Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Using Two Phase Heat Exchanger in Replacement of Separator for Sabalan Field

Soheil Porkhial[1], Ehsan Amini Moghaddam[1, 3], Parisa Yousefi[2], Hamzeh Sheydae[4]

1- Department of Mechanical Engineering Karaj Branch Islamic Azad University, Iran 2-Suna, Ministry of Energy, Tehran, Iran

1-Porkhial@ kiau.ac.ir , 2- eh.amini.egt@gmail.com, 3- parisa.yousefi48@yahoo.com, 4- HSH_7@yahoo.com

Keywords: heat exchanger, separator, power, geothermal

ABSTRACT

Sabalan field is located in South West of Iran and is the first geothermal field. In this paper we are going to compare the conventional single stage geothermal power plants with a vapor Rankin cycle where the boiler is a heat exchanger. As we know, vapor entering the turbine from the separator contains corrosive minerals that may harm the turbine blades; turbine maintenance costs increase, but by replacing the separator and using a heat exchanger we could inhibit the system from corrosion and scaling. It should be noted that after designing the heat exchangers, the rates of output vapor surpassed that of a separator, and this means that the output of plant goes up. Additionally, turbine maintenance costs are reduced compared to the separator.

1. INTRODUCTION

Gasketed plate heat exchangers (PHEs) are widely used in dairy and food processing plants, chemical industries, power plants and central cooling systems. They exhibit excellent heat transfer characteristics, which allows a very compact design, and can be easily removed for maintenance, cleaning or for modification of the heat transfer area by adding or removing plates. The PHE consists of a pack of thin corrugated metal plates with portholes for the passage of the fluids, as shown in Fig. 1. Each plate contains a bordering gasket, which seals the channels formed when the plate pack is compressed and mounted on a frame. The hot and cold fluids flow in alternate channels and the heat transfer takes place between adjacent channels. The corrugation of the plates promotes turbulence inside the channels and improves the mechanical strength of the plate pack.

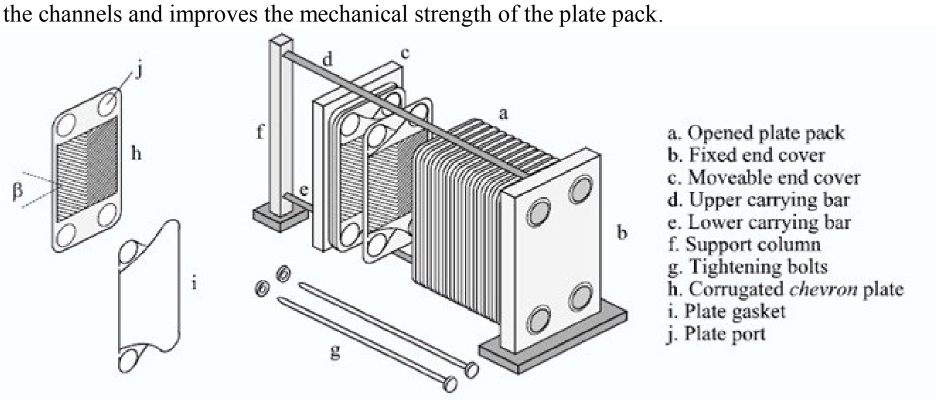

Fig.1.The Gasketed plate heat exchanger assemblage and parts

The PHE manufacturers developed exclusive design methods and, despite the large number of applications, rigorous design methods are not easily available, as are those for shell/tube or tubular exchangers. The available methods often have configuration limitations or depend on simplified forms of the thermal-hydraulic model of the PHEs.

A number of characteristics particularly attractive to geothermal applications are responsible for this. Among these are:
1. Superior thermal performance.
Plate heat exchangers are capable of nominal approach temperatures of 10^{o}F compared to a nominal 20^{o}F for shell and tube units. In addition, overall heat transfer coefficients (U) for plate type exchangers are three to four times those of shell and tube units.
2. Availability of a wide variety of corrosion resistant alloys.
Since the heat transfer area is constructed of thin plates, stainless steel or other high alloy construction is significantly less costly than for a shell and tube exchanger of similar material.
3. Ease of maintenance.
The construction of the heat exchanger is such that, upon disassembly, all heat transfer areas are available for inspection and cleaning. Disassembly consists only of loosening a small number of tie bolts.
4. Expandability and multiplex capability.
The nature of the plate heat exchanger construction permits expansion of the unit should heat transfer requirements increase after installation. In addition, two or more heat exchangers can be housed in a single frame, thus reducing space requirements and capital costs.
5. Compact design.
The superior thermal performance of the plate heat exchanger and the space efficient design of the plate arrangement results in a very compact piece of equipment. Space requirements for the plate heat exchanger generally run 10% to 50% that of a shell and tube unit for equivalent duty. In addition, tube cleaning and replacing clearances are eliminated.

