Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

A STUDY ON ENERGY CONSERVATION OF RESIDENTIAL DISTRICT HEATING USING GEOTHERMAL ENERGY

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Key Words: direct and indirect supply, quantitative and qualitative regulation, max-temperature adjustment, heat metering, intellectual control, energy conservation effect.

ABSTRACT
Based on the case studies of the residential district geothermal heating systems in Tianjin, this paper describes how to apply the theory and method of energy conservation in construction to various links of the heating source, the heating network and the heating consumer in geothermal heating system. Technical and economic comparison is made between direct supply and indirect supply in the geothermal heating system. This paper stresses the adoptable method of quantitative regulation and qualitative regulation. It also explains the way of comprehensive use of the geothermal water in many respects. In addition it discusses the design theory and technical method of heat metering. Finally, it summarizes the experiences of introducing advanced techniques and devices from foreign countries, and realizing the intellectual-control system.

1. RAISING OF PROBLEMS

The "energy conservation" and "environmental protection" are two major topics related to the existence and development of human being. In the early 1980s, China has already put forward the strategic targets of environmental protection, energy conservation and further realizing continual development of energy.

The architectural energy conservation includes two parts, one in protective structure, and the other in heating system.
According to current condition in China, the immediate effect to be made to meet the architectural energy conservation requirement is researching heating & energy conservation system, improving the standard of heating & energy conservation system, and using a feasible way of the combination of systematic intelligent management and the realization of scientific quantitative regulation and qualitative regulation.

The Xinyuan residential exemplary district has 140,000 square meters, which utilizes geothermal energy as the main heat source for its heat supply. It also is equipped with relevant max-temperature adjustment unit, water heating and control equipment. In order to save energy and reduce heating cost, it is necessary to take energy conservation measurement in an all round way and adopt advanced equipment and technologies to meet the requirement for heating and achieve the best result for energy conservation. Aiding this target, we conduct the research of comprehensive utilization of heating energy conservation and geothermal water, apply the result to construction, and verify the theoretic result through testing in our actual projects.

2. MAIN CONTENTS OF THE RESEARCH

Since 1996, we have done the research and implementation of geothermal heating & energy conservation system with following respects:

2.1 Research of Energy Conservation of Heating Source

Energy conservation of heating source is one of the important components in the research of heating system. In respect of energy conservation of heating source, we mainly make research in the four points as follows:

2.1.1 Conduct technical and economic comparison between direct heating supply and indirect heating supply, and select the better method.

The main heating source of the project in Xinyuan district is a geothermal well with depth of 3282 meters. The water is taken from the heat store layer of base rock of Wumi Mountain. It is obtained from water-quality report that the type of the water is Cl^-, SO_4^{2-}, HCO_3–Na, low-mineral, neutral soft water. However, the content of chloric ion is up to 500 mg/L which is a corrosive water. With comparison, it is considered that for such corrosive geothermal water, if direct supply system is adopted, the following problems could occur:

(1) The requirement of architectural energy conservation could not be met, because temperature-control valves and thermal energy meters are not allowed to be installed in a corrosive water, and variable current circulating system is not suitable to be implemented in the direct supply. According to this result, the energy conservation of the system is difficult to be implemented.

(2) It is unfavorable for comprehensive utilization of the geothermal water, because tail water of the geothermal heating water with corrosive is harmful to people, and if the tail water is recharged artificially, it will pollute groundwater.

(3) The problem of max-temperature adjustment is not easy to be solved. Once the corrosive geothermal water directly gets into a boiler, the boiler will be corroded seriously. And if the heat exchanging method is used to heat the directly supplying water, it will reduce the heat efficiency.

(4) Direct heat supply by geothermal water will produce extreme corrosion to pipelines and equipment, in particular, directly supplying end equipment of integrated air conditioners will leave dangerous troubles hidden and reduce use term of the system.

(5) Under the condition that the heating source required to be changed once the geothermal resource exists problems, the direct supply system shall reconstruct the geothermal station and heating system. The reconstruction will be with high cost and large quantities and inconvenient to users. In turn, the indirect supply system only needs to switch power supply, and it will keep general heat supply to the system under the condition of increasing less investment. When the geothermal well has fault in a short time, the max-temperature adjustment oil boiler can play the reservation role of temporary heating.

