GEOTHERMAL HEAT EXCHANGERS

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Introduction

This paper is going to be largely based on the practical aspects and experience gained first hand from our projects in direct heating using geothermal heat in the 100° F. to 200° F. range and mainly in the Klamath Falls KGRA. Our experience dates back to 1958 when we designed our first geothermal heat project using a downhole heat exchanger in a slight artisian well. Since that time, we have provided consulting, feasibility and design services on approximately 15 projects. I would be remiss to say that all of these projects were without problems, but I can say that to the best of my knowledge all of them are now operating satisfactorily at sizeable savings to the owners and indirectly saving the equivalent of approximately 1,000,000 gallons of imported oil per year.

Types of Heat Exchangers

Heat exchangers are a very necessary and integral part of any heating system be it gas or oil fired or geothermal hot water. The most common types of heat exchangers used in the geothermal heating systems are as follows:

1. Downhole
2. Water-to-Air Coils
3. Shell and Tube
4. Plate Type

Figure #1 illustrates the temperature ranges that are common to the direct heat application. Note that all systems shown in Figure 1. (heat pump, radiant panels or downhole pipe coil) have one thing in common, they are all heat exchangers. However, for this discussion I will try to confine most of my remarks to the four types enumerated above.

Selection Problems

The required capacity of a heat exchanger is selected on the basis of heat loss (similar to a boiler). We have found that most installations are used on a 24 hour basis without night set back and therefore it is not necessary to allow for warm-up or piping losses.

The second basic consideration is the temperature of the water, and I do not recommend to anybody that they make any assumptions on anticipated temperatures. Have your well drilled and pump tests made before starting any system design. Once the temperature is set, then one can set the temperature to be extracted and the temperature differential (Td). As a general rule, the higher the Td the less water that has to be circulated, hence smaller pipes and pumps and less cost. This brings us to the approach temperature, that is how close we raise the system temperature to that of the Geothermal water. A good approach temperature to aim at is 20° F., with 5° as a possibility,

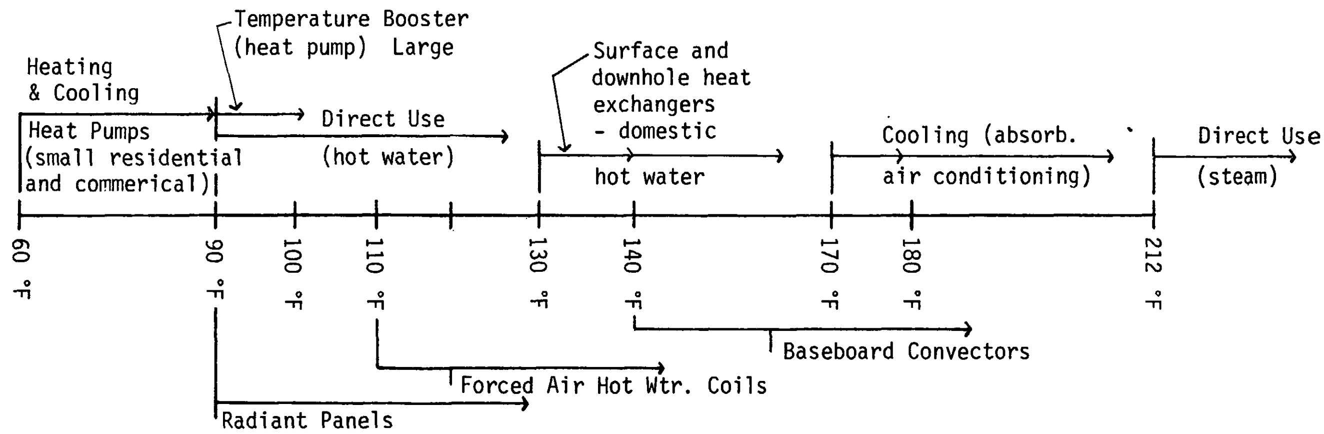

FIG. 1 Temperature ranges for heating and cooling methods

however, the closer the approach temperature is to the Geothermal water, the more costly the heat exchanger. In the case of shell and tube type exchangers, it will probably be necessary to use multiple units in order to obtain a very close approach temperature. At this point, it is well to remember that although we think of geothermal heat as free, we must remember that it costs money to pump it. To avoid wasting natural resources as much heat as practical should be extracted. This can be done by cascading the water through several separate heat exchangers or several passes through a single exchanger such as in the plate type.

The third consideration, and perhaps this should be the first consideration, is the quality of the water. The pH, mineral and chemical make-up, and suspended solids in the water all contribute to fouling within the heat exchanger.

Numerous papers have been written on this subject, however, I will just touch on what appears to be the most important to the engineer as he is selecting materials for a system.