2. SABALAN FIELD

The Sabalan geothermal prospect lies on the western slopes of Mt. Sabalan. The prospect site is located at about 20 km south of the City of Meshginshaar in the Province of Ardebil, North West of Iran. The area is located between 38° 12' 52" and 38° 20' 00" North and 47° 40' 30" and 47° 49' 10" East. The Mt Sabalan geothermal field is located in the Moil Valley on the north-western flank of Mt Sabalan, in the Ardebil Province of NW Iran. Fig 2 shows location of Sabalan field in Iran.

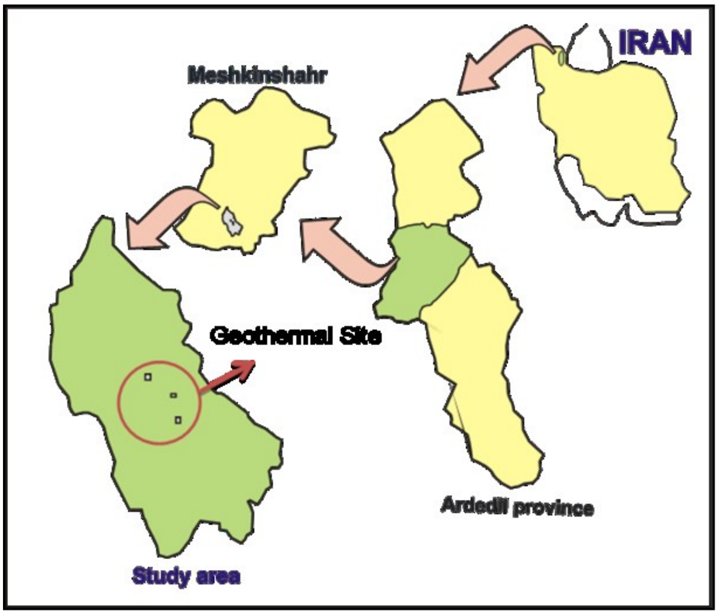

Fig 2. Location of Sabalan field in Iran

First Stage of exploration program in Meshkin-shar began in 1998 in conjunction with a New Zealand consulting engineer (KML). In this field there are 12 exploration wells. Of the 12 wells, one is shallow and 7 have capability of production. The position of the well site and output characteristics of the wells are shown in Fig. 3; table 1 shows physical properties of the 7 productive wells.

