# APPLICATION OF PLATE 'PIPE HEAT EXCHANGER TO GEOTHERMAL WATER

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## ABSTRACT

It is well known that plate type heat exchangers are most widely applied in heat recovery of various plants. The authers performed heat exchange test between geothermal water and river water using a plate type heat exchanger at Ohtake Power Plant of Kyushu Electric Power Co., Inc., of which geothermal water is believed to content relatively high $SiO_2$ component, and investigated the transition of heat exchanging performance, effects of materials and surface roughness and cleaning performance of the $SiO_2$ scale. As the results it was understood that: continuous operation up to 17 days or about can be made without sensible problem; even after one month continuous operation, $SiO_2$ scale on the heating surface can be removed by circulating heated aqueous solution of NaOH for about 18 to 20 hrs, and the heat exchanger can recover almost its initial condition; and Ti-plates finished by chemical milling to about 3S to 4S surface roughness (maximum height expressed in μm) is most suitable as the material and surface roughness.

## INTRODUCTION

Geothermal energy is an important resources of energy in energy scant countries such as Japan. Under such circumstance, at the vicinity of the power plants, hot water supply to the local community is being performed albeit with small scale, as a part of multi-purpose utilization of geothermal water. Generally, geothermal water is not utilized directly, but is used to warm good river water by exchanging heat through a heat exchanger, because in many cases, a harmful ingredient (e.g. about 2 ppm arsenic) is included in the geothermal water. On the other hand, however, geothermal water specially the volcanic geothermal water includes about 500 to 800 ppm of scale, of which main ingredient consists of $SiO_2$, and an effective counter measure against this scale is required in the case of geothermal water utilization, otherwise, Si02 scale deposits will accumulate in the transport piping or interior of the heat exchanger resulting to deteriorate its performance and may sometimes clog the passage. Therefore, direct heat exchange systems, which do not have heating surface, are sometimes applied. In the case of indirect heat exchange system, which has heating surface, stainless steel multiple tube heat exchanger and/or Teflon tube heat exchanger have been tested, however, the problems of adhesion of scale or economy couldn't be solved.

Under such conditions, the authers selected a plate type heat exchanger (APV PARAFLOW R 405) as an effective indirect heat exchanger for geothermal water including much of $SiO_2$ to perform tests, with the reason as following:
(a) APV PARAFLOW R 405 has high turbulence flow effect to select large coefficient of overall heat transfer.
(b) When scales of Si02 are adhered, the heat exchanger is easily disassembled and cleaned.
(c) Suitable materials can be selected for the plates.

For above item (a), some views exist that turbulent flow at near the heating surface may help to increase the $SiO_2$ scale deposit, however, heating surface positively to cause turbulence was accepted for this test, standing on the assumption that turbulence effect will prevent the yielding of the scale. The test was performed by continuously operating the heat exchanger passing geothermal water and river water performing heat exchange, and periodically measuring heat exchanging performance, pressure loss, and accumulation of $SiO_2$ scale. In this paper, transition of heat exchanging performance under continuous operation, condition of Si02 scale adhesion and easiness of the cleaning work are mainly discussed.

## METHOD OF THE PERFORMANCE TEST

Fig.1 is a schematic flow diagram during the performance test. Geothermal water from the No.9 well of the Ohtake Power Plant of Kyushu Electric Power Co., Inc. was introduced after eruption through steam separator to separate steam, and to the heat exchanger by a heat resistance rubber tube. The geothermal water after passing the heat exchanger was reinjected to a reduction well. Flow rate, inlet and outlet temperature and pressure were measured periodically 3 times a day. Table 1 indicates the details of the heat exchanger tested and Table 2 is the composition of the geothermal hot waters.