For comparison on economy, the lump-sum investment and operation expense should be compared, and the more important point is to compare the benefit recovery period within the use term of the equipment under good operation condition, i.e. the balance value of differential value of the working expense and that of the investment. Through comparison, for the direct supply, the lump-sum investment is less but the operation expense is higher; and for the indirect supply, the lump-sum investment is more but the operation expense is lower. By actual operation and measurement, it is provided that adopting indirect supply can recover the over money spent in lump-sum investment within a quarter (6~8 years) of the use term of the equipment under good operation condition.

Upon comprehensive comparison, with the more consideration to being favorable of energy conservation of the system, we take the indirect supply as the way of geothermal heating for Xinyuan district project.

2.1.2 Selection of high-efficiency energy saving heat exchanging equipment

The heat exchanger is key equipment ensuring geothermal indirect heating, also one of the main units implementing the measure of energy conservation of heating source. After comprehensively comparing the technical performance of various heat exchangers, we finally determined the titanium-plate heat exchanger with the five technical characteristics as follows:

The characteristics include: 1. Sheet plate, good materials, high heat transferring efficiency, small covering area; 2. Low log temperature difference for the heat exchanger and high heat supply capacity for its unit heat exchanging area; 3. Multiple combinable kinds for the plate and suitable for the selection of different parameters; 4. The accessory pipe designed with one-side flow to make the layout of the system more reasonable; 5. Sealing joint strip of the heat exchanger can bear high temperature and pressure of this system.

2.1.3 Research of the method how to organically combine the quantitative regulation and qualitative regulation to heating source and effect of energy conservation.

So far, the international advanced heating system achieves the best effect of energy conservation through organic combination of the quantitative regulation and qualitative regulation. The research starts from heating source to explore how to conserve energy by the use of quantitative regulation and qualitative regulation and method of combination of both regulations, we mainly research the two problems as follows:

(1) Measures for quantitative regulation and qualitative regulation to respective parts of geothermal water and circulating water and their effects:

For the part of geothermal water, the measure taken is that a drainage temperature transducer is set on the drainpipe of geothermal water, the transducer and deep-well pump frequency-converter constitutes the qualitative regulation system. When the heat load in the heating system changes, through controlling the drainage temperature and regulating frequency of deep-well pump, the system can save geothermal water in maximum limit, thus reach the purpose of energy conservation and protect the geothermal source. Generally, the regulation effect is more obvious at the beginning and end of cold solar terms. The feature of the measure for energy conservation for geothermal water is to take thermal energy conservation as main one and take electric energy conservation as secondary one.

Temperature-sensing valve is installed on the door radiator. Quantitative regulation must be implemented to the part of circulating water for the energy conservation of flow regulation. Therefore, a pressure-difference controlling point is set between the water knockout trap and the water collector of the part of circulating water. The pressure transducer and heating circulating pump frequency-converter constitute the quantitative regulation system. When the flow in the heating system changes, with the premise of normal pressure for water supply, the system can automatically adjust the number of turns of water pump, reduce flow and power, thus save electric energy in maximum limit. The feature of the measure is to take electric energy conservation as main one and take thermal energy conservation as secondary one.

(2) Measure for electric energy conservation to hot-water system for life use:

Constant-pressure variable control shall be adopted for hot-water supply for life use. A pressure controller is installed on hot-water supply pipe. The pressure controller and the power supply frequency-converter of the water supply pump constitute constant-pressure variable controlling system. When the water supply pressure changes, the water pump can automatically switch among different steps, thus reach good effects of electricity and energy conservation with the premise of stable water supply.

The system adopts appropriate frequency-converting equipment to make the water pump keep in status of soft start all along, so impulse current is not produced, noise is reduced and service life is extended.

According to the relation in proportion between electrotechnology and the impeller of centrifugal pump, we obtains:

The relation between speed of rotation (n) and frequency (f) is:
$n_1/n_2 = f_1/f_2$,

and the relation between speed of rotation (n) and power (N) is:
$N_1/N_2 = (n_1/n_2)^3$,

After the power supply frequency changes, the power of centrifugal pump will change by its cube. Thus, the effect of electricity conservation is obvious.