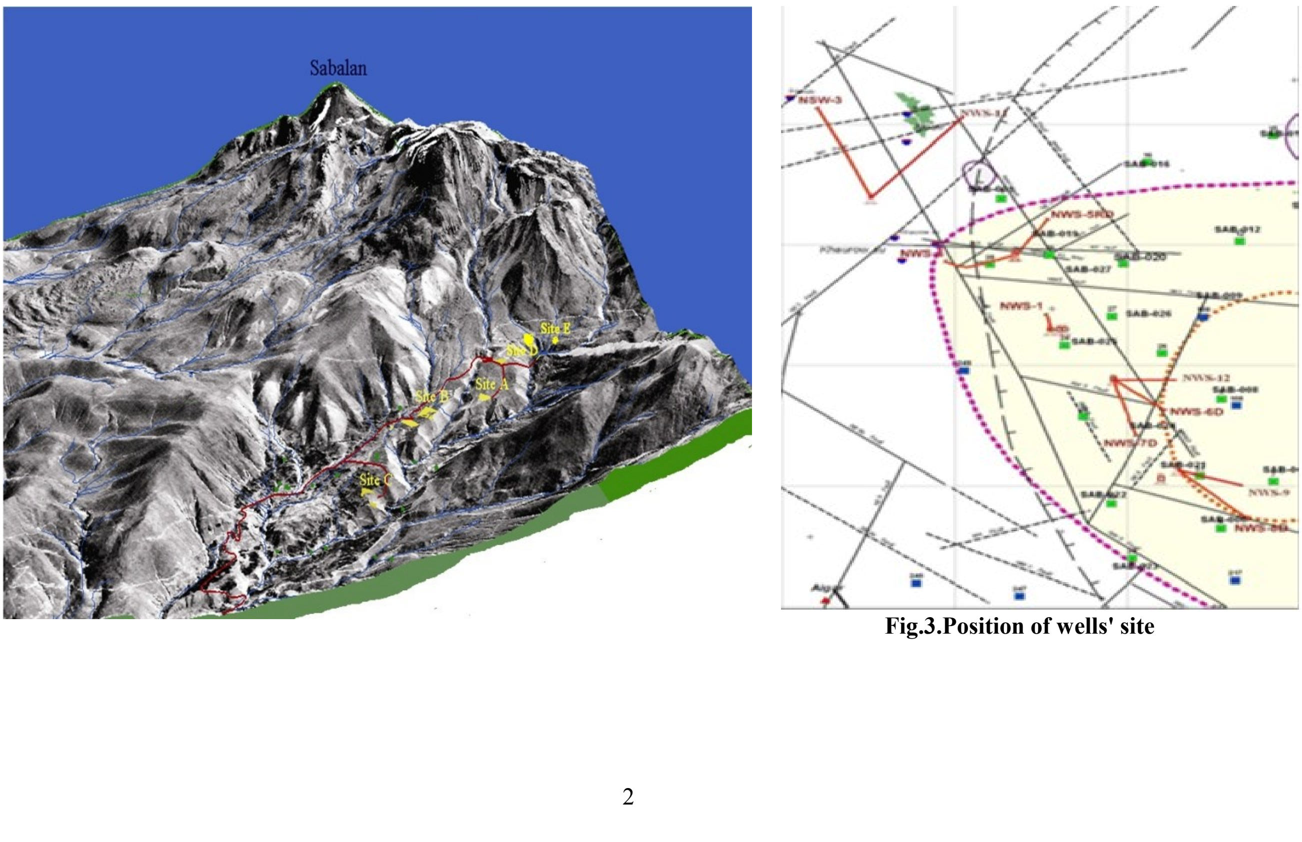

Fig.3.Position of wells' site

Table 1.Output characteristics of wells

number of wells	$T(°C)$	$P(bar)$	Enthalpy $kj/_{kg}$	quality	$\dot{m}(^{kg}/_{s})$	Density $cl\ (ppm)$	wells height above sea level(m)
NWS 1	138.41	3.46	960	0.175	27.7	2453.4	2632
NWS 4	155.19	5.46	950	0.14	56.1	2480	2474.4
NWS 5	198.27	15	986	0.07	52	2600	2474.4
NWS 6	180.62	10.3	1156.31	0.19	52.09	2378.5	2742.8
NWS 7	184.47	11.1	1189.21	0.2	57.65	2414	2742.8
NWS 9	166.07	7.2	1093.43	0.19	40.54	2384.7	2885.2
NWS 10	182.4	10.6	1144.96	0.185	53.56	2514	2742.8

3. DIAGRAM OF CYCLESS

In this paper we have 2 diagrams of cycles. One is a single flash cycle (fig4), which has a separator for producing vapor for the turbine, and another has a heat exchanger instead of a separator for vapor production (fig5). It is noted that the working fluid of both cycles is water.

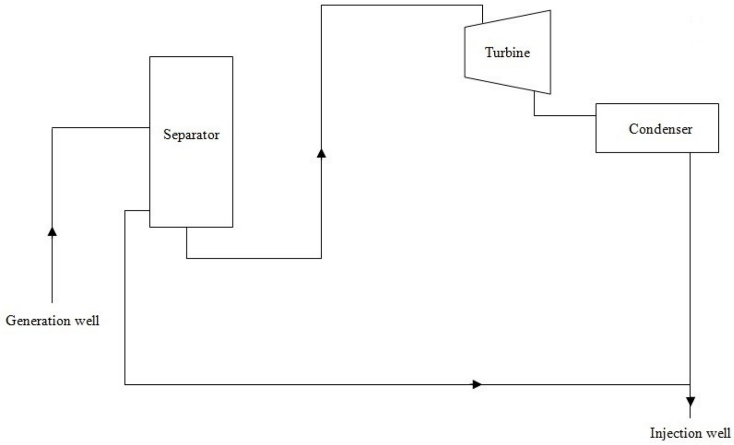

Fig.4. Diagram of single flash cycle with Separator

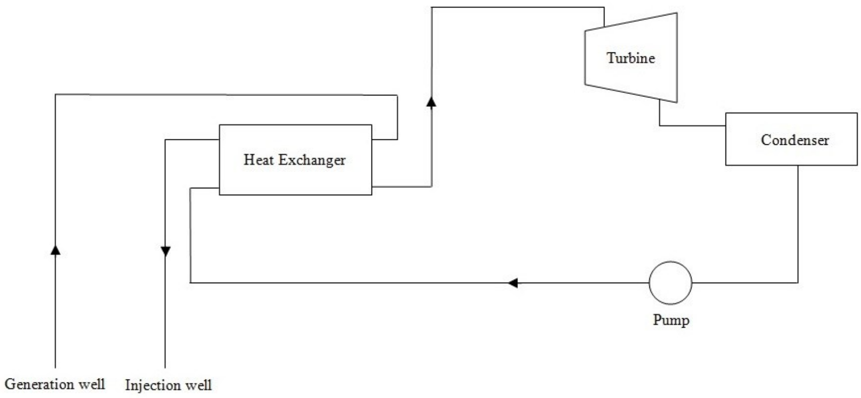

Fig.5. Diagram of cycle with heat exchanger

4. VAPOR-LIQUID SEPARATOR

A vapor–liquid separator is a device used in several industrial applications to separate a vapor–liquid mixture. In the common variety, gravity is utilized in a vertical vessel to cause the liquid to settle to the bottom of the vessel, where it is withdrawn. In low gravity environments such as a space station, a common liquid separator will not function because gravity is not usable as a separation mechanism. In this case, centrifugal force needs to be utilized in a spinning centrifugal separator to drive liquid towards the outer edge of the chamber for removal. Gaseous components migrate towards the center. The gas outlet may itself be surrounding by a spinning mesh screen or grating, so that any liquid that does approach the outlet strikes the grating, is accelerated, and thrown away from the outlet.

