BRAZED PLATE HEAT EXCHANGERS FOR GEOTHERMAL APPLICATIONS

Kevin Rafferty, PE
Research Associate
Geo-Heat Center

INTRODUCTION

Most geothermal fluids used for direct use purposes contain various chemical species which can be detrimental to conventional materials of construction. For this reason, the standard design practice is to isolate the geothermal fluid from the balance of the system through the use of a heat exchanger as illustrated in Figure 1. In the majority of applications, the plate and frame heat exchanger has been the design of choice for this duty. Plate and frame heat exchangers offer many advantages for geothermal applications including their availability in corrosion resistant materials (stainless steel, titanium, etc.) at reasonable cost. In addition, their design permits disassembly for cleaning or the addition of plates to accommodate increased heating loads. The units are very compact and efficient with heat transfer rates 3 to 10 times those of shell and tube exchangers (ASHRAE, 1991).

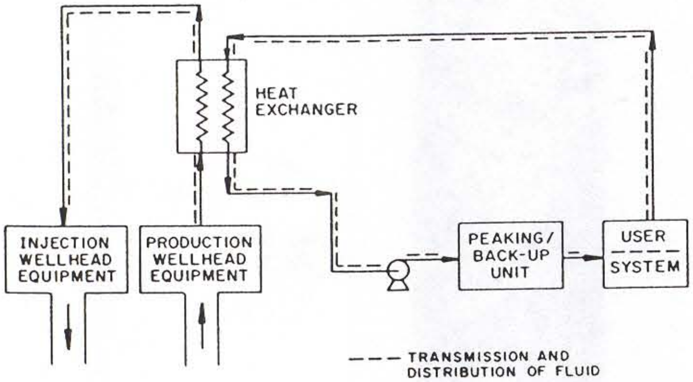

Figure 1.
(ASHRAE, 1991)

In very small applications (less than approximately 40 ft^2 heat transfer area), however, the cost of plate and frame heat exchangers rises rapidly. These applications would include the space and domestic hot water heating for residences and small buildings, and small commercial and industrial process applications.

Recently, a low-cost version of the plate heat exchanger, the brazed plate heat exchanger has become available. Due to their simpler construction, these units can be economically produced in very small sizes. Considering the reduced cost (as little as 40% of a plate and frame unit for the same duty), these exchangers could greatly enhance the economics of small direct use geothermal systems.

Brazed plate heat exchangers, as the name implies, are manufactured using copper to braze the heat transfer plates together. The question at hand is whether this copper material will demonstrate an acceptable life in the geothermal fluids to which it will be exposed. The object of this report is to examine whether brazed plate heat exchangers will be an economical choice for small direct use systems.

The results of failure analysis conducted on brazed plate heat exchangers exposed to three different geothermal fluids is presented along with information on design considerations, equipment cost and life cycle costs for brazed plate heat exchangers.

CONSTRUCTION

As the name implies, brazed plate heat exchangers differ from the more common plate and frame exchangers in the method used to attach the plates. As shown in Figure 2, plate and frame exchangers are characterized by heavy steel end plates which along with the tie bolts, compress the individual plates together. Sealing between each plate and between the fluid passages and the atmosphere is provided by elastomeric gaskets on either side of each plate.

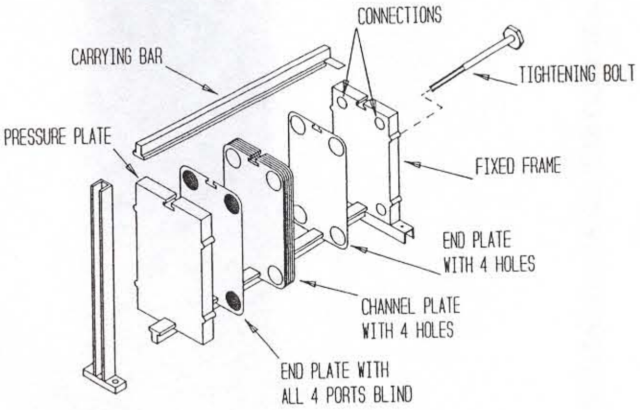

Figure 2. Plate and Frame Heat Exchanger (Rafferty and Culver, 1991).

