OPTIMAL DESIGN OF PLATE HEAT EXCHANGER IN THE GEOTHERMAL HEATING SYSTEM

ZHU Jialing ZHANG Wei MIAO Changhai

Tianjin Geothermal Research and Training Center, Tianjin University, Tianjin 300072, China

Abstract This paper discusses the designs of material, placement, size and flow rate of plate heat exchanger in a geothermal heating system. Based on the technology, economy, environment and protect resources, the optimal design of PHE by computer has been carried out. The paper also points out factors that affect the result of design and compare with practical works.

Keywords geothermal heating, plate modality, plate heat exchanger, optimal design

Geothermal as a kind of environment friendly heat resource, has been widely used for district heating. But most geothermal fluids contain a variety of dissolved chemicals. The buildings mechanical system may be dissolved in 1 ~ 2 years in geothermal water directly using system (Popvski, 1999). It is very expensive if the heating equipments are often replaced.

To solve these problems, it was decided to isolate the geothermal water from the heating system by using plate heat exchangers (PHEs). The counter-current flow and high turbulence can be achieved in PHEs in a small volume. The PHEs have the advantage on occupying less space compared to shell-tube exchangers, and can easily be expanded when addition load is added and the cost can be 40% less (Lund, 1998). PHEs are commonly used in geothermal heating system. In this paper, optimal design and utilization of PHEs are discussed.

1 CALCULATION METHODS OF HEAT TRANSFER AND PRESSURE DROP

1.1 Overall Heat Transfer Coefficient

The overall heat transfer coefficient is below:

$$K = \left(\frac{1}{\alpha_1} + R_{s1} + \frac{\delta}{\lambda} + R_{s2} + \frac{1}{\alpha_2}\right)^{-1} \quad (1)$$

where α_1——The heat transfer coefficient between the warm medium and the heat transfer surface (W/m^2·℃);

α_2——The heat transfer coefficient between the heat transfer surface and the cold medium (W/m^2·℃);

R_{s1}, R_{s2}——The foul factor (m^2·℃/W).

In geothermal heating system, K is always about a range of 2900 ~ 4650 (m^2·℃/W) in practice.

1.2 Equation of Heat Transfer

The equation of heat transfer is described as:

$$Q = K \cdot A \cdot \Delta t_m \quad (2)$$

For single phase fluid: $Q = q_m c_p (t' - t'')$

where A——the area of heat transfer (m^2);

Δt_m——Logarithmic Mean Temperature Difference (℃);

q_m——flow rate (kg/s);

c_p——specific heat (kJ/kg·℃).

1.3 Calculation of Pressure Drop

The pressure drop in the system can be calculated as:

$$\Delta p = bRe^d m \rho w^2 \quad (3)$$

where w——velocity of fluid (m/s);

m——flow paths;

ρ——density of fluid (kg/m^3);

Re——reynold's number;

Pr——Prandt number.

2 UTILIZATION CONSIDERING OF PHE IN GEOTHERMAL HEATING SYSTEM

2.1 Material Selection

According to Elli's figure (Zhu, 1995), when temperature is above 80 ℉ (27 ℃) and chloride (Cl^-) content is more than 500×10^{-6}, both 304 stainless and 316 stainless are not considered as a kind of safety material for PHEs. Titanium has a very low rate of corrosion, it is so expensive that makes the investment much higher. However, titanium is, as the general material, selected to maintain the system's lifetime.

2.2 Plate Modality

There are two kinds of plate modalities: lambdoidal modality and plain-straight modality. The operating pressure of lambdoidal modality can be over 1.0 MPa (Yang, 1995), and plain-straight modality is about 1.0MPa. And heat coefficient and pressure drop of lambdoidal modality is higher than that of plain-straight modality. In geothermal heating system lambdoidal modality is often used.

2.3 Plate Size

The holes on the plate are related to the plate size. To reach a high efficiency, the flow velocity in the holes is determined about 6 m/s. If the size is too small, the numbers of flow paths will be increased and pressure drop will go up. On the other hand, if the size is too big, the flow velocity in the holes cannot reach the allowance scope, so that the heat transfer coefficient will be too low. Taking into account factor, such as flow rate, flow velocity and pressure drop, there are several kinds of plate size are proper for the geothermal heating system, such as 0.5, 0.8, 1.0m^2, and may be more.