The vapor travels through the gas outlet at a design velocity, which minimizes the entrainment of any liquid droplets in the vapor as it exits the vessel. The feed to a vapor–liquid separator may also be a liquid that is being partially or totally flashed into a vapor and liquid as it enters the separator. A vapor–liquid separator may also be referred to as a flash drum, knock-out drum, knock-out pot, compressor suction drum or compressor inlet drum. When used to remove suspended water droplets from streams of air, a vapor-liquid separator is often called a demister.

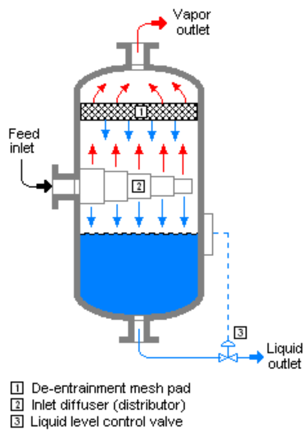

Fig.6.Vapor-liquid separator

A demister is a device often fitted to vapor liquid separator vessels to enhance the removal of liquid droplets entrained in a vapor stream. Demisters may be a mesh type coalescer, vane pack or other structure intended to aggregate the mist into droplets that are heavy enough to separate from the vapor stream. Demisters can reduce the residence time required to separate a given liquid droplet size thereby reducing the volume and associated cost of separator equipment. Demisters are often used where vapor quality is important in regard to entrained liquids particularly where separator equipment costs are high (e.g., high pressure systems) or where space or weight savings are advantageous. For example, in the process of brine desalination on marine vessels, brine is flash heated into vapor. In flashing, vapor carries over droplets of brine which have to be separated before condensing; otherwise the distillate vapor would be contaminated with salt. This is the role of the demister. Demisted vapor condenses on tubes in the desalination plant, and product water is collected in the distillate tray.

If a separator is used in the wells of Sabalan field, the relevant data is in line with table 2: the pressure of the inlet turbine is equal to the pressure of the separator. We could calculate the quality of fluid at the inlet of the separator by using the pressure of the separator and enthalpy. We could then calculate the mass flow rate of vapor which entered the turbine. If we compare this rate of vapor with the vapor of the heat exchanger in fig3, then we could discuss the efficiency of these cycles.

Table2-Seperator vapor mass flow rate

Number of wells	turbine inlet pressure	enthalpy $^{kj}/_{kg}$	wells mass flow $\dot{m}(^{kg}/_{s})$	X	Separator vapor mass flow $\dot{m}(^{kg}/_{s})$
NWS1	3.3	960	27.7	0.1785	4.944
NWS4	5.4	950	56.1	0.1415	7.939
NWS5	5.4	986	52	0.1587	8.251
NWS6	7	1156	52.09	0.222	11.57
NWS7	7	1189	57.65	0.238	13.72
NWS9	6.9	1093	40.54	0.1926	7.808
NWS10	7.1	1145	53.56	0.2157	11.55

5. HEAT TRANSFER FROM GEOTHERMAL ENERGY

The task of transferring heat from the geothermal fluid to a closed process loop is most often handled by a plate heat exchanger. The two most common types used in geothermal applications are: bolted and brazed.
Shell and tube heat exchangers play only a minor role in low-temperature, direct-use systems. These units have been in common use in industrial applications for many years and, as a result, are well understood.

6. GASKETED PLATE HEAT EXCHANGER

The plate heat exchanger is the most widely use configuration in geothermal systems of recent design.

6.1. General Capabilities

In comparison to shell and tube units, plate and frame heat exchangers are a relatively low pressure/low temperature device. Current maximum design ratings for most manufacturers are: 204.45^{o}C and 20.7 bar (Tranter, undated).
Above these values, an alternate type of heat exchanger would have to be selected. The actual limitations for a particular heat exchanger are a function of the materials selected for the gaskets and plates; these will be discussed later.
Individual plate area varies from about 0.03 to 2 m^2 with a maximum heat transfer area for a single heat exchanger currently in the range of 1208 m^2. The minimum plate size does place a lower limit on applications of plate heat exchangers. For geothermal applications, this limit generally affects selections for loads such as residential and small commercial space heating and domestic hot water.
The largest units are capable of handling flow rates of 1362.7 m^3/h and the smallest units serviceable down to flows of approximately 1.13 m^3/h. Connection sizes are available from 0.02 to 0.356 m. to accommodate these flows.

6.2. Materials

Materials selection for plate heat exchangers focuses primarily upon the plates and gaskets. Since these items significantly affect first cost and equipment life, this procedure should receive special attention.