The brazed plate unit as shown in Figure 3 eliminates the end plates, bolts, and gaskets from the design. Instead, the plates are held together by brazing with copper. This results in a much less complicated, lighter weight and more compact heat exchanger. The simpler design also results in greatly reduced cost.

On the negative side, the brazed plate approach eliminates some of the advantages of the plate and frame design. In terms of maintenance, the brazed plate units cannot be disassembled for cleaning or for the addition of heat transfer plates as bolted units can.

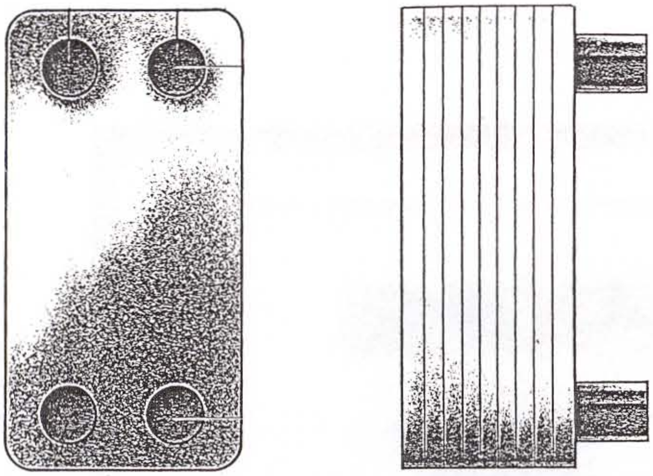

Figure 3. Brazed plate heat exchanger.

Most importantly, however, the brazing material is copper. Since most geothermal fluids contain hydrogen sulphide (H_2S) or ammonia (NH_3) copper and copper alloys are generally avoided in geothermal system construction. The situation with brazed plate heat exchangers is especially critical due to the thickness (less than one tenth of an inch) and length (a few tenths of an inch) of the brazed joints.

APPLICATION CONSIDERATIONS

In addition to the material related questions, there are also issues related to the standard configuration of brazed plate heat exchangers.

Physical size of the exchangers limits application flow rates to approximately 100 gpm (although one manufacturer produces units capable of 200 gpm). Maximum heat transfer area is limited to 200 ft^2. Heat transfer rates are similar to those of plate and frame heat exchangers and range from 800 - 1300 Btu/hr ft^2 °F in most applications (SWEP, 1980)(ITT, 1988).

The major design consideration for brazed plate exchangers is that standard units are manufactured in only single pass flow arrangement for both hot and cold fluids. This influences the ability of the exchanger to achieve close approach temperatures in certain applications.

This limitation is best illustrated through the Number of Transfer Units (NTU) approach to heat exchanger analysis. The NTU is a dimensionless value which characterizes the performance of a heat exchanger based upon the log mean temperature difference and the temperature change occurring in the unit. It can be expressed as follows:

$$NTU = \Delta T\text{max}/LMTD$$

where $\Delta T\text{max}$ = the largest temperature change occurring in any one fluid in the heat exchanger

LMTD = log mean temperature difference

$$= \frac{\Delta t_1 - \Delta t_2}{\ln(\frac{\Delta t_1}{\Delta t_2})}$$

Δt_1 = greater temperature difference between hot and cold fluids

Δt_2 = lesser temperature difference between hot and cold fluids

An example best illustrates the use of these values.

Consider a heat exchanger in which geothermal fluid enters the hot side at 180° and cools to 140°. Process water enters the cold side at 100° and is raised to 150°.