2.4 Flow Velocity

Flow velocity may influence both heat transfer efficiency and pressure drop. High flow velocity can obtain a high heat transfer coefficient and high pressure drop. It gives a velocity scope of 0.2 ~ 0.8 m/s in the system.

2.5 Flow Paths

If the flow rate of hot and cold sides is approximately equal, the PHEs should be designed as symmetrical exchangers. In geothermal heating system, the equivalent flow path PHEs are always used, because it can achieve counter-current flow.

3 DESIGN OF PHE

As optimization design, the main purpose is to keep the heat transfer area as smaller as possible with a basic heating requirement. The optimization design improves not only the efficiency of design but also the reliability and correctness of the design. Especially, it can select data arbitrarily in a large range and find out the best design solution as fast as possible. The computer scheme is illustrated in Fig.1.

From a set of conditions and Eq (2), the heat load (Q) can be calculated. Based on the dimensions of heat exchanger and parameters, heat transfer area (A_e) and the number of heat exchangers (T) can be estimated as:

$$A_e = \frac{Q}{K_i \times \Delta t_m} \tag{4}$$

where K_i = experiential figure of overall heat transfer coefficient [2900 ~ 4650 W (m$^2\cdot$℃)].

$$T = \frac{A_e}{A_0 \times N} \tag{5}$$

where A_0 = the size of single plate (m^2);
N = plate number per heat exchanger.

By applying A_e and T, combined of PHE, the flow path (m) and channels (n) of each flow path can be determined. Thus the flow velocity (w) and the heat transfer coefficient (α) can be given as:

$$w = \frac{q_m}{N_z \times A_s \times \rho \times n} \tag{6}$$

where N_z = numbers of parallel connection groups;
A_s = flow cross section (m^2);
n = number of flow channels.

$$\alpha = \frac{N_u \times \lambda}{d_e} \tag{7}$$

where λ = the thermal conductivity of metal;
d_e = equivalent diameter (m);
N_u = Nusselt number.

Then considering the fouling and contact resistance, overall heat transfer coefficient (K) and the heat load of exchanger (Q_1) can be calculated. Comparing Q and Q_1, if heat requirements is satisfactory, pressure drop will be examined through E_q. (8) below:

$$\Delta p = N_t \times m \times E_u \times w^2 \times \rho \tag{8}$$

Where N_t = exchanger numbers of each group.

If pressure drop is in the allowance scope, this design step is accomplished. However the whole design process may have many solutions. The selecting design which the heat transfer area is the minimum is the most optimal.

4 APPLICATION COMPARING

4.1 Plate Size

Fig.2 and Fig.3 illustrate the influence of different plate size on heat transfer area. Once the flow velocity can be covered the heat demand by the design, the plate size should be first considered to select a higher heat coefficient and a lower pressure drop with the same Reynold's number. It may obtain the minimum heat transfer area and lowest investment.

4.2 Different Flow and Temperature Conditions

Logarithmic Mean Temperature Difference (LMTD) is an effective driving force in the heat exchanger. LMTD relates to the flow and temperature parameters, and choice of the parameters has much to do