(3) Measures of qualitative regulation taken to geothermal well and max-temperature adjustment oil boiler and their effects:

In the heating construction of Xinyuan district, the heat quantity obtained from geothermal well is taken as main heating source, i.e. bearing primary load, which takes 58% of entire design load; and the heat quantity obtained from max-temperature adjustment oil boiler taken as secondary heating source, i.e. max-temperature adjustment load, which takes 42% of entire heat load. But actually, as the cold solar term of Tianjin district is shorter, heating runs at the status lower than

design heat load within much of time. So the heat quantity obtained from basic heat load borne by the geothermal well takes about 80% of total yearly heat supply, and that obtained from max-temperature adjustment load borne by the max-temperature adjustment equipment takes about 20% of total yearly heat supply. It is indicated that selecting flexible, simple and convenient max-temperature adjustment equipment suitable for change of heat load is an important measure for energy conservation. Therefore, in this construction, the non-pressure boiler for oil and gas is selected as max-temperature adjustment equipment.

In order to reduce time and quantity of max-temperature adjustment as much as possible, and cut the cost for heating, a series of control devices is selected in this system, such as water temperature sensor set on the water knockout trap; three-port electronic water mixing valve set at the cross place of the inlet of the water knockout trap, outlet of water supply pipe of oil boiler, and feed water inlet for circulating water; outdoor temperature sensor set out of the house by geothermal station; and climate compensating controller set in the house of geothermal station.

All the devices constitute intellectual-controlling max-temperature adjustment system. At the time, cold solar term comes and the geothermal well can not meet heating requirement, the intellectual-controlling system begins to work. According to the fixed heating curve, based on the signal transmitted from the outdoor temperature transducer, the climate compensating controller starts three-port electronic water mixing valve and the oil boiler to adjust max-temperature automatically. In process of adjusting max-temperature, according to change of outdoor temperature, the climate compensating controller controls the three-port electronic water mixing valve to indirectly regulate the water supply temperature of circulating water. When the water supply temperature is up to standard, the oil boiler shut off itself. Thus, qualitative regulation is realized and the purpose of energy conservation is reached.

Through the research on the aforesaid two problems, we took a series of measures for energy conservation in quantitative regulation and qualitative regulation to heating source, ensured the system in stable run, reduced the cost of heating for first-stage works, obtained obvious economic benefits, and achieved comparatively ideal energy conservation effect.

2.2 Research of Energy Conservation To Heating Network

The measure for energy conservation to heating network is taken to ensure the effect of energy conservation to heating source. For the purpose of energy conservation to heating network, for the part of double-pipe system at the heat inlet of a building, a self-supporting pressure-difference controller is adopted to stabilize pressure difference and balance the system; and for the part of single-pipe system, compensation valve and control valve are set at the inlet and outlet of water supply and return respectively to limit flow and regulate horizontal disturbance. In order to reduce the heat loss of heat-transmitting pipelines and make the heat efficiency of the pipe network not less than 90%, for all the external network, poly-cyanogen plastic vertical insulating pipe with the insulating layer of thickness of 50mm is adopted, and using the heating characteristic of low-temperature supply at any time makes the heat pipe network keep in comparatively low temperature for a long term, thus to reduce heat loss of the pipelines in maximum limit and improve the heating efficiency of the pipelines.

2.3 Research of (Indoor) Energy Conservation To Residents

The energy conservation to residents is also one of the important links for energy conservation of the entire system. In order to accomplish the trial charging of heat metering in Tianjin, in first-stage works, we choose four-story building for housing with 32000 square meters as trial point. In order to ensure constant, comfortable and adjustable temperature indoors, the double-pipe system is adopted indoors, and the self-supporting thermostatic control valve is installed at the inlet of radiator. An automatic steam escape valve is installed at the highest place of the system to ensure automatic exhaust and prevent the pipelines and devices from producing air lock; we also took a series of technical measures, e.g. using the preset value of temperature-sensing valve to solve the problem of vertical disturbance. The metering method is realized, that total heat quantity is metered by the general meter in the double-pipe system and spared by every user. In order to reach higher standard of energy conservation, combining with actual construction, we designed and researched the under-supplying and -returning horizontal parallel double-pipe system for metering every user's meter, so the users can control and adjust heat quantity by themselves, thus the charging of heat metering is realized.

