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STUDY ON THE OPTIMUM DESIGN OF THE INDIRECT GEOTHERMAL HEATING SYSTEM

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ABSTRACT

In recent years some geothermal heating system in China have been transformed from direct heating system into indirect ones. The materials used to make the plate heat exchanger are anticorrosive plated mild steel, stainlees and titanium. This paper explains the reason why the transformation is needed, and describes the fan coil of the air conditioner used in conjunction with geothermal water. Mathematical models for indirect low temperature geothermal heating system have been established, FORTRAN 77 software designed and techno-economic analysis made. The results can be used in the feasibility study of geothermal heating project and engineering. Examples of engineering application are also given.

Introduction

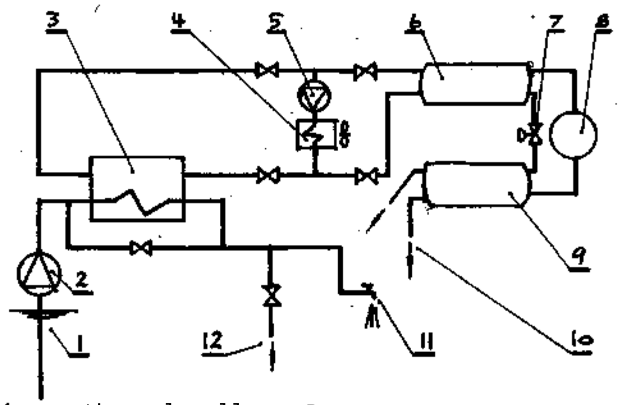
China will rely on coal as the main source of energy at least till the end of this century, but burning much coal will badly pollute the atmosphere. The air pollution in many Chinese cities has reached the same severe level of pollution as that in the developde countries of 1950s.

At least half of China's cities and towns must have heating in winter. According to the measurements made in the heating period in Beijing, 77% of sulphur dioxide in the air comes from the coal burning boilers and small stoves. In many regions in China there are abundant low temperature geothermal resources, which are rational and usable in heating. If they are used properly and treated by effluent reinjection and treatment, environmental pollution can be reduced or eliminated. In recent years direct economic and indirect social benefits have been reaped.

For the sake of saving investments geothermal water was mostly directly fed to the heating system in early stage of geothermal heating. As most of the geothermal water contains chlorine ions, they corrode metals badly,and sometimes the equipment scales heavily. If the direct heating system is converted into the indirect by using plate heat exchangers, and using clean circulating water to absorb the heat from geothermal water, the above-mentioned shortcomings can be avoided. But the initial investment in the heat exchanger will be high. The energy source comparable to geothermal energy in China is coal, which is rather cheap. But it is usually very unlikely to compensate the initial investment in heat exchangers with the money saved by burning coal.

In the past few years changes have taken place. First, facing the bad air pollution in many cities and towns by burning coal, the public and authorities are willing to harness geothermal water. Secondly, the corrosion in the existing geothermal heating system is worsening year from year, and at the same time the price of coal is going up so that the investment in the heating system is increasing. It is now economically possible to use the indirect system with plate heat exchangers.

A typical example is a geothermal system put into operation in the northern suburb of Beijing this year. See Fig. 1. This system heats six buildings with geothermal water and supplies hot water for daily use. The terminal unit in the room is the fan coil in conjunction with air conditioners. The use of the plate heat exchanger prevents the corrosion in the fan coil, but the temperature drop for heat exchange is required.



1. geothermal well   B. compressor
2.vw^tsteJULt turbine pump
3. titanium plate heat exchanger
4. fan coil   9. candensex
5. circulation pump   10. to heat- sink
6. evaporator   It. domestic hot water
7. expansion valve   12. aquaculture

Pig.1

The optimum design of such a system must be worked at so as to make full use of geothermal resources, to select the appropriate area of heat exchange and to gain even better benefits in geothermal heating.