6.2.1-Plates

One of the features that make plate-type heat exchangers so attractive for geothermal applications is the availability of a wide variety of corrosion-resistant alloys for construction of the heat transfer surfaces. Most manufacturers offer the alloys listed below:

1. 304 Stainless Steel
2. 316 Stainless Steel
3. 317 Stainless Steel
4. Titanium
5. Tantalum
6. Incaloy 825
7. Hastelloy
8. Inconel
9. Aluminum Bronze
10. Monel

In addition to these, a larger number of optional alloys are available by special order. Most manufacturers will quote either 304 or 316 stainless steel as the basic material.

For direct use geothermal applications, the choice of materials is generally a selection between 304 stainless, 316 stainless, and titanium. The selection between 304 and 316 is most often based upon a combination of temperature and chloride content of the geothermal fluid. This is illustrated in Figure 7. This figure contains two curves, one for 304 and one for 316. At temperature/chloride concentrations that fall into the region below the curve, the particular alloy in question is considered safe to use. Combinations of temperature and chloride content located above the curve offer the potential for localized pitting and crevice corrosion. Fluid characteristics above the curve for a particular alloy do not guarantee that corrosion will absolutely occur. However, this curve, based on oxygen-free environments, does provide a useful guide for plate selection. Should oxygen be present in as little as parts per billion (ppb) concentrations, the rates of localized corrosion would be significantly increased (Ellis and Conover, 1981).

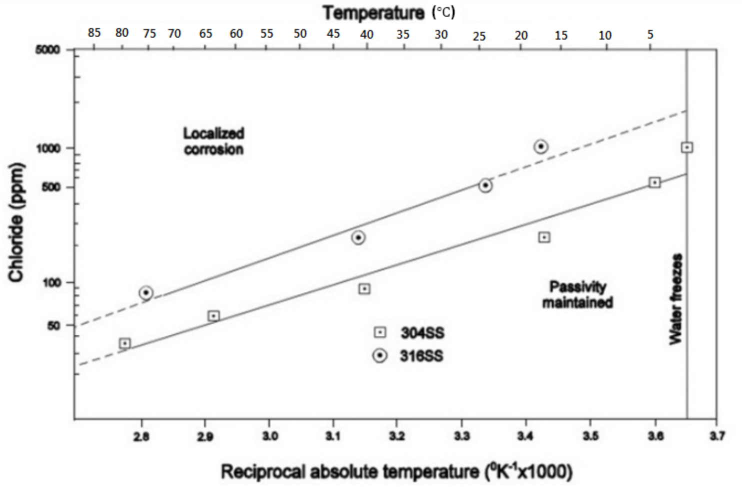

Fig.7.Chloride required to produce localized corrosion of Type 304 and Type 316 as a function of temperature (Efired and Moller. 1978)

Titanium is only rarely required for direct use applications. In applications where the temperature/chloride requirements are in excess of the capabilities of 316 stainless steel, titanium generally offers the least cost alternative.

Austenitic stainless alloys with higher chromium and molybdenum contents could be recommended for this application also. These alloys, however, are generally not available as standard plate materials as is titanium (Ellis and Conover, 1981).

6.2.2. Gaskets

As with plate materials, a variety of gasket materials are available. Among the most common are those shown in Table 3.

Table3. Plate Heat exchanger Gasket Materials (APV, Alfa-Laval, Tranter)

Material	Common Name	Temperature Limit (°C)
Styrene-Butadiene	Buna-S	85
Neoprene	Neoprene	120
Acrylonitrile- Butadiene	Buna-N	135
Ethylene/Propylene	EPDM	150
Fluorocarbon	Viton	150
Resin-Cured Butyl	Resin-Cured Butyl	150
Compressed Asbestos	Compressed Asbestos	260

The discussion of materials selection for both the plates and gaskets is based primarily upon the geothermal fluid characteristics. This assumes that the secondary fluid is of a relatively non-aggressive nature. Should the secondary fluid be a chemical process or other than treated water, additional materials selection considerations would apply.

6.2.3. Frame, Tie Bolts, and Fluid Connections

The frame of most plate heat exchangers is constructed of carbon steel. This is generally painted with an epoxy based material.
Tie bolts are of nickel-plated carbon steel. Alternative materials are available (stainless steel), though these are generally unnecessary for geothermal applications.
Standard connections are 70-kg flange-type of carbon steel construction (0.05-0.0127 m. and larger). Connections of 0.0254-0.0127 m. and smaller are generally threaded. Alternate materials and configurations (threaded, grooved end, plain end, etc.) are available.

