to foreign products of the same kind, the Chines invention is more attractively priced, being only one tenth to one fifth the cost of its equivalent abroad. This technique has met a basic requirement for further exploration of geothermal resources in China.

2.1 Fully Automatic, Constant-Pressure Water Supply with Variable-Frequency Speed Regulation

The amount of water extracted varies continuously during the direct application process. For example, in the geothermal heating process, the amount of water extracted is relatively small in early winter when the heating load is lighter, whereas the well pump is required to operate at full load in late winter when the heating load is heavier. The heating load becomes lighter again by the end of winter, and the amount extracted should decrease accordingly. Because of the different environmental temperatures throughout the day, the heat loads in daytime and at night will also differ, as will the amount of water extracted. Regulating the speed of the well pump is a good way of saving water and energy and of prolonging the service life of the pump. The preferred technique for regulating pump speed should be variable frequency speed regulation of the pump. This entails a soft start, stepless speed regulation, easy implementation of automatic control and reliable operation. A fully automatic, constant pressure, variable frequency speed regulation control system has already played an important role in many geothermal projects. Its users have gained substantial benefit from the energy savings and water savings achieved with this system.

2.2 Multi-Function Geothermal Wellhead Assembly

The multi-function geothermal wellhead assembly has been awarded a patent from the Chinese government. Its features include: (1) device to prevent breakage of the pump base and water leakage caused by expansion/contraction of well pipes, facilitating the installation of a submersible pump; (2) return pipe, providing regulation of the system water supply by returning part of the geothermal water. For artesian wells, it can also be used as an artesian supply pipe; (3) easy measurement of water-level. A special water-level aperture and matching instrument are provided to facilitate easy and practical water-level monitoring. The water-level detector or aperture is equipped with a blind flange, which can be easily removed and assembled, and is capable of preventing large quantities of oxygen from mixing with the geothermal water, causing severe corrosion in the system. A nitrogen protection system can also be fitted.

2.3 Cyclone Sand Eliminator

The cyclone sand eliminator has also obtained a national patent. The sand eliminator is a device designed to prevent sand from entering the system where the sand content in the geothermal water is high when the well is completed.

The sand in geothermal water must be prevented from entering the heat supply system, as it can cause system blockage and prevent a proper heat supply. However, if a conventional grit chamber were to be adopted to eliminate the sand, it would have to measure scores of cubic meters in volume. Furthermore, a large area of geothermal water will be in contact with air, thus increasing the oxygen content in the water, which will accelerate oxygenation of the pipe when the water flows in. This plan has many disadvantages and is therefore not recommended.

The cyclone sand eliminator is compact, occupying less ground area, with a high sand-eliminating efficiency, low heat loss and ability to eliminate sand continuously. Many Chinese geothermal projects were provided with this sand elimination equipment, which provided satisfactory results.

2.4 QR-GR Forced Ventilation Warm Air Exposure Tower and CT-GQ Iron Elimination Device

These two devices are specially designed to solve the problem of eliminating the iron in geothermal water. The residual geothermal water has a relatively high iron content in Northern China and therefore created problems in heating projects. These devices have represented a comprehensive economic benefit to all operators and users.

3. R & D OF WELLHEAD ASSEMBLY IN DIRECT APPLICATION PROJECTS IN CHINA

There are several problems still to be solved in geothermal direct application projects in China. Corrosion is one of them. The international geothermal community has gained valuable experience in this sector, but their solutions may not be entirely applicable to the Chinese situation. For example, deoxidizers are adopted in some foreign geothermal applications, but these may not be economical in China. It has become an increasingly more pressing task to find an anti-corrosion technique that is applicable to Chinese conditions and also technically reliable. The authors have conducted some R & D on the wellhead assembly directed at this problem.