The Establishment of Mathematical Models

The schematic diagram of the low temperature indirect heating system without peaking load is shown in Fig. 2.

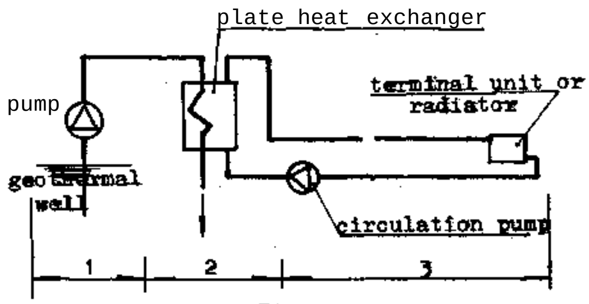


Fig. 2

The system is composed of three sections: 1. the section of geothermal water, 2. the section of the heat exchanger, and 3. the section of circulating water. Suppose the flow rate GA of the geothermal well, the temperature Tl of the water in the well, and the distance Lg from the well to the heat exchange station, and the initial investment TGO are known.

l.Heat exchanger The initial investment (only the initial investment in pumps and motors Tghi and investment in heat exchangers Tofe are considered.) and cost of operation (only the annual cost of geothermal water Cyhi, annual electric charge Cyfi2 i management expenses plus workers' wages and maintenance cost CyK?) are the functions of the following seven independent variables (N_{sy}, N^ »Nad ,N§d , Gx , At, TG). On this section the following constrainments should be imposed.

(1) The equation of heat transfer is

$$\frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} \cdot \frac{FM}{Q} = \frac{1}{U \cdot A_N} \qquad (1)$$

Rearrangement of Eq (1) results

$$\frac{\left(\frac{G_x \cdot C_{px}}{G_d \cdot C_{pd}} - 1\right)}{G_x \cdot C_{px} \cdot \ln \frac{T_l - T_G}{T_l - T_G - \left(\frac{G_x \cdot C_{px}}{G_d \cdot C_{pd}} - 1\right)\cdot \Delta t}}$$

$$FM - FO \cdot (N_{dx} \cdot N_{sx} + N_{dd} \cdot N_{sd}) = \frac{DB}{BK} + RF + \frac{N_{dx}^{n}}{C \cdot \frac{e_x}{DE}\left(\frac{G_x \cdot DE}{FB \cdot \mu_x}\right)^{n} \cdot Pr^{m_1}} + \frac{N_{dd}}{c \cdot \frac{Cl}{DE}\left(\frac{G_d \cdot DE}{FB \cdot \mu_d}\right)^{n} \cdot Pr^{m_2}} \qquad (2)$$

(2) The pressure drop through the exchanger

$$\Delta P_x - \Delta P_a <= 0 \qquad (3)$$

$$\Delta P_d - \Delta P_a <= 0 \qquad (4)$$

i.e.,

$$Al \cdot K_{21} \cdot G_x \cdot \left(\frac{DE}{\mu_x}\right)^{-l} \cdot \left(\frac{Gtf}{FB}\right)^{2+B} \cdot N_{sx} \cdot N_{dx}^{-(2+BI)} - \Delta P_a <= 0 \qquad (5)$$

$$Al \cdot K_{21} \cdot \left(\frac{DE}{\mu_d}\right)^{-l} \cdot \left(\frac{G}{FB}\right)^{2+B} \cdot N_{sd} \cdot N_{dd}^{-(2+BI)} - \Delta P_A <= 0 \qquad (6)$$

(3) The combination of the through (Number of water feeds) and the passes.