6.3. Performance

Superior thermal performance is the hallmark of plate heat exchangers. Compared to shell-and-tube units, plate heat exchangers offer overall heat transfer coefficients 3 to 4 times higher. These values, typically 4543 to 6814 W/m^2.K (clean), result in very compact equipment. This high performance also allows the specification of very small approach temperature (as low as -17 to -15^{o}C), which is sometimes useful in geothermal applications. This high thermal performance does come at the expense of a somewhat higher pressure drop. Figure.8 presents a generalized relationship for overall heat transfer and pressure drop in plate exchangers, based on several different total fouling factors.

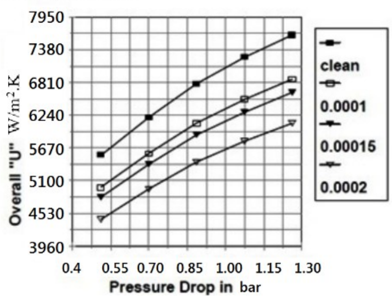

Fig.8. Performance of Plate Heat Exchanger

Fouling considerations for plate heat exchangers are considered differently than for shell-and-tube equipment. There are a variety of reasons for this, but most important is the ease with which plate heat exchangers can be disassembled and cleaned. As a result, the units need not be over-designed to operate in a fouled condition. Beyond this, the nature of plate heat exchanger equipment tends to reduce fouling due to:

- High turbulence,
- Narrow high-velocity flow channels which eliminate low flow areas found in shell-and-tube equipment, and
- Stainless steel surfaces that are impervious to corrosion in most groundwater applications

Table4 presents some recommended ranges for fouling factors in plate heat exchangers.

Table4. Fouling Factor for plate heat exchanger

Fluid	Fouling Factor (m^2.K/W)
Distilled water	0.0000088
Soft water	0.000018
Hard water	0.000044
Treated cooling tower water	0.000035
Sea water - ocean	0.000026
River water	0.000044
Engine jacket	0.000053

It is important to bear in mind the impact of the fouling factor on a heat exchanger size. For a nominal clean heat transfer coefficient of 5678 W/m^2.K, a fouling allowance of 0.000017 would result in an additional surface requirement of roughly 10%. A fouling allowance of 0.000088 would require a 50% larger heat exchanger. Overly conservative fouling factor selection has a much larger impact upon plate heat exchanger surface area compared to shell-and-tube equipment, due to the higher overall heat transfer of plate heat exchangers.

6.4. Selection

Final selection of plate heat exchangers is done by a vendor using proprietary selection software. There are some general rules of thumb, however, which allow the designer to refine the flows and temperatures prior to submitting values to the vendor.
Heat exchangers, regardless of the type, are selected to transfer a specific quantity of heat under a specific set of conditions. The key parameter in the selection process is the heat transfer area required to accomplish this task. The general formula below describes this situation.

$Q = U * A * LMTD * C_f$

Where: Q = Heat load in kW
U = Overall heat transfer coefficient in W/m^2.K
A = Area (m^2)

LMTD = Log mean temperature difference (°C)
C_f = LMTD correction factor (0.85 - 1.0 for most geothermal applications).

The log mean temperature is calculated using the difference between the entering and leaving temperatures of the two fluids according to the following relationship:

Fluid 1 t_{out1} ● t_{in1}
Fluid 2 t_{in2} ● t_{out2}

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

Where: $\Delta t1 = t_{out1} - t_{in2}$
$\Delta t2 = t_{in1} - t_{out2}$

Example LMTD calculation:

Geothermal side 170° ● 130°C
Building loop side 150° ● 115°C

$\Delta t1 = 20°$ $\Delta t2 = 15°$

$$\mathrm{LMTD} = \frac{20-15}{\ln(\frac{20}{15})} = 17.4°$$

The question of permissible pressure drop is one which should be viewed in the context of the project. Obviously, the higher the pressure drop, the greater the energy consumption associated with the well pump (on the geothermal side) and the loop pump (on the other side). As an example, consider a system with the loop operating at 0.95 m^3/min and the well pump selected for 0.57 m^3/min. Assuming the well pump operates at 1500 hours per year and the loop pump 2500 hours per year (constant flow), the annual pumping energy consumption (loop and well) would be 6558 kWh for a heat exchanger with a 0.862 bar pressure drop and 3908 kWh for an exchanger with a 0.517 bar pressure drop. At $0.08 per kWh, this amounts to a cost difference of $212/year. A heat exchanger sized for average conditions at a 732.7 kW load would require about 25% (3.25 m^2) additional surface area at 0.517 bar compared to 0.862 bar. At a value of $1.9 per m^2, this amounts to an additional heat exchanger cost of approximately $700. As a result, the simple payback on the added cost of the heat exchanger (selected for lower pressure drop) would amount to about 3.3 years.