For this case:

$$\Delta T\text{max} = 150 - 100 = 50°F$$

$$\Delta T_1 = 140 - 100 \qquad \Delta T_2 = 180 - 150$$

$$LMTD = \frac{(140-100) - (180-150)}{\ln\frac{(140-100)}{(180-150)}}$$

$$= 34.8°F$$

$$NTU = 50°/34.8$$

$$= 1.44$$

Consider a second case in which we wish to heat the process water to a temperature closer to the geothermal fluid.

Geothermal (hot) side	180° - 140°F
Process (cold) side	175° - 125°F

For this case:

$$\Delta T\text{max} = 175 - 125 = 50°F$$

$$LMTD = \frac{(140-125) - (180-175)}{\ln\frac{(140-125)}{(180-175)}}$$

$$= 9.1°F$$

$$NTU = 50/9.1$$

$$= 5.49$$

The importance of the NTU value lies in the fact that heat exchangers are capable of generating a given NTU for each fluid pass. The value is dependent upon their specific construction. For plate heat exchangers, depending upon plate design, an NTU of 0.6 to 4 per pass is generally possible.

Using a conservative value of 3, this would place an upper limit on the type of application to which single pass brazed plate heat exchangers could be applied. Of our two examples, only the first would be within the capabilities of a brazed plate heat exchanger.

Table 1 provides a broader view of the affect of this limitation in single pass performance.

Table 1. Brazed Plate Heat Exchanger Application Limitations (Based on an NTU of 3.0 per pass)

	LMTD				
ΔTmax	2	5	10	15	20
10	5	2	1	0.67	0.5
20	10	4	2	1.33	1.0
30	15	6	3	2.0	1.5
40	20	8	4	2.67	2.0
50	25	10	5	3.33	2.5
60	30	12	6	4.0	3.0

The line indicates the limits of the brazed plate units based on an NTU of 3.0 per pass. Applications which fall above the line would be within the capabilities of brazed plate units; while, applications below the line would require a multiple pass heat exchanger.

In summary, brazed plate heat exchangers would in most cases be limited to applications characterized by greater than 10° log mean temperature differences, flows of less than 100 gpm and heat transfer area of less than 200 ft^2.

HEAT EXCHANGER MATERIAL COST

As discussed above the low cost of the brazed plate heat exchanger is its most attractive feature. Since heat exchanger cost is influenced by a host of factors including hot and cold side fluid flows and temperatures, it is most useful to discuss costs in terms of heat transfer area.

Costs for both types of exchangers are combined on Figure 4 for units of less than 65 ft^2 heat transfer area. It is apparent that brazed plate units offer a significant savings for exchangers in the 2 - 20 ft^2 size range.

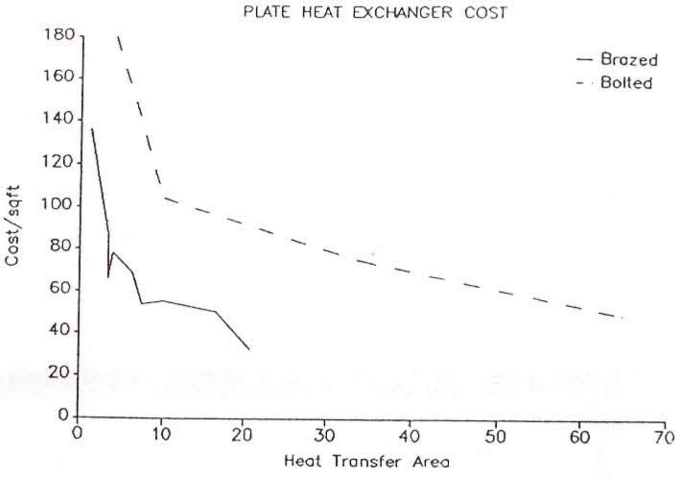

Figure 4.