Free oxygen will cause accelerated rusting and pitting in any system. The boiler manufacturers proved this many years ago, which led to the design of deareators for steam boiler systems.

Dezincification of zinc-bearing copper alloys has been caused by dissolved carbon dioxide and oxygen in the water. In addition, hydrogen sulfide in the water will cause a copper sulfide to form. Failure of the zinc-bearing copper alloys occurs primarily in the high velocity areas of a system.

Suspended solids in water tend to deposit on the surfaces of a heat exchanger especially where high temperature differentials occur.

Finally, 50-50 copper as used in joining copper pipes has proved to be very susceptible to attack. There is strong evidence to indicate galvanic attack in steel pipes and heat exchange headers where they are joined or closely allied with copper tubing.

This leads us into the fouling factors to be considered. Most engineers are familiar with fouling factors in the range of .0015 to .0030 hr./ft.^{2} F./Btu for coil selection. It is generally recognized that the prime variables affecting fouling build-up are water quality, flow velocity, surface temperature and surface material. The aforementioned fouling factors seem to be reasonable for the shell and tube type heat exchangers, however, one of the leading manufacturers of plate heat exchangers advocate fouling resistance approximately half that for the tube type. This will be discussed in more detail under Plate Heat Exchangers. From our own experience, I feel it is a mistake to try to control heat transfer rates by reducing the rates of flow through the geothermal water side of shell and tube heat exchangers. We feel the flow rates probably have a greater effect on fouling than any of the other variables recited above. If a shell and tube heat exchanger is selected, we strongly recommend the straight through tube type in preference to the U-tubes since they can be cleaned by rodding if necessary. (It is assumed that the Geothermal water is in the tubes and the end plates are removeable for access to the tubes.)

After knowing the capacity of the well and heating capacity required, the temperatures available, the materials required to be compatible with the water quality, the fouling factors and the space available for the equipment it is then possible to select a suitable heat exchanger. In the case of shell and tube heat exchangers it is a simple task by referring to manufacturer's catalogs to make this selection, however, most manufacturers, given the above data, have computer programs available to make a selection of the most economical units.

Following is a detail discussion of these types of heat exchangers.

1. Downhole: This type usually consists of a single "hairpin" loop of black iron pipe suspended into a well and in direct contact with the geothermal water, with clean, treated secondary system water circulated through the loop. Figure #2 illustrates a typical well configuration. The casing must be perforated near the top of the static water level and near the bottom, with an open annulus or passageway for water circulation between the casing and the well bore to obtain good heat transfer. Similar good results have been obtained without perforating the casing where an artisian flow is encountered. This type exchanger is especially adaptable to small commercial and residential since the cost is the lowest of all types. In most instances, experience has shown that the secondary water will thermal cycle thus alleviating the cost of a pump and its operational cost. Most wells have two heating loops with the second serving to heat the domestic hot water.

   On the negative side, experience has shown that the tubes must be removed from the well approximately every five years for cleaning. Corrosion occurs most severly at the static water level and is accelerated to some extent due to stray electrical currents. Insulating unions should be used between the coil and connection to dissimilar metals or city water services.

   Determination of the amount or length of coil within a well is a very difficult calculation. The interaction between the fluid in the aquifer and that in the well is not fully [illegible]ood or predictable but it appears that [illegible]emperatures are attainable where there [illegible]h degree of mixing within the well. [illegible]s reason, most engineers will be well [illegible]sed to use a safety factor of at least 2 i[illegible]heir heat transfer rate calculations.

