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AN EXPERIMENTAL STUDY OF PLATE HEAT EXCHANGERS FOR HEATING BUILDINGS WITH GEOTHERMAL WATER

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ABSTRACT

An experimental study on plate heat exchangers, which consist of different plate materials and are used for heating of buildings with geothermal water, is being carried out at the site of No. 2 geothermal water well located on the campus of Tianjin University. The aim of the study is to search for those heat exchangers which can be adapted to geothermal application, have good corrosion resistance, and are economic?

The results and comparison of the two plate heat exchangers (one titanium, another steel with a special plating) are reported, emphasizing their corrosive and thermal performances. At the same time, corrosion exposure testing with four types of specimens was done, and relevant results are also presented in this paper.

Introduction

Since the Energy Crisis in the 1970's, much attention has been paid to energy conservation and exploitation of so-called "new energy" sources centred on solar, geothermal, biological and wind energies all over the world. Some encouraging progress has been achieved since then. Geothermal energy, as an alternative energy, has its special attraction. There are huge geothermal resources spread widely throughout the world.

Special research institutes have been established, and development plans for long-term research have been adopted by many countries. Among them, the United States, Italy, New Zealand and Japan are leading in this field.

Geothermal energy can be used in many ways such as generating electricity, heating of buildings, utilization in greenhouses, agriculture and medical treatment, etc. Because of the strong corrosion of some geothermal fluids, heat exchangers with high corrosion resistance and good thermal character are usually necessary for many geothermal applications.

To develop and make heat exchangers of good performance and low cost for geothermal use is an important aspect for speeding up exploitation and utilization of geothermal resources, thereby gradually reducing costs.

There are abundant geothermal resources distributed.., over every province of China, but most of those which have already been discovered are at low, or intermediate, temperatures. The city of Tianjin lies over a sedimentary basin with numerous aquifers which produce warm and hot water. The aim of our study was to investigate appropriate heat exchange focilitics for space heating in winter, with low temperature (about 50°C) geothermal water, of high corrosion resistance, good thermal performance, long service life and low costs.

Brief description of testing facilities

In order to investigate in detail heat exchangers for geothermal utilization, experimental facilities were established at the site of a deep geothermal well on the campus of Tianjin University. The schematic diagram of the facilities is shown in Fig. 1. Analysis of chemical composition for the geothermal water from No. 2 well indicates that the content of harmful ions, such as F^-, Cl^-, SO4, etc., is quite high.

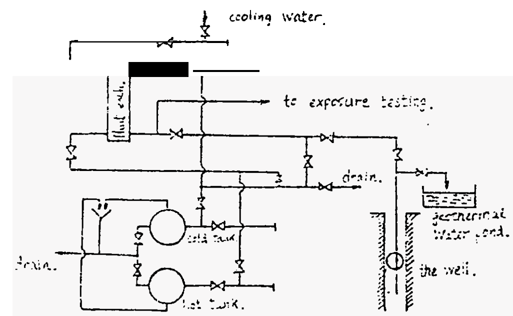

Fig. 1: Diagram of test facilities.

One of the plate heat exchangers ($4M^2$) is locally available and has 41 plates, each with an effective area of 0.1 m^2, and consists of herringbone corrugated shaped plates. Counter flow was arranged €or two sides of the passages; each side of the fluids has twenty plates in parallel. The plates of this exchanger were made of ordinary steel, with a layer of special plating on each side of the plate. The overall thickness of the plate, including the outer ones, is 0.5mm. Inlet and outlet temperatures and pressures were measured with glass thermometers (1/10°C graduation) and standard gauges (0.025 kgf/cm^2 graduation). For measuring the mass flow of geothermal and cold water, a simple and exact method was used: timing and weighting.

In parallel with the first heat exchanger, another plate heat exchanger with $20m^2$ heat transfer area was tested. The second exchanger consists of 100 titanium plates and was tested to compare the corrosion resistance of the two under exactly the same conditions. The usual range of operating parameters during the whole experimental period is listed below:

Temperature of fluid at entrance:

geothermal water:	49 to 51°C
cooling water :	20 to 27°C

Pressure of fluid at entrance:

geothermal side:	usual	1.5 kgf/cm^2
	top	3.0 kgf/cm^2
cooling side:	usual	1.0 kgf/cm^2
	top	2.0 kgf/cm^2

mass flow rates:

geothermal side:	8 to 19.5 ton/hr
cooling side :	5.7 to 14 ton/hr.