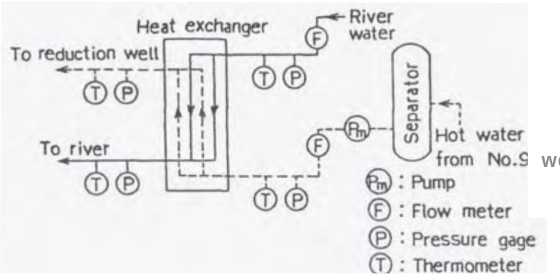



Fig. 1 Schematic flow diagram during performance test

| Type | APV PARAFLOW R405 | |
|---|---|---|
| Heat Trans. Area ($m^2$) | 1.13 | |
| Fluid | Hot Water | River Water |
| No. of passages | 2 | 2 |
| Nom. flow rate (ℓ/h) | 4000 | 4000 |
| Inlet temp. (°C) | 85 | 14 |

| Plant Site | Ohtake | |
|---|---|---|
| Well No. | 9 | 10 |
| Na | 1050 | 1030 |
| K | 132 | 124 |
| Ca | 28.4 | 29.7 |
| Mg | 0.01 | 0.21 |
| Cl | 1774 | 1738 |
| $HCO_3$ | 57 | 77 |
| $SO_4$ | 145 | 193 |
| $HBO_2$ | 84 | 78 |
| $SiO_2$ | 531 | 433 |
| As | 2.0 | 2.1 |
| pH | 8.57 | 8.44 |

Table 2. Chemical composition (ppm) of geothermal hot waters

## TRANSITION OF OVERALL HEAT TRANSFER COEFFICIENT AND PRESSURE LOSS

In a heat exchanger, equation (1) is applicable among amount of heat exchange $Q$ (W), effective mean temperature difference $\Delta tm$ (°C), effective heating surface $A$ ($m^2$), and overall heat transfer coefficient $U$ ($W/m^2$ °C):

$$U = \frac{Q}{\Delta tm \cdot A} \quad (1)$$

The overall heat transfer coefficient U can be obtained from the heat transfer coefficient of both fluids to be heat exchanged, $\alpha_h, \alpha_c$ ($W/m^2$ °C), and the value at the initial operation $U_c$ (U of clean heat exchanger) will be:

$$\frac{1}{U_c} = \frac{1}{\alpha_h} + \frac{1}{\alpha_c} \quad (2)$$

Because of increasing contamination accompanied with operation, value of $U_f$ (including fouling resistance) at a certain time for the design of the heat exchanger is given by equation (3), taking fouling resistance R ($m^2$ °C/W) into consideration:

$$\frac{1}{U_f} = \frac{1}{U_c} + R \quad (3)$$

To obtain transition of the performance of the heat exchanger and pressure loss, change of $U_c$ and pressure loss by changing flow rate of geothermal water had been calculated and was shown in Fig.2. On the other hand, change of flow rates of geothermal water and river water during the test are shown in Fig.3 and that of pressure losses in Fig.4. Because of the characteristics of the pump used for the geothermal water feeding to decrease flow rate rapidly with increasing discharge pressure, the flow rate is decreased by increased passage resistance with adhesion of scale. Value of $U_f$ obtained by equation (1) with measured data and the value of $U_{cr}$ (corrected clean U) changes with decreasing geothermal water flow rate during the test is obtained from Fig.2 and Fig.3 and are indicated in Fig.5. In the change of $U_f$ in Fig.5, reduction of heat transfer coefficient $\alpha_h$ of geothermal water caused by the reduction of the flow rate of geothermal water, and increase of fouling resistance R are included simultaneously. The change of $U_{cr}$ in Fig.5 is the value calculated only by reduction of $\alpha_h$ at fouling resistance R=0. The fouling resistance R during the test can be obtained from two curves of Fig.5 using equation (3), and the result is shown in Fig.6.

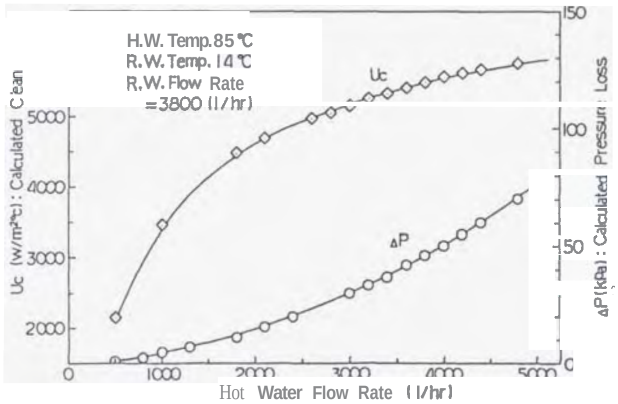



Fig.2 Relation between geothermal hot water flow rate and calculated clean U and calculated pressure loss