In summary, preliminary calculations for plate heat exchangers can be made using the guidelines in Table 5:

Table5. Plate Heat exchanger Design - Parameters

Fouling factor (total)	0.000017 to 0.000035
Pressure drop	Less than 0.7 bar
Resulting overall heat transfer coefficient	4259 to 5110 W/m².K
Plate materials	316 SS or Titanium
Gaskets	Medium nitrile rubber (NBR)

Although the final selection of plate heat exchangers is made by the vendor using proprietary software, in order to reduce the number of alternatives submitted to the vendor, preliminary calculations are generally made to refine the selection. The general procedure is to:

- Calculate heat exchanger surface requirements for the heating load based on available geothermal flow and temperature,
- Compare with desired operating conditions, and
- Re-select if necessary based on alternate pressure drop, approach temperature, etc.

7. BENEFITS OF USING PHE IN A GEOTHERMAL HEATING SYSTEM

7.1. Plate arrangements

There are two arrangements of plates, lambdoidal and straight. The operating pressure of the lambdoidal arrangement can exceed 1.0 MPa (Yang, 1995), and that of the straight model is about 1.0 MPa. In addition, the heat coefficient and pressure drop of the lambdoidal arrangement are higher than that of the straight model. The lambdoidal arrangement is often used in geothermal heating systems.

7.2. Plate size

The holes in the plate are related to plate size. In order to attain a high efficiency, the flow velocity in the holes is generally set at about 6 m/s. However, if this is too small, the number of flow paths should be increased so that the pressure drop increases. On the other hand, if they are too big, the flow velocity in the holes is unable to reach the required value, and the heat transfer coefficient will be too low. Taking into account factors such as flow rate, flow velocity and pressure drop will reveal several plate sizes suited to a geothermal heating system only, through optimization, such as 0.5, 0.8, 1.0 m^2; these will depend on heat demand, utilization requirements, and economic factors.

7.3. Flow velocity

Flow velocity may influence both heat transfer efficiency and pressure drop. A high flow velocity can produce too high a heat transfer coefficient and pressure drop. This occurs with a velocity range of 0.2–0.8 m/s in the system.

7.4. Flow paths

If the flow rates on the hot and cold sides are approximately equal, the PHEs should be designed as symmetrical exchangers. In a geothermal heating system, equivalent flow paths PHEs are always used, because this produces a counter-current flow.

In Sabalan field we have 7 geothermal wells; the specifications of heat exchangers used on these wells are:

Table 6. Specifications of Heat exchangers in Sabalan field

Number of Heat exchangers			1	4	5	6	7	9	10
specifications									
		No. of exchangers	1	2	1	1	1	1	1
Hot Side	in	Temperature (°C)	138.41	155.19	198.27	180.62	184.47	166.07	182.4
		Vapor mass fraction	0.175	0.14	0.07	0.19	0.2	0.19	185
		Operating pressure(bar)	3.44	5.46	14.87	10.15	11.12	7.12	10.51
	out	Temperature (°C)	80	95	100	100	100	100	100
		Vapor mass fraction	0	0	0	0	0	0	0
		Operating pressure(bar)	3.096	4.914	13.383	9.646	10.616	6.616	10.006
		Mass Flow rate(kg/s)	27.7	56.1	52	52.09	57.65	40.54	53.56
Cold Side	in	Temperature (°C)	50	50	50	50	50	50	50
		Vapor mass fraction	0	0	0	0	0	0	0
		Operating pressure(bar)	3.3	5.4	5.4	7	7	6.9	7.1
	out	Temperature (°C)	137	155	170	170	175	165	170
		Vapor mass fraction	1	1	1	1	1	1	1
		Operating pressure(bar)	2.97	4.86	4.86	6.5	6.5	6.4	6.6
		Mass Flow rate(kg/s)	6.7	12.1	11.18	14.5	17	10.6	15

The number of heat exchangers is the same as the number of wells.

8. INSTALLATION AND MAINTENANCE

The question of whether to use multiple heat exchangers instead of a single unit is more a function of the building use than system design. Going to a multiple heat exchanger design always increases cost. In general, two exchangers should only be necessary in applications where system downtime cannot be tolerated (detention facilities, hospitals, computer facilities, etc.). The time required to disassemble and clean plate heat exchangers is a function of size and number of plates; but, in most applications, the work can be accomplished in less than 8 hours by two workers. Small units require less time and labor. This work can easily be accomplished during off hours in a building used less than 24 hours per day.

Protective shields for heat exchangers are typically included in quotes from vendors. These shields are installed over the plate pack and are intended to protect the plates from damage. Cost of the shields is approximately 3% to 5% of exchanger cost. Unless there is regular activity around the exchanger by personnel not associated with the mechanical equipment, these shields are not necessary.

Piping and location of the heat exchanger should be designed to allow easy access to the unit for disassembly and cleaning. If piping must be attached to the movable end plates (sometimes necessary in multi-pass designs), the piping should be of flanged or grooved end material which allows removal for maintenance purposes. Sufficient clearance should be allowed for plate removal from the frame.