Corrosion exposure testing of specinens

In order to acquire exact, detailed corrosion data for various materials, corrosion exposure testing was done using four different materials, i.e. carbon steel, stainless steel, titanium, and ordinary steel with a special plating mentioned above. The testing was done in the flowing geothernal water at the site of the geothermal well under two different conditions: (a) specimens were completely immersed without any interruption during the whole period; (b) specimens were intermittently immersed. , For (b), the specimens were immersed in the flowing geothermal water for one day, then partly withdrawn, thus exposing the upper half to a mixed environment of geothermal vapour and air, while the lower half of the specimen was still in the water. For the following day, this was repeated during the whole testing period.

It is well known that corrosion rates for the same material differ if they are partly or completely immersed in corrosive fluids. Plates of heat exchangers in operation inevitably come into contact with air. Therefore it seems that the second programme of exposure testings tells us more about the corrosion resistance than the first programme.

The results of the corrosion exposure tests with four different materials are as follows:

Table. 1 Results of corrosion exposure tests

Material	Penetration rate mm/year	
	A	B
carbon steel	0.3833	0.5643
stainless steel	0.00125	0.00327
special plating	0.0113	0.02026
titanium	0.0000	0.0000

The values in column A are for successively immersed specimens, and those in column B for intermittently immersed specimens. It should be noted that each value listed here is an average of several specimens of the same kind. It can be seen that the penetration rate measured by the second exposure testing method is roughly twice as large as those obtained by the first method. We can also see from the values in Table 1 that the corrosion resistance of plates with special plating is good. According to G.B. National Standard of China for corrosion, it belongs to the grade of "good" or "quite good". In addition, exposure testing with other specimens of this special plating in fluids containing HCl, HNO_3, H_2SO_4 and $NaOH$ also showed good corrosion resistance.

Disassembling and checking

In August 1985, the two test heat exchangers were taken apart after operating continuously for about three months. Appearance of' the plates of the two exchangers showed that no obvious corrosive trace could be seen. We noticed that the side in contact with geothermal water was covered by a thin layer of a black, well-distributed substance whose contents have not yet been analyzed. It is thought to be mainly sulphide. In addition, it was observed that the thin layer of black substance adhering to the titanium plate was thinner and easier to remove than' that on plates of the other heat exchanger.

Performance Analysis

Various measurements were made to assess the thermal performance of the two heat exchangers during the three months of operation; more than one hundred testing data were acquired and analyzed. The overall thermal resistance of a heat exchanger consists of the following terms:

$$R = 1/K = 1/h_c + R_p + R_d + 1/h_H \qquad (1)$$

where: R, R_p, R_d represent the overall resistance, conductive resistance of the plate (which is known to be about 0.1 x 10^{-4} $m^2.°C/W$) and fouling resistance of both sides of the plate, respectively (unit m^2 $°C/W$); K is the overall heat transfer coefficient of the exchanger ($W/m^2.°C$); h_c, h_H are the convective coefficients at the cooling and heating side respectively ($W/m^2.°C$).

Because of the two fluid media at both sides of the exchanger, the regularities and relations of convective heat transfer for two sides of the plates are of the same pattern, as long as a turbulent state is maintained. This means that the Reynolds Number of the two flows must be larger than a certain critical value, which is quoted in general as 200. Reynolds Numbers in our tests were all greater than 2,000. The relation for convective heat transfer in passage between heat exchanger plates is given by:

$$Nu_f = C.Re_f^n \;.\; Pr_f^m \qquad (2)$$

where, m is 0.3 when the fluid is cooled and *0.4* when heated.

We have for the cold side:

$$h_c = C \;.\; A \;.\; W_c^n \qquad (3)$$

and for the hot side:

$$h_H = C \;.\; B \;.\; W_H^n \qquad (4)$$

where W_c , W_h are average fluid speeds for the two passages respectively. A and B stand for all other terms in equation (2) except for the coefficient C and the term of fluid speed. Equation (1) can be re-arranged in the form:

$$(1/K\text{-}Rp\text{-}Rd) = 1/(C.A.W_c^n) + 1/(C.B.W_H^n\;). \qquad (5)$$

Multiplying by $A.W^n$ we have

$$(1/K\text{-}Rp\text{-}Rd).A.W_c^n = 1/C + (1/C)((A/B).(W_c/W_H)^n) \quad (6)$$

When the heat exchanger is new or has been cleaned recently, the fouling resistance R_d can be assumed to be zero. Equation *(6)* is a linear equation of the type:

$$Y = a + b\,X \qquad (7)$$

The linear regression method was used to solve for the constant a, b, and the power n by means of iterative calculation. For the $4M^2$ special plating exchanger we obtained: n = 0.771, a = 14.339 and b = 14.408; the relative error of constants a and b is only 0.48 per cent and therefore c = 0.0695. The relation for convective heat transfer in the plate heat exchanger is given by:

$$Nu_f = 0.0695\,Re_f^{0.771}\,Pr_f^m \qquad (8)$$

where m is 0.3 when the fluid is cooled and ***0.4*** when heated. The reference temperature is taken as mean temperature of the fluid at the entrance and exit of the exchanger; the characteristic dimension is token as twice the gap of the fluid passage between adjacent plates.