Geothermal water usually contains seven major corrosive substances: Cl^-, H^+, H_2S, CO_2, O_2, NH_3 and SO_4^- , of which Cl^- is the most corrosive. Theory and practice have shown that Cl^-, when combined with O_2, is most corrosive on carbon steel, high strength low-alloy steel, and stainless steel, which are the most commonly used in engineering, resulting in pitting and stress corrosion. However, when oxygen is absent, even in high Cl^- content water, thick-walled carbon steel and austenitic stainless steel with a high nickel content can both provide good anti-corrosion properties under critical temperatures. Nevertheless, with oxygen of only 30 ppb dissolved in geothermal water, the average rate of corrosion of carbon steel will increase 4 times; and an oxygen content of more than 50 ppb may cause pitting. The average corrosion rate may increase more than 10 times by charging air into the water (see Fig.1)

3.1 Anti-corrosion Measures in Geothermal Systems

Nowadays there are two anti-corrosion measures that can be adopted in direct application systems:

(1) To use anti-corrosion materials throughout the system;
(2) To prevent oxygen from entering the system or eliminate any oxygen in the system.

A highly reliable system can be achieved with the first of these, but the cost will be enormous. It is currently not practical in China to adopt such a measure.

With the second, carbon steel can be used throughout the system to reduce the initial investment. This technique is therefore readily accepted by geothermal developers. However, the oxygen content of the geothermal water in the system must be kept at a minimum (<30 ppb) to ensure that corrosion does not begin. If we could find a simple, reliable and economical way of maintaining the oxygen content at a minimum level, so that carbon steel can be used extensively in direct application systems, then the initial costs could be substantially reduced with little increase in operation costs and ultimately an increase in the social and economic benefits of using geothermal. There are two approaches to controlling oxygen content in the system: oxygen isolation and oxygen elimination.

At present, some countries with advanced geothermal technology have been successful in eliminating oxygen by using additives. The most common deoxidizer in use is sodium sulfate, which has proved an effective deoxidizer in boiler applications in the 30s. For a concentration of oxygen of 1 ppm in geothermal water, the calculated additive of Na_2SO_3 is actually 11.8 ppm, which is near the 10 ppm adopted in Iceland. With a flow of 100 tons/hour, daily consumption of Na_2SO_3 will be 28.8 kg. The cost of such a consumption is hard to accept in Chinese direct application systems, so an anti-corrosion technique based on oxygen isolation must be developed.

3.2 Anti-Corrosion Technique Involving Oxygen Isolation

No oxygen is contained originally in geothermal water. How does the oxygen enter the geothermal water? By analysis, oxygen in the outside air permeates the system mainly through the following four channels: (1) the wellhead. There is a free water surface in the wellhead where the oxygen in the air can easily diffuse into the water; (2) the moving parts of the different pumps of the system; (3) local negative pressure occuring when geothermal water passes through throttling components such as valves and orifices, where air can be sucked in if the sealing is inadequate; and (4) bad venting of the system. Non-condensible gases may be present inside the pipes and equipment, and not expelled from the system; the oxygen in these gases may dissolve in geothermal water.

Good progress has been achieved in limiting the quantity of oxygen entering by channels (2), (3) and (4). These factors are therefore not decisive in the oxygen content of a system. Most of the oxygen permeates by channel (1) and is difficult to isolate. The main reason for this is that the water level varies greatly with the flow so that there is a large volume variation of gas space inside the wellhead; consequently “aspiration” occurs, causing high oxygen content in the gas at the wellhead.

Practical experience has currently led to the development of a wellhead sealing device. The widespread use of high-temperature submersible pumps, which helps to reduce the dissolution of oxygen in geothermal water, also brought favorable conditions for wellhead sealing. However, because of the large variations in gas volume in the wellhead, it has been impossible to isolate oxygen completely by relying simply on wellhead sealing. We have naturally considered designing a system in which first nitrogen would be introduced and a container inserted to recapture the nitrogen when the gas volume decreases and return it to the well when the gas volume increases. Thus, the pressure fluctuation inside the wellhead could be reduced and the inside of the wellhead filled with pressurized nitrogen in time to effectively isolate the oxygen. According to our studies of the literature, there have so far been no experiements in using nitrogen protection for geothermal wells.

3.3 Floating-Tank Wellhead Nitrogen-Pressurizing Anti-Corrosion Device

Two components are required to implement the above concept: a wellhead sealing device and a device for reclaiming and supplying the nitrogen. Wellhead sealing devices are already on the market. The main task is to design a reliable nitrogen reclaiming and supplying device as shown in Fig. 2.