BRAZED PLATE HEAT EXCHANGER PERFORMANCE IN GEOTHERMAL FLUIDS

A key factor in the determination of the economics of brazed plate heat exchangers is their expected service life in geothermal fluids. In order to evaluate this issue, plate heat exchangers were placed in service in three different geothermal fluids. The three locations for the installations (Boise, ID; Pagosa Springs, CO and Klamath Falls, OR) were chosen specifically due to the previous experiences with copper in geothermal fluids at these sites. Fluid chemistry for the three locations are detailed in Table 2.

Table 2. Test Site Fluid Chemistry*

	Klamath Falls, OR	Boise, ID	Pagosa Springs, CO
H_2S	0.5 - 1.5	0.3	5.0
Temp.	193°	176°	140°
TDS	795	290	3160
pH	8.6	8.2	6.7
Ca	26.0	2.0	240.0
F	1.50	14.0	N/A
Cl	51.0	10.0	160.0
CO_3	15.0	4.0	0
HCO_3	20.0	70.0	810.0
Na	205.0	90.0	640.0
K	1.50	1.6	87.0
SO_4	330.0	23.0	1520.0
SiO_2	48.0	160.0	61.4

* All values in mg/L except temperature (°F) and pH

In the past, the performance of copper tubing in Boise geothermal fluids has been good with water-to-air heating coils (with copper tubes) lasting as long as 10 years (Griffiths, 1990). In Klamath Falls, failure of copper tubing has occurred in approximately half this time with leaks reported in

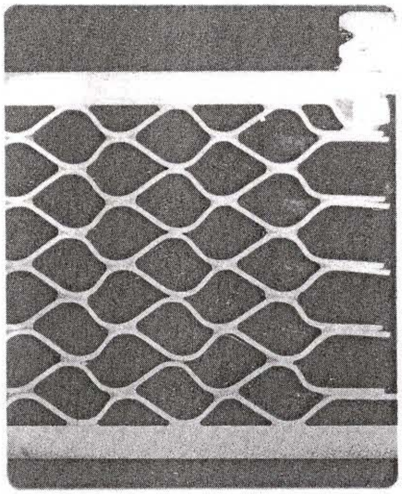

Figure 5. Crossection of Boise heat exchanger. Magnification 11x (Hudson, 1992).

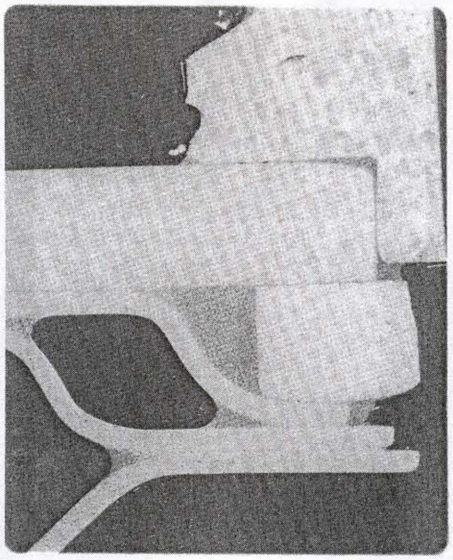

Figure 6. Crossection of Boise heat exchanger. Magnification 100x (Hudson, 1992).

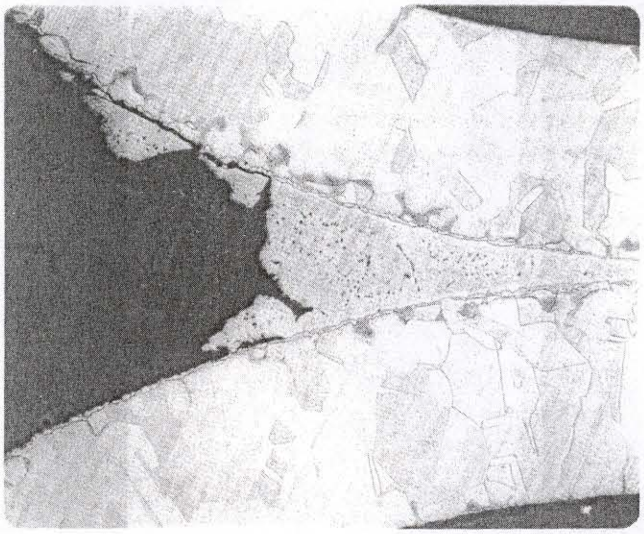

Figure 7. Crossection of Boise heat exchanger showing corrosion of copper braze material (center) between two stainless steel plates. Magnification 500x (Hudson, 1992).