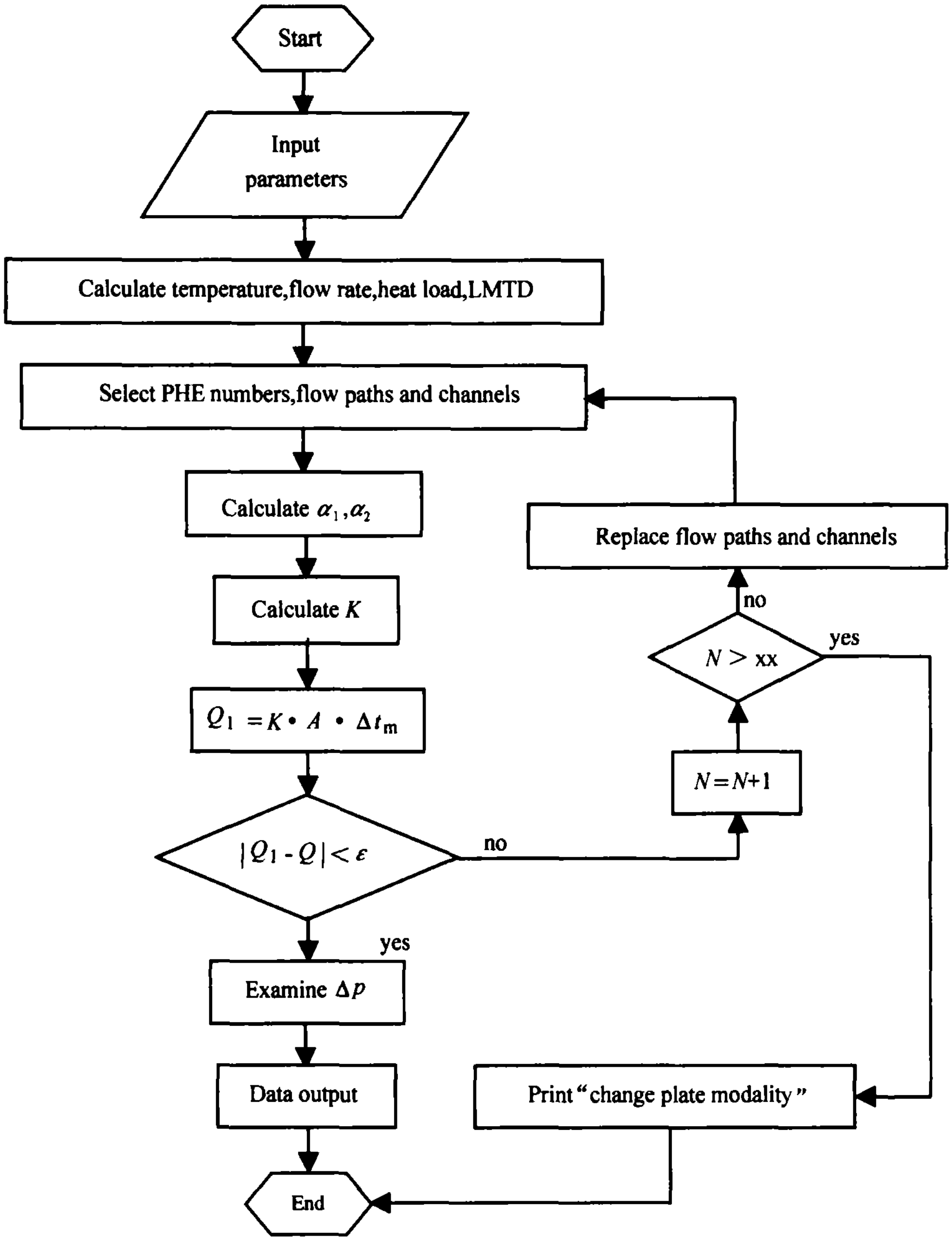

Fig.1 scheme of computer design

with the cost of equipments. Fig.3 shows the relationships between heat transfer area, temperature outlet (hot side) t_{a2} at the constant temperature inlet (cold side) and geothermal water rate. The heat transfer area will be reduced with elevated t_{a2}. There are two main reasons: first, LMTD is enhanced with the elevation of t_{a2}; second, at the same time heat load is decreased, then heat transfer area is naturally reduced. But it cannot draw a conclusion that it is a good project with high t_{a2} and low investment. For selecting optimal design of heat exchangers in geothermal heating system, not only economic effects but also environmental and technical effects should be evaluated. Therefore it is important to consider all the effects in selecting a solution.

In Fig.4, "r" means the ratio of circulating water flow rate to geothermal water flow rate. It shows that at a constant temperature outlet (hot side) (t_{a2} = 45 ℃) and geothermal water flow rate (100 t/h), heat transfer area changes with circulating water flow rate. The more circulating water flow rate is, the less heat transfer area is. For LMTD is enhanced. But in practice r is always taken as 1.1 to 1.3 in geothermal heating systems.