The combination of the through and passes must satisfy the following equation

$$\left|N_{dd} \cdot N_{sd} - N_{dx} \cdot N_{sx}\right| - 1 <= 0 \qquad (7)$$

i.e.

$$N_{dd} \cdot N_{sd} - N_{dx} \cdot N_{sx} - 1 <= 0 \qquad (8)$$

$$N_{dx} \cdot N_{sx} - N_{dd} \cdot N_{sd} - 1 <= 0 \qquad (9)$$

(4) The relationship of temperature

$$TG - Tl < 0 \qquad (10)$$

$$TH - TP < 0 \qquad (11)$$

i.e.

$$TG - Tl + \left(\frac{G_x \cdot C_{px}}{G_d \cdot C_{pd}} - 1\right) \cdot \Delta t < 0 \qquad (12)$$

2. The circulating water This section consists of the indoor pipe network (vertical pipe and branch pipe), indoor supply and return pipe networks. The initial investment in the above items and the cost of operation (Only the annual electric change C of the circulating water pumps, wages of the managing personnel C , management expenses C of the pipe network are considered.) are the functions of G , t and TG. In this section exists a temperature constrainment.

$$TH - TN > 0 \qquad (13)$$

i.e. $$TN - TG + \Delta t < 0 \qquad (14)$$

3. As for the section of geothermal water, the initial investment Tgc$ in the pipe network can be determined by the known conditions. The initial investment TGO in the sinking of the well can be obtained by the statistics.

4. Based on the mathematical models of the above-mentioned sections, with the lifetime of the sections being given, the total mathemtical model can be established using the net present value method in the technoeconomic assessment, the objective function F is minimum cbst spent in the recovery of unit heat.

Symbols

Gx — the flow rate of the circulating water kg/s

At -- the possible temperature drop (supplied and returning water) in heating °C

TG — the temperature of the supplied circulating water °C

G4 — the flow rate of geothermal water kg/s

N_{sx} — the number of the passes of the circulating water in the heat exchanger

N^x — the number of the through of the circulating water in the heat exchanger

N^-- the number of the through of the geothermal water in the heat exchanger

N54-- the number of the passes of the geothermal water in the heat exchanger

DE -- the equivalent diameter of the through m

FB -- the sectional area of the through of the heat exchanger m^2

c_{px} — the specific heat of the circulating water J/kg°C

c_{pa} — the specific heat of the geothermal water J/kg°C

Tl -- the wellhead temperature °C

FM — the correction coefficient of mean

temperature difference
FD -- the area of plate heat exchanger per piece m^2
DB — the thickness of a piece of plate heat exchanger m
BK -- the conductivity of the plate heat exchanger J/m°C
RF — the dirt coefficient m^2-°C /J
ΔP_A — the limit pressure drop through the heat exchanger PA.
TN -- indoor design temperature °C

The Results of Optimization

Based on the mathematical model, using the penalty function method in mathematical planning and FORTRAN 77 language, the universal software OPS3 for the optimum design of the low temperature geothermal heating system without peaking load was compiled. In choosing the types of the heat exchanger and radiator the OPS3 is applicable to the optimum design of any geothermal well and find any optimum design parameter needed. Besides, after inputting the practical data of the present engineering in China and applying OPS3 to the analysis of the above model, the following concluations are reached.

1. The optimum flow rates on both sides of the exchanger are roughly the same. They are independent of the wellhead temperature, wellhead flow rate, the distance from the well to the heat exchange station, and the initial investment in the sinking of the well, and the type of the radiator. They are related only to the type of the plate heat exchanger. Plate heat exchangers of the same type have an optimum flow rate (or economic flow rate), which can serve as the basis for the optimum design of the plate heat exchanger.

2. The ratios of the optimum flow rates of the geothermal and circulating water on both sides are within 0.8-1.0, mostly within 0.9-1.0. When the wellhead flow rate increases, the side of the circulating water is the smaller one", when the wellhead temperature goes up ,and the initial investment in the sinking of the well increases, the side of the circulating water is the larger one.

3. The distribution of the feasible districts From Fig.3 derived is relationship between the wellhead flow rate and wellhead temperature. Fig.4 is the feasible district when the heating cost Ct is ¥10/10^6KJ. It can be referred to in the discussion of the feasibility of geothermal heating.