2.4 Research On Comprehensive Utilization of Geothermal Water For Energy Conservation

The problem of the comprehensive utilization of geothermal water is also an important part of energy conservation of the system. The main content of the research is arranging flow according to used water's temperature drop so that the tail water of geothermal heating can be utilized effectively and comprehensively.

2.4.1 Change to medical and healthy water for life use and improvement of the standard of using water

According to water quality analysis, the geothermal water of this system contains abundant rare minerals benefiting human people, can be well used for hot spring recuperation. But the water contains excess ferro and sulfur ions. If the water is exposed in the air, it would get red with fishy and H_2S smell, and change the touched clothes and containers to yellow, thus the use scope of the geothermal water is limited. In order to solve the problem, a device to eliminate the ferro ion in the geothermal water is set in the system. According to the characteristics of the used water, the selected device meets the following specifications:

- The technique of physical absorption is applied to remove ferro and sulfur in the tail water to improve water quality and reduce corrosion of the water. The disposal can not produce secondary pollution and lose the healthy mineral components.
- After the disposal, the content of ferro in the water is 0.035mg/L and that of sulfur is 0.010mg/L, the water is limpid, and the effect is stable.
- Used equipment is simple and heat loss in process of the disposal is less.

Geothermal heating tail water after the disposal can directly be used for bathing, swimming and medical health etc. A good

effect of mineral water for family use is brought, and the research has extensive social benefits.

2.4.2 Feasibility research of using the geothermal water after the disposal in swimming pool has the significance as follows:

- The geothermal water contains rich minerals, so hot-spring bathing is healthy.
- With the temperature of about 45°C, the geothermal heating tail water can be considered as heating source of hot-spring swimming pool, thus energy can be saved.
- In water, the geothermal heating tail water can be taken as adding-in water for swimming pool to save water resource; in addition, swimming pool can play the role of cooling the drained geothermal water.
- With higher salt content of 1928mg/L, which is obtained by measuring, the geothermal water has very strong capability of sterilization. If management work is appropriate, the water can be up to the standard of health quarantine by utilizing the capability of sterilization of the geothermal water itself and the method of adding new water to filtering circulation, so the expense on feeding medicine is reduced and the standard of the water for swimming is improved.

To sum up, directly using the geothermal tail water after the disposal in swimming pool is feasible both in economy and technology.

2.4.3 Research of utilizing the geothermal heating tail water for floor radiation heating

Utilizing the geothermal heating tail water for floor radiation heating belongs to reutilization of the tail water and is a measure for energy conservation by reutilizing heat energy. The drainage temperature at the side of geothermal water of heat exchanger is about 45°C generally, which can be taken as heating source of floor radiation heating. If the measure is reasonable in financial condition, it will be a measure for energy conservation with great results, meanwhile, it has very high value on popularization and application. Therefore, combining with practical construction, we make theoretic research and technical and economic analysis in this works. Through actual calculation, 10,000 square meters of heating areas can be increased, and water temperature after floor radiation heating can go down by about 10°C again, in the meantime, relevant rules of the state on drainage of tail water for environmental protection is satisfied. It is proved through verification in actual construction that its effect is distinct.

3. TESTING AND WORKING CONDITIONS OF ENERGY CONSERVATION SYSTEM

For the heating & energy conservation system in first-stage construction of Xinyuan district, through inspection for the system during a heating quarter, all the equipment and pipe network run in good condition and reach design requirement and expected results.

In process of running the system during the heating quarter, we have the suggestions in the following aspects:

3.1 Indoor System:

(1) The temperature-sensing valve is unsuitable to be installed on cast iron radiator.
(2) The filtering net pressure-difference controller shall not be too dense.
(3) For the double-pipe system, under-supplying and -returning circulating way shall be adopted to solve the problem of vertical disturbance through natural thermal pressure.
(4) When the automatic steam escape valve is out of control, which causes that indoor system is not heated, we can remove the steam escape valve and wash it, or check if the automatic steam escape valve is installed at right place.