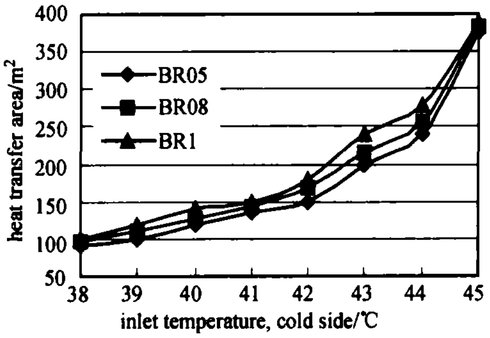

Fig.2 Heat transfer area of different plate size

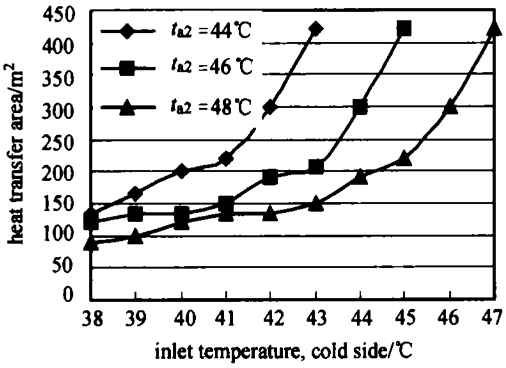

Fig.3 Heat transfer area at different t_{a2}

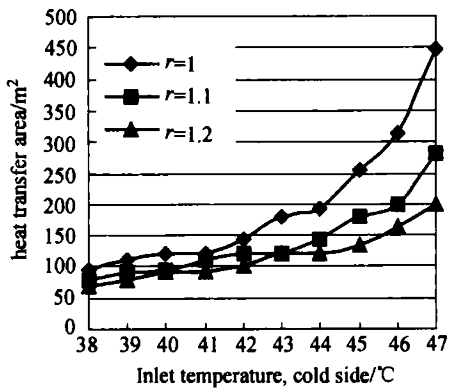

Fig.4 Heat transfer area at different flow rate

4.3 Comparison of Design Results with Practical Works

Table 1 shows that the heat transfer area by the optimal design is less than in practical works. The main reasons for the differences of heat transfer areas are:

Table 1 Heat transfer area comparing

Location (Tianjin)	Heat transfer area of practical works m²	Heat transfer area of optimal design m²
Xinyuan district	175	140
Zijin district	684	600
Zhongping district	120	100
Yishang district	390	360

(1) The plate modality selection

The selection relates to the heat transfer efficiency, pressure drop.

(2) The combined plate selection

The selection influences the flow paths, flow channels.

The computer design are much more better that the practical works, because the computer design can select data widely and arbitrarily, which traditional design method cannot do.

5 CONCLUSIONS

(1) During the optimal design process, the selection of types may have great influence on the design of plate heat exchangers. Therefore the plate type, which is available to geothermal heating system and with high heat transfer coefficient, should be selected.

(2) The flow rate and temperature are important influencing factors, and should be carefully considered in the design process.

(3) Plate heat exchanger design by computer, combined of PHE, flow paths and flow channels can be deployed rationally. Furthermore, data selection in computer design is wider than that of artificial calculation. Therefore it can obtain the best schemes.

REFERENCES

[1] John W. Lund, 1998; Geothermal Direct-Use Engineering and Design Guidebook. USA: Geo-Heat Center Oregon Institute of Technology

[2] Kiril Popovski, 1999. Direct Utilization of Geothermal Energy. USA: Geo-Heat Center Oregon Institute of Technology

[3] Yang C L. 1995; Plate Heat Exchanger Design Handbook. Beijing: Mechanical Industry Press (In chinese)

[4] Zhu J. L. 1995; Geothermal Energy Utilization and Technology. Tianjin: Tianjin University Press (In chinese)

地热供暖系统板式换热器的优化设计

朱家铃　张　伟　苗常海

天津大学地热研究培训中心，天津　300072

摘　　要

本文重点对板式换热器传热、流动阻力进行了研究，其中包括总传热系数、换热方程、传热系数、流动阻力等内容。重点分析了板式换热器在地热供暖系统中选取的原则，如板片材料、板片形式、单板面积、流速、流程的选取等。在综合考虑技术、经济、环境效益及节能的基础上，论述了对板式换热器进行优化设计的方法。本文利用计算机进行优化设计，已达到在给定工况下换热器所需板片面积最小的优化设计目标，在相当宽的参数范围内任意挑选并快速找到最理想的设计方案。指出了影响优化设计结果的几种因素，并对设计结果与实际工程的应用进行了比较与分析。对于板式换热器板型的选择对换热所需的板片面积的影响及不同工况的影响，本文通过实例比较，得出结论：

(1) 针对地热供暖系统中板式换热器优化设计，因选型对设计有很大的影响，所以应选择适合于地热供暖、性能较好的型号。

(2) 地热供暖系统的工况也是影响板式换热器设计的重要因素，因此在选择地热供暖系统工况时应考虑其对换热设备的影响。

(3) 利用计算机优化设计板式换热器，可以对换热器安装形式、流程、流道等进行合理的排列，而且较人工设计选择范围要宽得多，相比之下可能会取得更好的设计方案。

关键词　地热供暖　板片组合形式　板式换热器　优化设计