The operating principle of the device is described below. When the inside of the device is pressurized with nitrogen up to a pressure of P_1 , this produces an upward force. When the force produced by P_1 overcomes the combined weight of the inner tank and the ballast, the inner tank is lifted upwards and the pressure gradually decreases. When the decreasing pressure reaches P_0, which produces a force equal to the combined weight of the inner tank and ballast, the inner tank remains stable and maintains the pressure P_0. The process is reversed when the tank provides nitrogen to the wellhead. When the nitrogen inside the tank is reduced and the inner tank lowered to point B in Fig. 3, nitrogen cylinders are used to supply nitrogen to the tank to maintain the inside pressure at P_0 (See Fig. 3).

3.4 Test Results of Floating-Tank Nitrogen-Pressurizing Device

Experimental studies were made on the floating-tank nitrogen-pressurizing device and numerous data were collected, as shown in Table 1. The experiment has shown that:

(1) Without nitrogen protection, the oxygen content in water output from the well is still near 900 ppb, even though wellhead sealing has been provided.

(2) Nitrogen protection can effectively isolate geothermal water from oxygen, and oxygen content has been reduced to less than 20 ppb.

(3) When the pump operates intermittently or with small flow, the oxygen content in the water still fluctuates. The reason for this is that when the system stops operating, a negative pressure occurs between the check valve and the pump and this negative pressure varies with the water level in the wellhead. Gases will be attracted by this negative pressure from two sources, one being the vapor from vaporization of hot water inside the pump and the pipe, the other being the outside air permeating through the sealing of valves and flanges to form non-condensible gases containing oxygen. This is why oxygen content in the water supply may increase during system startup. When the system operates under low load, the piping of the system may not be fully filled with water. The non-condensible gases, which are not easily carried by water, remain in the system and the oxygen contained in these gases will continually dissolve into the geothermal water so that its oxygen content will increase over a certain period of time.

(4) Experiments have proven that with industrial nitrogen (≥99.9% concentration), the requirements can be met.

3.5 Conclusions from Experiment

(1) Oxygen isolation by nitrogen at the wellhead can effectively prevent outside oxygen from entering the system via the wellhead. The oxygen content in the supply water has been reduced to less than 20 ppb.

(2) A floating-tank nitrogen-pressurizing device is simple in construction and reliable in operation. It is suitable for use in combination with a wellhead sealing device. At the same time, its operating performance has still to be improved.

(3) Connecting the space inside the pump and pipe with the wellhead space and filling it with nitrogen will effectively reduce the volume of the nitrogen-reclaim and supply device and will improve the operating conditions of the wellhead as regards pressure variation, making the pressure at the wellhead more stable.

(4) The wellhead sealing device can maintain a long-term pressure of 50 mm H_2O when the geothermal water level is stable. However, leakage can be induced when pressure fluctuates. The sealing device used in the experiment presents a leakage rate of $0.7m^3$/day under normal operating conditions of the experiment.

(5) Oxygen content may increase during transport of geothermal water within the piping.

4. ENHANCE INTERNATIONAL COOPERATION TO FURTHER PROMOTE THE DEVELOPMENT OF DIRECT APPLICATIONS IN CHINA

As stated above, the wellhead assembly for direct application of geothermal energy has already been subject to some improvement. However, there are still several problems to be solved. They are:

(1) To improve the durability of submersible pumps for geothermal water applications.

(2) In order to decrease the temperature of the water leaving the geothermal heating system, and to increase the heating area, heat pump technology should be adopted to increase heating efficiency.

(3) International cooperation is needed in the sector of anti-

corrosion technology. We welcome offers for collaboration from colleagues in the international geothermal community interested in helping us promote direct applications of geothermal energy in China.

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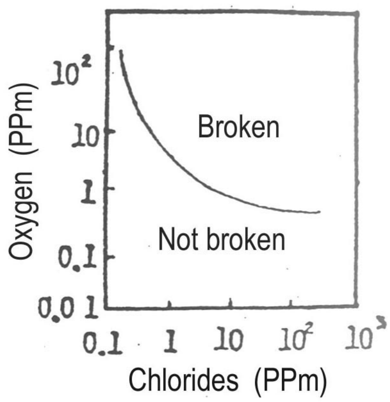