3.2 External Network System:

After the heat pipe network puts into run, if the indoor temperature of the users at the near end is too high, or the indoor temperature of the users at far end is too low, in particular, that of the users at the terminal of double-pipe system is lower, we can adjust the pressure-difference control valve and control valve at every heating inlet, specially check whether the flow limiting measure to near-end single-pipe system is appropriate.

3.3 Heating Source System:

(1) After the automatic variable-frequency qualitative regulation system puts into run, if the temperature of circulating water has large fluctuation, we can change into semiautomatic control temporarily, and operational personnel can, according to the changes of outdoor temperature and use load, taking the drainage temperature of well water as control point, limit the frequency of well water pump within in a certain proportional bandwidth periodically, so as to ensure the supplying temperature of the circulating water keeping stable for the purpose of energy conservation; or improve the industrial control process of the system to make the frequency curve of deep-well pump smooth, thus realize full-automatic control of the qualitative regulation system.

(2) If for floor radiation heating cut-off water tank, the appearances of water break and water blocking of the de-ironing tank occur, we can raise the frequency of the water pump properly and control the open degree of geothermal water draining valve to make the back-pressure value of the system meet the requirement for use.

(3) If the temperature difference of the return water in water circulating system is lower that design value, further the effect of energy and electricity conservation is not so ideal, we can: set a compensation valve on the water-returning pipe at the heating inlet of the single-pipe system, and take the measure of limiting flow to increase resistance at the water-returning outlet, adopt indoor double-pipe flow circulating system to increase the proportional of double-pipe system in the circulating system, and adjust the pressure-difference valve in water circulating qualitative regulation system in the geothermal station, determine appropriate pressure-difference value, adjust the flow to minimum with the precondition of normal pressure for water supply of the system, so as to reach the effect of energy and electricity conservation.

(4) If the pressure drop of the side of circulating water of heat exchanger rises suddenly, we can install a filter with net pitch of 20 holes /square inch.

(5) If the automatic water pump starts frequently, and water loss of the system exceeds 2%, we can consider whether the pipe network leaks or valves is bad.

(6) After the oil boiler max-temperature adjustment system enter the stage of max-temperature adjustment, if the oil boiler starts frequently and oil consumption is a bit higher, we can adjust control value according to heating curve to keep some delay time for heating process, make the interval of starting the oil boiler longer, control reducing the temperature of water supply by clock at night.

(7) If the water in the de-ironing system for hot water for life use after heating finishes becomes yellow, we can drain before the driving pump starts till the water temperature at the outlet is about 50^{o}C, then conduct de-ironing treatment.

4. RESEARCH AND APPLICATION RESULTS

With two-year research and practice, on this research topic, we have obtained some results and experiences in the respects, such as the research on the theory in energy conservation of heating system, the design in energy conservation of heating system, the combination between theory and practice, the work of lectotype, installation and debugging of energy conservation equipment, and the management for the working process of the entire energy conservation system.

The effect of energy conservation of the first-stage works of Xinyuan district is distinct, the changing ratio of heating is up to 95%, and 80% of houses has been sold out.
At the end of 1998, Xinyuan district was selected as exemplary district with excellent property management in all cities of the country by Ministry of Construction.

The energy conservation results and economic benefits of this exemplary district are summarized below:

1 The overall rate of energy conservation is 42%, which is equivalent to an enlargement of the heating area by about 30%;
2 Comprehensive rate of electricity conservation is equivalent to 40.4%;
3 Overall cost reduction resulting from these energy conservation efforts is 22%;
4 Standard coal consumption index is 14.02 kg/m^2, which is 12.37% lower than the index of one-step energy conservation;
5 Comprehensive utilization rate of geothermal water is 40%;
6 Up to now, comprehensive economic benefit of the project is about RMB 350,000.

5. CONCLUDING REMAKES

Through the construction of the exemplary residential district, we have conducted the research and practice for geothermal heating & energy conservation, a coordinated process from design, research, installation and debugging to working management, and obtained some theoretic results and practical experiences. We realize that theoretic research must depend on construction project, just as so, an energy conservation construction can be built, a batch of research results can be brought.