It is useful to specify provision of at least one extra of each type of plate in the exchanger (with gaskets) for use by the owner during maintenance operations. Although it is not necessary to replace gaskets each time the exchanger is opened, should damage occur, the availability of the spare plates and gaskets would eliminate unnecessary downtime. For exchangers that use glue to attach the gaskets, standby plates should have the gaskets already glued in place. Most gasket glues require an 18 to 24 hour curing period before use. Pre-gluing the gaskets on the plates eliminates delay.

Maintenance personnel should be carefully instructed regarding plate cleaning and re-torqueing procedures. Metal brushes should be avoided for plate cleaning. Scratching of the plate surface can result in premature failure. If a metal brush is absolutely necessary, it should be of the same alloy as the plate (stainless brush for stainless plates). Re-torqueing the exchanger should proceed carefully adhering to the manufacturer’s tightening sequence and plate pack dimensions. Over torqueing can cause gasket failure.

9. COSTS

For most geothermal systems, the plate heat exchanger can constitute a large portion of the mechanical room equipment cost. For this reason, it is useful to have a method of evaluating the capital cost of this component when considering the system design.

Final heat exchanger cost is a function of materials, frame size and plate configuration.

Figure 9 presents a plot of plate heat exchanger costs in 1996 dollars/ft^2 of heat transfer area. Since heat transfer area takes into account duty, temperature difference and fouling, it is the most useful index for preliminary costing.

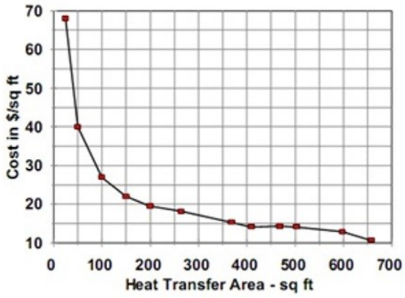

Fig.9. Plate heat exchanger cost for Buna-N Gaskets and 316 stainless steel plates

The data used to generate Figure 9 are from a number of manufacturer's quotes for various geothermal applications. The costs are based on 316 stainless steel plate construction and medium Nitrile gaskets.

10. CONCLUSION

Table 7 shows a comparison of heat exchanger versus separator output:

Table7. Vapor mass flow difference

Number of wells	turbine inlet pressure	enthalpy $^{kj}/_{kg}$	wells mass flow $\dot{m}(^{kg}/_{s})$	X	Separator vapor mass flow $\dot{m}(^{kg}/_{s})$	Heat exchanger vapor mass flow $\dot{m}(^{kg}/_{s})$	vapor mass flow difference $\dot{m}(^{kg}/_{s})$
NWS1	3.3	960	27.7	0.1785	4.944	6.7	1.756
NWS4	5.4	950	56.1	0.1415	7.939	12.1	4.161
NWS5	5.4	986	52	0.1587	8.251	11.18	2.929
NWS6	7	1156	52.09	0.222	11.57	14.5	2.93
NWS7	7	1189	57.65	0.238	13.72	17	3.28
NWS9	6.9	1093	40.54	0.1926	7.808	10.6	2.792
NWS10	7.1	1145	53.56	0.2157	11.55	15	3.45

In this table, output mass flow from the separator and heat exchanger enters the turbine, such that the higher mass flow rate, the more turbine output power. In consideration of the table, it can be seen that the exchanger transfers to the turbine at a higher mass flow rate. On the other hand, use of the separator would result in output vapor from the well entering the turbine directly. This vapor consists of several minerals, high chloride density, etc. which damage the turbine. With the heat exchanger, however, the hot vapor enters the turbine without damaging the turbine blades; this is because the well's output vapor heats the water without minerals. If a separator is selected, water management, system efficiency, gathering system, operational flexibility, and associated costs (foundations, assembly) are poor.

REFRENCES

Optimal configuration design for plate heat exchangers (Jorge A.W. Gut a, Jose M. Pinto)

Rafferty, K., 1993. "Direct-Use Geothermal Applications for Brazed Plate Heat Exchangers," Geo-Heat Center, USDOE Contract # DE-FG07-90ID 13040, Klamath Falls, OR

APV Company Inc., undated. "Heat Transfer Handbook," APVCompany Inc., Tonawanda, NY.

Alfa-Laval Inc, undated. "Plate Heat Exchangers".

Efird, K. D. and G. E. Moller, 1978. "Electrochemical Characteristics of 304 & 316 Stainless Steels in Fresh Water as Functions of Chloride Concentration and Temperature", Paper 87, Corrosion/78, Houston, TX.

Tranter Inc., undated. "Supercharger Plate and Frame Heat Exchangers", (sales literature, form SC4), Tranter Inc., Wichita Falls, TX.

Lund, J.W. (Ed.), 1998. Geothermal Direct-use Engineering and Design Guidebook. Geo-Heat Center, Oregon Institute of Technology, USA

Popovski, K., 1999. Direct Utilization of Geothermal Energy. Geo-Heat Center Oregon Institute of Technology, USA

www.wikipedia.com

"Fundamental of heat exchanger Design", Ramesh K. Shah, Dusan P. Sekulic.