as little as 5 to 7 years. Pagosa Springs fluids have demonstrated the most aggressive reaction to copper with some failures as early as 2 years of service (Martinez, 1990). In all cases, these failures have been traced to corrosion promoted largely by hydrogen sulphide (H_2S). H_2S is present to some extent in virtually all geothermal fluids.

In order to evaluate the influence of fluid chemistry on the braze material, a test program involving four heat exchangers was developed. Three of the units were exposed to the geothermal fluid and a fourth was used as a control. In each location, the heat exchanger was connected to a continuous source of geothermal fluid with a flow rate of approximately 1 gpm. The Boise unit remained in place for 46 weeks, the Klamath Falls unit for 55 weeks and the Pagosa Springs exchanger for 26 weeks. All four heat exchangers were then forwarded to an engineering firm specializing in materials analysis. The heat exchangers were sectioned, etched with acid and examined under various levels of magnification to determine the rate of corrosion. Figures 5 -7 illustrate the process.

The result of the analysis suggested a minimum expected life of approximatley 12 years for the Boise and Klamath Falls units, and 10 years for the Pagosa Springs heat exchanger.

Clearly the rate of corrosion of the brazed joints within the test heat exchangers was much slower than the most serious corrosion of tubing products observed previously at the test sites.

Based on this limited testing, brazed plate heat exchangers of the design similar to these should demonstrate a minimum service life of 12 years in fluids of less than 1 ppm H_2S and 10 years in fluids of 1 to 5 ppm H_2S.

LIFE CYCLE COSTS

The decision between a brazed plate heat exchanger and a plate and frame heat exchanger for a particular application includes considerations of a variety of issues. These would include: capital cost of the exchangers, service life of the exchangers, discount rate, maintenance requirements, installation costs and inflation rate.

Capital cost of the two types of exchangers was discussed earlier in this report. Based on the data presented, brazed plate heat exchanger first cost is on the order of 50% that of similarly sized plate and frame units.

Expected service life (minimum) for brazed plate exchanger in the fluids considered for this report would be in the range of 10 to 12 years. Service life for a plate and frame heat exchanger is less well publicized. According to the 1992 ASHRAE Handbook of Applications, shell and tube heat exchangers have a medium service life of 24 years. Because plate and frame heat exchangers are constructed of stainless steel in most of the fluid flow paths, it is reasonable to expect that they would have a service life somewhat longer than (steel and copper) shell and tube exchangers. In the absence of any long term data on service life of plate and frame exchangers in geothermal fluid applications, a value of 30 years will be used in this report for comparison to brazed plate units.

For cost comparison, a discount rate of 8% will be used for determining present value. It is customary in economic analysis to use a discount rate which approximates the rate which the owner is earning on other investments. For the general case considered in this report, no owner exists. As a result, a discount rate which approximates the current cost of capital will be used.

Maintenance of heat exchangers whether plate and frame or brazed plate amounts to primarily removal of deposits from the heat transfer surfaces on a periodic basis. For the plate and frame unit, this consists of loosening the tie bolts, sliding the plates out, manually cleaning them, and reassembling the unit. For small heat exchangers, this task can be accomplished by one worker in approximately 2 - 3 hours depending upon the number of plates. For the brazed plate exchanger, cleaning would have to be done by circulating a fluid through the unit until the fouling is removed. The process would be similar to cleaning of a water cooled condenser on a refrigeration unit. In all likelihood, the task would be contracted out for the size heat exchanger in question. For the size exchanger considered in this report, a 2-hour service call should be sufficient for the task.