The calculated values of the overall heat transfer coefficient K were compared with the measured ones; it can be seen from Table 2 that the two values are very similar.

The basic relation between the convective coefficient h and the main variable fluid speed W is shown in **Fig.** 2.

Other measurements were made to assess the fouling resistance of the heat exchangers. This has proved to be a difficult subject in the study of thermal performance of heat exchangers. It can be expected that the rate of fouling is related to many factors such as type of fluid, speed, temperature, material and shape of plate (or tube), its roughness, etc.

Table 2: Comparison of calculated and observed overall heat transfer coefficient K.

	K calculated (W/m^2 °C)	K measured (W/m^2 °C)	Relative error (%)
1	4478.8	4558.5	- 1.75
2	4511.2	4534.9	- 0.52
3	4322.3	4331.2	- 0.20
4	4367.2	4407.2	- 0.90
5	4125.0	4182.0	+ 1.03
6	4151.3	4117.8	+ 0.81
7	3939.5	3937.0	+ 0.06
8	3824.3	3851.2	- 0.69

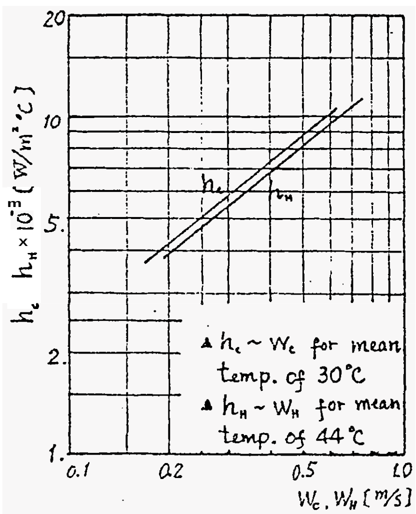

Fig. 2: Relation between the convective coefficient h and speed of fluid W.

Therefore, it is a difficult problem for theoretical treatment, and information about fouling resistance is obtained from experiments. We took a set of measurements every month (the first measurement for the new exchanger). The fouling resistance was obtained as: R_d = 0.2044 x 10^{-3} m^2 °C/W and is shown in Fig 3.

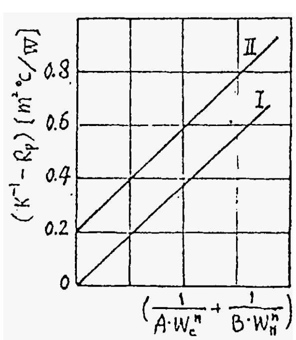

Fig. 3: Diagram of fouling resistance.

It was found that the fouling resistance is about twenty times the thermal resistance of the plate itself. (In order to acquire a real value of fouling resistance, none of the provisions was taken at the inlet pipes during the whole testing period.)

DISCUSSION

1. After a continuous experiment lasting three months, preliminary conclusions can be drawn. The corrosion resistance character of the heat exchanger with a special plating is good and can be used to operate with local geothernal water for long periods to satisfy space heating loads in the winter. There is no doubt that the titanium plate heat exchanger is excellent in its corrosion resistance, and for this reason it is used abroad. In China at present, however, because of the high costs of titanium, it is difficult to use titanium heat exchangers for low-temperature heating with geothernal water. We place our hopes on the locally produced special plating heat exchanger which has good corrosion resistance. Based on preliminary estimates and considering the present limited production, this type of plate exchanger is not only less expensive than the titanium plate unit, but also cheaper than a stainless steel unit. If further improvement in the processing technique of the plating can be made, its price could be reduced for larger scale industrial production.

2. The exchanger with herringbone corrugated plates is good in themal performance. The overall heat transfer coefficient K is about 4,500 W/m^2 °C when the average speed of fluid in the passage of exchanger reaches about 0.7 m/s.

3. It appears that fouling is a serious problem which can be found from the observed rapid reduction of K values, even though the input temperature was not high. These factors: the narrower passage for fluids, the comparatively lower speed of fluids used in our testing, and the fact that none of the provisions were taken during the experiment, etc., caused and accelerated the production of fouling. So it is necessary to take effective measures for preventing fouling by cleaning the fouled unit periodically.

4. In view of the great importance of heat exchanger equipment for the exploitation of low temperature geothermal resources, development and testing of other types of heat exchanger is also required. These should be firstly of good corrosion resistance and have a long life, and secondly have a good thermal performance and be inexpensive. We plan to test other materials, metallic and non-metallic, in the near future, to find those which are most suitable, technically and economically.

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