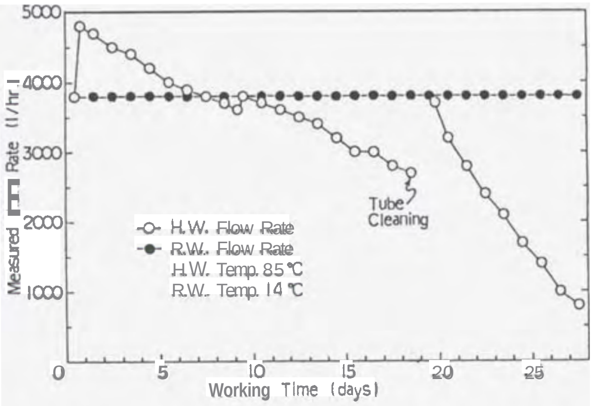



Fig.3 Change of flow rates of geothermal hot water and river water

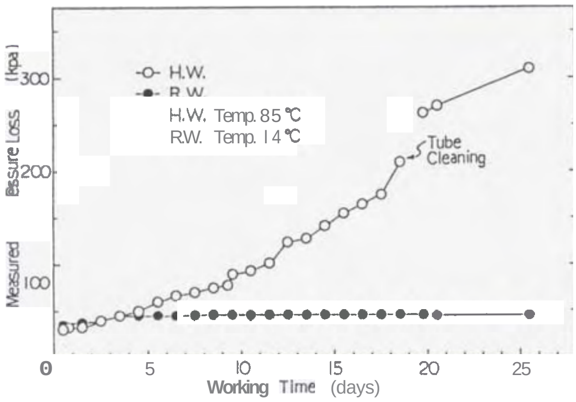



Fig.4 Change of pressure losses of geothermal hot water passage and river water passage

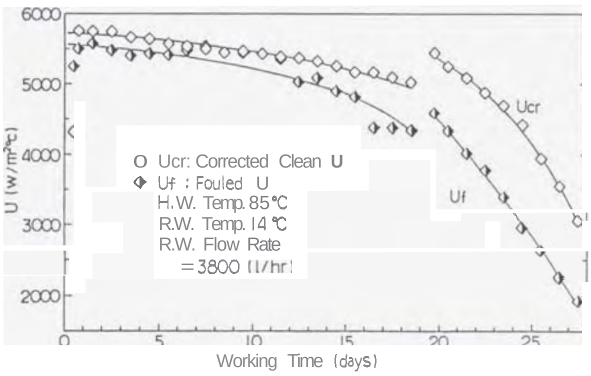



Fig. 5 Relation between corrected clean U and fouled U

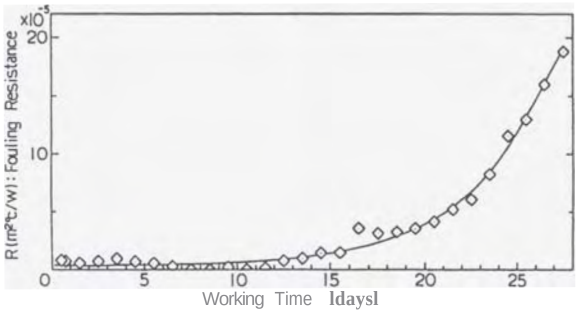



Fig.6 Increase of fouling resistance during test period

## EXAMINATION OF CONTINUOUSLY OPERATABLE DURATION

From Fig.3 the flow rate of river water is taken as almost constant throughout the test at 3800 ℓ/hr. The flow rate of geothermal water decreases almost on a straight line except 9th and 18th date of the working time. The flow rate was 4800 ℓ/hr at the start of the test and decreased to 2700 ℓ/hr on the 18th day, therefore, decreasing rate per day AG (ℓ/hr/day) is:

$$AG = \frac{4800-2700}{18} = 117 \ \ell/hr/day$$

The river water (at 14°C) shall be heated to 40°C at the lowest for local supply. Therefore, flow rate of geothermal water necessary to obtain 40°C of warmed water is calculated. Putting the input temperature of geothermal water as 85°C, the outlet temperature 50°C, and the inlet temperature of river water as 14°C:

$$V \times (85-0) = 3800 \times (40-14)$$

$$V = 2820 \ \ell/hr.$$

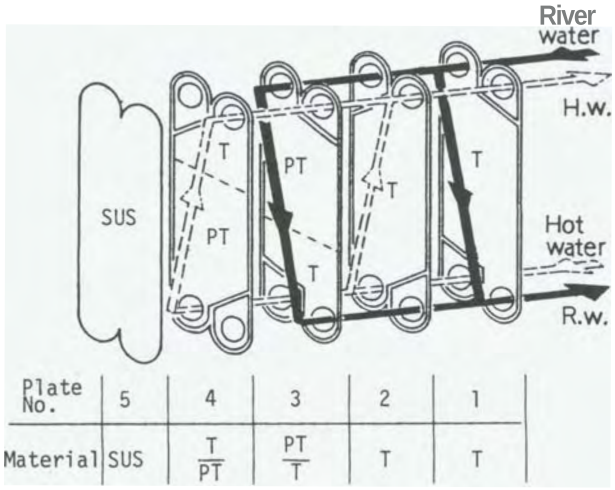
Days necessary to decrease to this flow rate are:

$$\frac{4800-2820}{117} = 17 \text{ days.}$$

Therefore, it was clear that the heat exchanger can supply warmed water of 40°C or more stably up to about 17 days. Values of Fig.4, Fig.5, and Fig.6 are also indicating substantial changes at about 17 days, and the time to allow continuous operation is likely can be determined as 17 days or about.

## EFFECT OF SURFACE ROUGHNESS OF THE HEATING SURFACE ON THE FORMATION OF $SiO_2$ SCALE

Fig.7 is a conceptional drawing showing the interior of the heat exchanger. Two types of plate materials, namely SUS 316 (SUS) and Ti were prepared, and further 2 types of Ti plates, namely as-pressed (T) and processed with chemical milling (PT) were prepared. Surface roughness of the plates were 4S to 5S for (SUS), 7S to 8S for (T) and 3S to 4S for (PT). Plates were disassembled on each lst, 2nd, 3rd, 19th and 30th date and the conditions of Si02 scale generation were observed




Note; Because of equipment available, about 60% area of heating surface was treated by chemical milling for plate No.3 and No.4

Fig. 7 Conceptional drawing of heat exchanger

visually. No visually identifiable $SiO_2$ scale was observed up to the 3rd date. On the 19th day, generation of scale was observed at all the passage of geothermal hot water. The generation of scale was large at the hot water inlet (about 80 to 85°C hot water temperature) and fewer at the exit portion (hot water temperature about 50°C) than at the inlet. The difference of material and surface roughness also affect the scale deposit, and the visual observation indicates that chemically milled Ti plate (PT) is most hard to build the scale, and the same extent of scale generations were observed on as-pressed Ti-plate (T) and SUS 316 (SUS). Specially at around the inlet port, scales are generated to form bridge between the plates forming hot water passage as clogging the passage, and is thought to make the cause to raise pressure and decrease flow rate during operations. Scales deposit and adhere on the heating surface are naturally cause fouling resistance and reduce the performance, however, it is seen from the result of the test of this time that increase of flow passage resistance by clogging at the inlet caused larger effect for performance reduction.

## TEST METHOD FOR THE CLEANING OF $SiO_2$ SCALE

To restore the performance of plates continuously operated for 30 days, the authors tried to clean the $SiO_2$ scale in heating water passage with caustic soda. Fig.8 indicates the schematic flow diagram by which cleaning operation was performed. Hot water was passed to the normal river water passage, and 2% NaOH aqueous solution was circulated as cleaning liquid through the normal hot water passage. Total quantity of the cleaning liquid was about 70ℓ, the flow rate was 1400 ℓ/hr, about 1/3 of the normal flow, and the temperature of the cleaning liquid being circulated was about 80°C.