Based on current rates of $40 per hour for refrigeration service and $30 per man hour for in-house maintenance staff, the difference in maintenance costs for cleaning amounts to only about $5. Assuming this task is required on intervals of only 2 to 5 years, the difference between the two types of exchangers can be disregarded in the economic analysis.

Using the above discussed assumptions, a present value comparison of the two types of exchangers can be accomplished as follows:

For the 10-year minimum life brazed plate heat exchanger, a new heat exchanger would have to be purchased in years 10 and 20 in order to provide the same 30 years of service as the plate and frame heat exchanger. We will assume an installation cost of 20% of the heat exchanger equipment cost.

Inflation rate: 3%
Discount rate: 8%
Installation cost: 20% of equipment cost
BPHX life: 10 years
PFHX life: 30 years

BPHX cost = x
PFHX cost = y

Year	BPHX	PFHX
0	1.2x	1.2 y
10	1.2x	
20	1.2x	

For the BPHX, because costs are incurred in years 10 and 20, these costs must be converted to present value for accurate comparison to the PFHX costs. To do this, the effect of inflation is considered to arrive at a future cost for the exchanger and then the discount rate is used to bring the cost back to present value.

Year 10 cost = 1.2x

Correct for effect of inflation: $1.2x \overset{F/P,3,10}{(1.344)}$

Correct to present value: $1.2x \overset{F/P,3,10}{(1.344)} \overset{P/F,3,10}{(.4632)}$

The present value of replacing the exchanger in year 10 is then = $1.2 \bullet 1.806 \bullet .4632x$

$$= .747x$$

Similarly the value of replacing the exchanger in year 20 is:

$$= 1.2 \bullet 1.806 \bullet .2146x$$
$$= .465x$$

The total present value of the costs associated with the BPHX is the sum of the year 0, year 10 and year 20 costs or

$$= 1.2x + .747x + .465x$$
$$= 2.412x$$

The cost of the plate and frame heat exchanger is simply 1.2y since it requires no replacement over the 30-year period.

Based on these figures, it is possible to define the break-even cost of the brazed plate heat exchanger in terms of the plate and frame heat exchanger as follows:

$$\begin{aligned} 2.412\,x &= 1.2y \\ x &= (1.2/2.412)y \\ x &= .498y \end{aligned}$$

That is, the brazed plate heat exchanger (at a 10-year minimum life) is the correct economic choice if it costs 49.8% or less of the cost of the plate and frame heat exchanger.

If the above procedure is represented for the 12-year minimum life heat exchanger, a value of 50.6% results.

Based on the economic assumptions in this report, brazed plate heat exchangers are the clear economic choice at capital costs of 50% or less of the cost of an equivalent plate and frame heat exchanger. This assumes that the costs of replacement will be borne by the same entity responsible for the capital cost of the system. For situations in which a separate entity is responsible for the maintenance of the system, brazed plate heat exchangers would be the choice at higher capital cost percentages.

CONCLUSIONS

Brazed plate heat exchanger were placed in three geothermal fluids (Klamath Falls, OR; Boise, ID; and Pagosa Springs, CO) in order to determine the effect of H_2S on braze material. Based on subsequent analysis, it appears that the rate of corrosion of the braze material is much slower than corrosion of copper tube materials in the same fluids. Minimum expected life of the heat exchangers based on these corrosion rates is reported to be 12 years in fluids of less than 1 ppm H_2S and 10 years in fluids of less than 5 ppm.

Based on these expected lives, and using a 3% inflation rate and 8% discount rate, brazed plate heat exchangers are a clear economic choice in which the capital cost is 50% or less of the cost of a plate and frame heat exchanger for the same duty.

Due to their single pass design, brazed plate heat exchangers are generally limited to approach temperatures of 10°F or greater. Size limitations restrict applications to 100 gpm and/or 200 ft^2 heat transfer surface area.

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