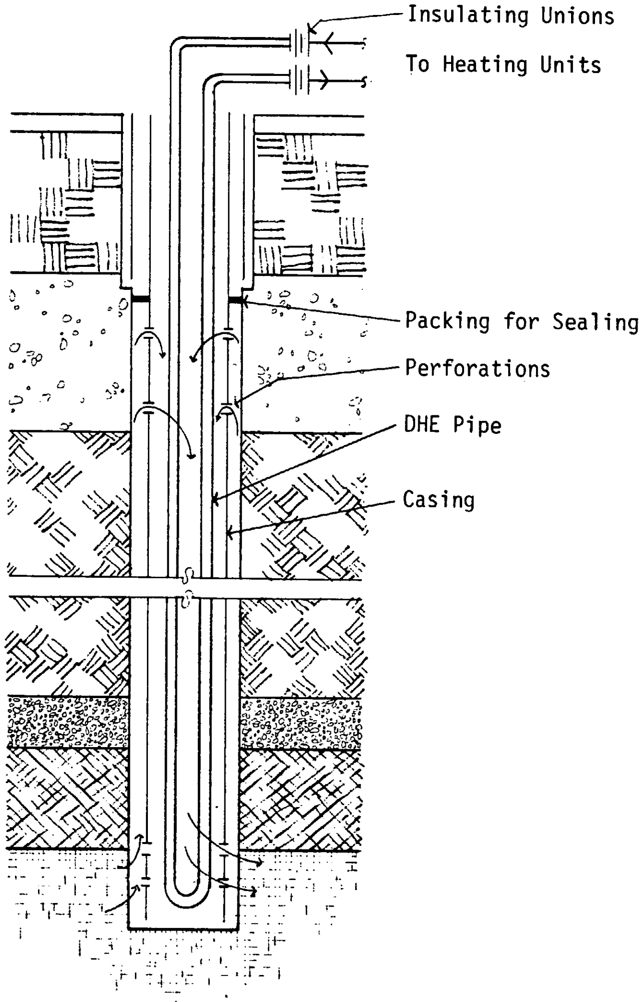

FIG. 2 Typical downhole heat-exchanger installation

In addition to several hundred wells in the Klamath Falls area that are used for residential usage, there is at least one school that uses this principal. The school has two wells with two 2-1/2 inch loops in each which are in turn connected to a large storage tank. The system water is then pumped out of this tank to the various heating units. The purpose of the tank was to provide a heat reservoir for peak loads. This system has been in operation for at least 10 years with very few problems.

Another unique system is one devised by an automobile dealership. A city storm sewer running through their property carried hot water from springs and overflow from other geothermal resources throughout the City of Klamath Falls. The owners constructed a concrete tank approximately 80 ft. long by four feet wide and laid a horizontal serpentine coil in the bottom. The system water was then pumped through the coils to heating ventilating units in their building. This same water was also used by an adjacent concrete mixing plant for warm mix water during the winter months. This might be referred to as a "horizontal downhole, heat exchanger", and has been very satisfactory.

2. Water-to-Air Heat Exchangers: This system has been used quite successfully in a 100,000 sq. ft. manufacturing plant not only to heat the building, but also to heat 100,000 cfm of make-up air. This is using the geothermal water direct in the heating system and is not a system to be recommended except in unusual circumstances.

   The reason for its use in this instance was that the well water temperature was too low (115° F.) to allow for the temperature loss in a heat exchanger and still have sufficient temperature for adequate heat. One heating coil was opened up last summer after two years of operation and showed very little corrosion or deposition of minerals. Although the water shows about a 40° F. temperature drop through the system, I feel that the lack of corrosion is due to the low operating temperatures.

3. Shell and Tube: Both U-tube and straight tube types have been used with varying results. Mazama High School in the Klamath Falls District has a series of seven straight tube exchangers which have been in use since 1968 and have never been cleaned. These are straight tube exchangers with the geothermal water at about 140° F. entering. In this same installation, three "U" tube heat exchangers used for heating domestic water (55° to 120° F.) have failed. We learned of this just last April and have not, as of this writing, been able to obtain one for analysis.

   On the other hand, a larger installation of shell and tube heat exchangers at the hospital in Klamath Falls have shown a very high rate of fouling, pitting of the header plates and errosion of the copper coil material. These units are using 195° F. water which apparently, due to the higher temperature, makes the geothermal water much more aggressive.

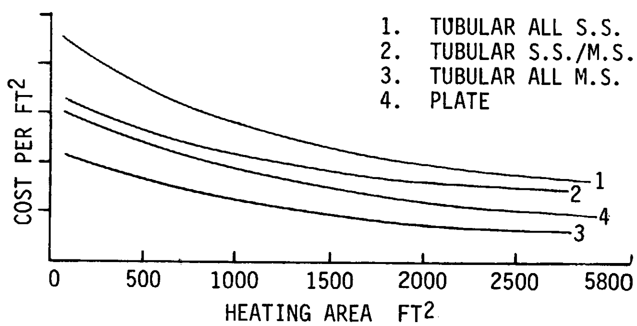

FIG. 3 Price comparison of tubular and plate heat exchangers based on cost per unit area

The shell and tube exchangers are generally made for a multitude of uses with copper coils, steel headers and outside shell. The more exotic metals and stainless steel trim are obtainable but they loose their cost advantage under these conditions, refer to Figure 3. These heat exchangers do take up considerably more space than the plate type.

4. Plate Type: These heat exchangers have been used for many years in the chemical and pharmaceutical industries, also where sea water has been used in cooling applications such as on board ships.

The plate type heat exchanger (PHE) consists of a series of flat plates with a trough and dimple pattern pressed into the plates to increase the effective heat transfer area, strengthen the plates and produce turbulance of the liquid flow through the plates. The plates can be pressed from various materials, however, stainless steel to date has proven very satisfactory for Geothermal heating purpose (titanium plates would double the cost of the heat exchanger).