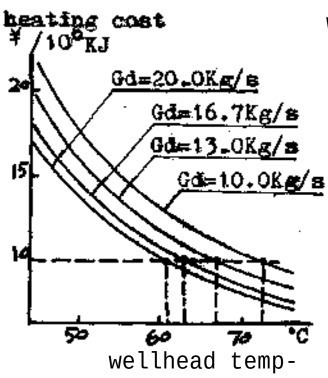


Fig. 3

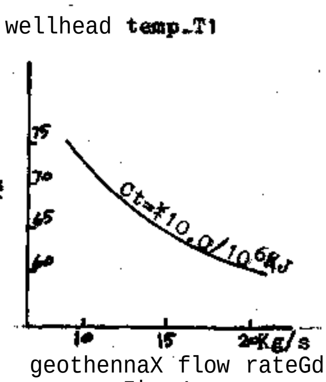


Fig. 4

4. The selective curve of the optimum heating area
The optimum heating floor area is mainly determined by the wellhead parameters. When the investment in the sinking of the well and the distance from the well to the heat exchange station are not taken into account, the optimum heating floor area can be derived from Fig.5.

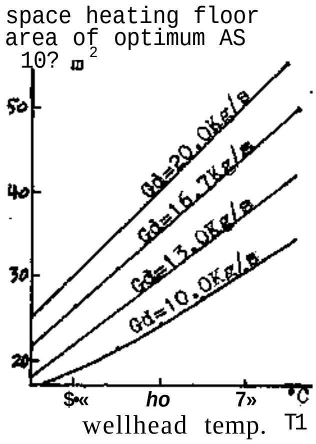


Fig. 5

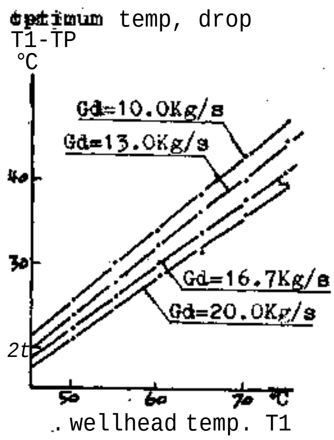


Fig. 6

5. The selective curve of the utilizable temperature drop of geothermal water
The optimum utilizable temperature drop of geothermal water is determined by wellhead parameters. When the investment in the sinking of the well and the distance from the well to the heat exchange station are not taken into account, the optimum temperature drop can be derived from Fig.6.

6. The selective curve of the optimum temperature of the circulating water.
From Fig.7 it can be seen that the optimum temperature of the supplied circulating water has nothing to do with the wellhead flow rate, neither with the initial investment in the sinking of the well. However, it is directly proportional to the wellhead temperature Tl. Its selective curve is shown in Fig.7

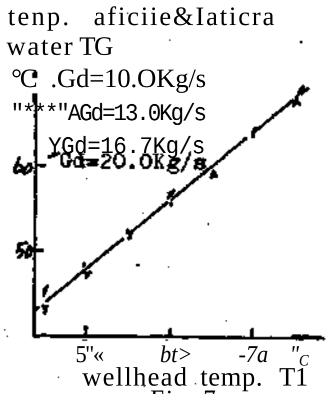


Fig. 7

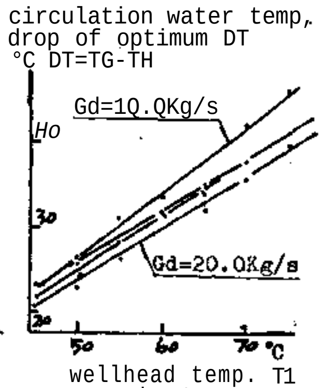


Fig. 8

7. The selective curve of the optimum temperature difference between the supplied and returning circulating water
The temperature difference between the supplied and returning water is mainly determined by the wellhead parameters. If the initial investment in the sinking of the well and the distance from the well to the heat exchange station are not considered, its selective curve is shown in Fig.8.