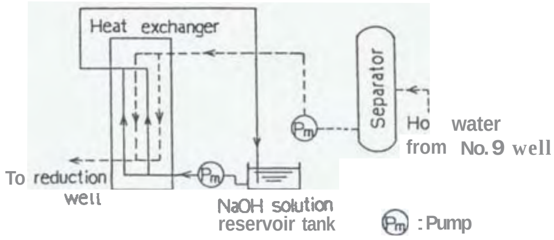



Fig. 8 Schematic flow diagram during cleaning test

## CLEANING EFFECT OF $SiO_2$ SCALE

Fig.9 indicates the relation between increase of $SiO_2$ scale concentration dissolved into the cleaning solution during the circulation cleaning and time duration. According to the Fig.9, $SiO_2$ concentration in the solution becomes constant at about 18 to 20 hrs, and it can be thought that almost all of the scale were cleaned up in consideration of the fact that the allowable solubility of the cleaning liquid is far larger than this asymptotic value. Residue of surface $SiO_2$ scale was observed after disassembly. By comparing hot water inlet portion (high temperature portion) with outlet portion (low temperature portion), the scale at the outlet portion is almost dissolved and a certain degree of cleaning effect was also recognized at the inlet portion. Further, the Ti-plate treated with chemical milling (PT) was most excellent in cleaning effect. The circulation flow rate of the cleaning solution was limited only to about 1/3 of the normal flow rate because of the equipment available, however, further efficient cleaning can be performed by selecting an appropriate pump for the purpose, increasing circulating flow rate and raising turbulent flow-effects.

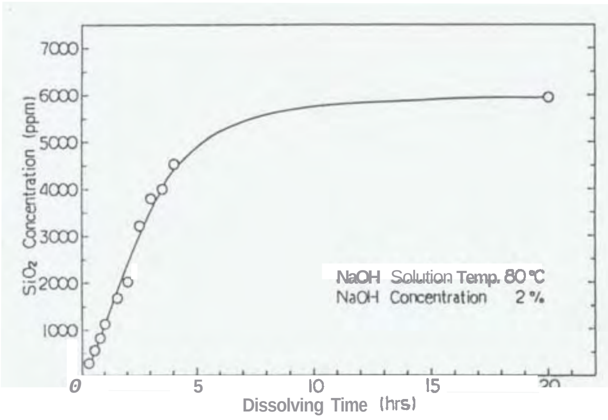



Fig.9 Relation between increase of $SiO_2$ scale concentration into the cleaning liquid and dissolving time

After observation of the cleaning effect, the plates were reassembled, and the thermal performance was checked with the piping system as shown in Fig.1. The resultant $U_{cl}$ (U after cleaning) is shown in Fig.10. Comparing this result with $U_c$ in Fig.2, it is seemed almost possible to consider that the heat exchange performance was restored to the level of the initial condition,

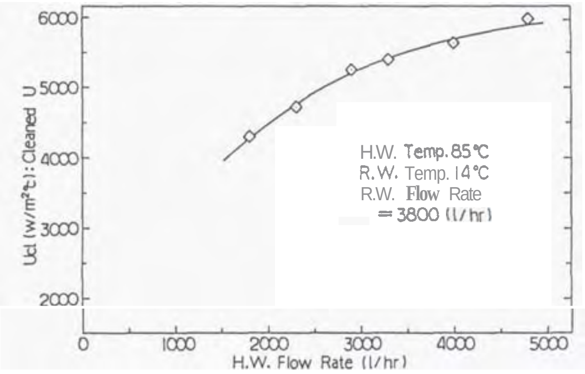



Fig. 10 Relation between geothermal hot water flow rate and cleaned U

## CONCLUSION

1. APV PARAFLOW R 405 proved to bear for the continuous operation of about 17 days in the heat exchange between geothermal water and river water.

2. In case 2% NaOH aqueous solution at 80°C was used as cleaning liquid, it was confirmed that $SiO_2$ scale deposited during 30 days operation can be cleaned almost perfectly by cleaning operation of about 18 to 20 hrs and the performance can be restored to the initial condition.

3. As for the plate material and surface roughness, Ti-plate finished to the surface roughness of 3S to 4S by chemical milling was superior in preventing deposit of scale and cleaning ability.

## PROBLEMS FOR THE ACTUAL APPLICATION

It was observed that passage clogging occurs at the geothermal water inlet portion by generation of $SiO_2$ scale under long term continuous operation. From such phenomena, it is expected that continuous operation time can further be extended if a plate to allow to make larger free flow area at the inlet portion will be developed. Further, it is considered that the practical application will be expedited by using combination of cleaning equipment and operating by changing over.

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