At present, the only limitations are 550° F. maximum temperature and a maximum pressure of 300 psig. These limits are incurred due to the gasket material. Neither of these limitations should present any problems in the Geothermal field.

It has been proven that far less fouling will occur in the plate heat exchanger than in the shell and tube type due to the turbulent flow caused by the trough and dimple design of the plates. It is necessary to consider this factor when specifying the unit, since halving the fouling factor from .0005 Btu/hr./sq.ft./°F. to .00025 will halve the square foot area of the plates required. While a .0005 fouling factor in a shell and tube heat exchanger is common, the manufacturers of PHE equipment infer that a factor of perhaps one half or .00025 is probably adequate although they admit that relatively little accurate data is available. Figure #4 shows typical curves for effects of velocity and fouling in shell and tube heat exchanger and PHE as related to time.[3] Velocity in the PHE is not as critical as in the shell and tube due to the higher turbulance in the PHE.

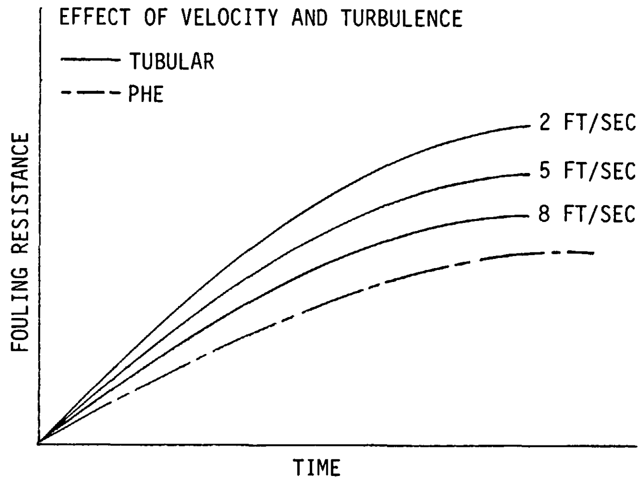

FIG. 4

Probably the most crucial decision an engineer must make is the approach temperature or log mean temperature difference (LMTD). Figure #5 shows a comparison of the affect of this LMTD has on cost.[3] This is rather dramatic and indicative of how important it is to select the proper and largest possible temperature differences. In retrofitting of existing systems to Geothermal it sometimes is necessary to use a very close approach to meet existing coil transfer rates.

EFFECT OF PERCENTAGE OF HEAT RECOVERY ON PLATE HEAT EXCHANGER COST

Heat recovered is 3,600,000 BTU/HR in all cases
15 PSI pressure drop each way in all cases

GPM WATER EACH WAY	%	TEMP °F	LMTD	AREA SQ. FT	PRICE
120 GPM	60	200⟶140 160⟵100	40	94	$ 5,800
96 GPM	75	200⟶125 175⟵100	25	163	$ 7,800
85 GPM	85	200⟶115 185⟵100	15	292	$11,000
80 GPM	90	200⟶110 190⟵100	10	420	$13,700

FIG. 5

Selecting pressure drops through any heat exchanger will effect not only the sizing of the heat exchanger but also pump and pump motor sizing. The shell and tube heat exchangers will generally produce a larger pressure drop through the tubes and a lower pressure drop through the shell side than is experienced in a plate heat exchanger assuming equal flow in both media. In the case of PHE, the pressure drops will be equal.

<u>Conclusions</u>

1. Know your water quality and quantity before selecting any type system or heat exchanger.

2. Materials containing high zinc alloys when used with the higher temperature waters should be avoided. Avoid solders of all types. Consider use of insulating unions and galvanic protection in the form of magnesium anodes.

3. Take every precaution possible to prevent oxygen in a system.

4. Downhole heat exchangers are a very acceptable heat exchanger for the small commercial or residential system.

5. The present state of the art would strongly favor the plate heat exchanger over a shell and tube type. Advantages for the plate heat exchanger are 1. Requires less floor space; 2. Easily disassembled for cleaning; 3. Easily added to for future increased capacity and 4. Multiple heating media in a single exchanger.

Acknowledgements

I thank Mr. Larry Paulus and Mr. H. Susmann of the APV Company for providing the data for some of the Figures shown herein.

References

1. Ellis, Peter F. and Mitchell, David A., "Failure Analysis Report - Circulating Pump Impeller" by Radian Corp. dated November 30, 1979, DCN 79-212-003-03.

2. Ellis, Peter F., Radian Corp. "Failure Analysis of Conventional Heating System Components in Geothermal Direct Utilization Service".

3. Heat Transfer Handbook, Design and Application of Paraflow Plate Heat Exchangers, Second Edition; APV Company, Inc.