Fig.1 Effect of oxygen and chlorides on stress corrosion of stainless steel

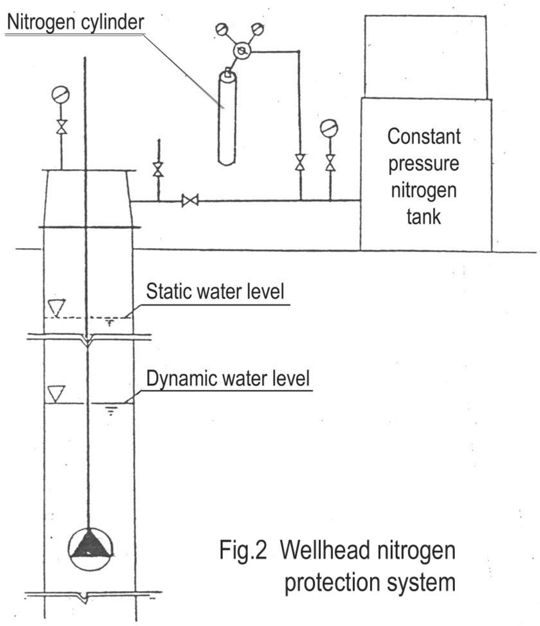

Fig.2 Wellhead nitrogen protection system

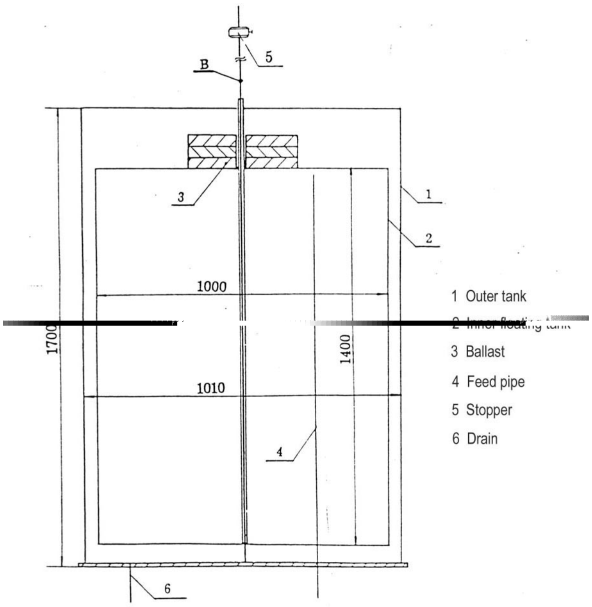

Fig.3 Floating tank type wellhead nitrogen pressurizing device.

Table 1. Measured oxygen content in geothermal water with and without nitrogen protection

Time	Flow of geothermal water, in tons/hour	Time of continuous operation, in hours	Oxygen content in ppb	Remarks
Start at 10:00	20	1	815	Without nitrogen charging
11:00	20	2	796	Without nitrogen charging
14:00	30	5	778	Without nitrogen charging
15:00	30	6	688	Without nitrogen charging
16:00	30	7	686	Without nitrogen charging
10:00 the 2nd day	30	1	559	With nitrogen charging
11:00	30	2	207	With nitrogen charging
14:00	30	5	75	With nitrogen charging
15:00	30	6	61	With nitrogen charging
16:00	30	7	52	With nitrogen charging
10:00 the 3rd day	100	1	62	With nitrogen charging
11:00	100	2	46	With nitrogen charging
14:00	100	5	20	With nitrogen charging
15:00	100	6	20	With nitrogen charging
10:00 the 4th day	100	3	20	With nitrogen charging
14:00	100	7	20	With nitrogen charging
15:00	100	8	20	With nitrogen charging
10:00 the 5th day	30	1	43	With nitrogen charging
11:00	30	2	31	With nitrogen charging
14:00	30	5	25	With nitrogen charging
15:00	30	6	21	With nitrogen charging
10:00 the 6th day	30	1	36	With nitrogen charging
14:00	20	5	20	With nitrogen charging
15:00	30	6	20	With nitrogen charging
10:00 the 7th day	30	1	24	With nitrogen charging
14:00	30	5	20	With nitrogen charging
15:00	30	6	20	With nitrogen charging
10:00 the 8 day	30	2	20	With nitrogen charging
14:00	30	7	20	With nitrogen charging

Note: Data in above table were processed by Tianjin Center of Physical & Chemical Analysis