All the above-mentioned can be for reference in the feasibility study of geothermal heating, and also serve as the basis for the preliminary design and the construction design of the indirect geothermal heating system. When the industrial waste heat is used for heating, and wasted hot water is not allowed to enter the heating system directly and has to undergo heat exchange, the above-mentioned method and conclusions hold good as well.

The Application of the Opimization Results

Table I and II list the initial data of the five user of geothermal heating and the output results of the optimization design of the indirect plate heat exchanger without peaking load.

The first line of the first user in Table II is the result excluding water resource fee. The second line is the result including water resource fee, ¥2.8X10~*/kg.

From Table II it can be seen that when the user has to pay the water resource fee, the area of heat exchange must be expanded to increase the quantity of heat exchange so that the cost can be made minimum. The cost at this point is higher than when the water resource fee is not charged. The higher the water resource fee, the less economical the system, and this will be analyzed according to the actual thermal price.

The cost of the fourth user in Table II is the highest. This is because the wellhead flow rate is too small, the wellhead temperature too low, and the initial investment in the sinking of the well is too high. For such a system the indirect heating without peaking load is obviously not appropriate.

If the heating cost is ¥10/10fe KJ, only the second and the third users can use the indirect heating system without peaking load and gain economic benefit. The other three users are losing.

For the sake of expanding the scope of geothermal , the indirect heating system with peaking load has been used in some places. This practice can raise the economic benefit and increase the utilization of geothermal energy. The study of the optimum design in this respect remain to be discussed.

$U.S.1.00=¥3.80(Chinese yuan)

Table ^ Initial data of well and equipment

User	Temp, af wellhead	Flow rate	Distance from the well to the heat exchanger	Dapth	Well cast	Heat ex-changer type	Heating floor area	Water resource. fee. needed or not	Radiator type
HO.	T-1 (°G)	Gd(Kg/s)	Lg (m)	h (m)	¥*10³		2 at		
1	58	16.7	40O	600	300	atainless steelBpO5	lfc,QQO	yes or no	cast iron SZ 815
2	75	16.7	600	1500	75a	titanium BRO84	40,000	na	cast iron SZ 815
3	70	13.9	t50	.1100	550	stainless steelBpO5	20,000	no	finned tube convector
4	48	6.7	200	1500	750	stainless steelBR35	8,000	no	cast iron SZ 813-
5	64	16.7	150	500	450	stainless steelBR35	40,000	yes	cast iron SZ 813

Table II The output results of the optimization design of the user after rounding of the through and passes *at* the plate heat exchanger

User	Through & passes	After rounding off	circulation water			Cost	Temp.drop AT of geothermal	Area *of* the heat exchanger	Area of the radiator	Heating floor area
			Flow rate	Supplied Temp.	Temp. drop					
HO.	nsxxndx / nsdxndd	UsxxIW / NsdXNdA	<^Kg/a)	TG(°C)	At(°C)	¥/IOKJ	°C	m²	m²	m²
1	10.96x12.28 / 11.15x12.07	11x12 / 11x12	15.8	54.2	29.5	11.49	27.9	137.8	19510.8	33456.6
	11.35x15.23 / 11.1xx15.47	11x15 / 11x15	17.4	53.2	30.9	13.69	32.2	172.1	24978.6	38571.0
2	11 ,74x 4.18 / 11.96x 4.08	12x 4 / t2x 4	16.4.	67.9	44.1	9.18	43.3	81.5	21764.0	51914.1
3	9.48x13.3 / 9.48x13-3	10x13 / 10x13	U~3	64.1	37.6	9-79	38-7	135.7	27352.3	38594.0
4	15.7 x9.63 / 15.7 x9.67	16x10 / 16x10	7.7	43.5	24.4	26.61	28.0	112.4	14428.8	13486.0
5	32.3 x8.t / 32.1xx8.1	32x8 / 32x8	16.3	59.6	38.6	11.59	37.7	179.6	25047.8	45162.5