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STEAM GENERATION FROM SEVERELY FOULING GEOTHERMAL BRINES

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ABSTRACT

The fluidized bed heat exchanger has been successfully applied for heat transfer applications involving severely fouling liquids, and can also be used in making clean steam from fouling geothermal brines. Overwhelming world wide interest confirms the potential of this technology.

This paper explains the principle of the fluidized bed heat exchanger, and compares it's fascinating new possibilities on steam generation with conventional technology.

1. INTRODUCTION

Over a period of more than twenty years, Dr. Klaren has developed a fluidized bed heat exchanger which is now being used to resolve severe fouling problems in a wide range of applications throughout the various industries.

Since 1982, the principle of this heat exchanger has proven to be successful in Iceland, where it is used to cool severely fouling geothermal brines for district heating purposes.

Due to the climatological situation, California and Mexico are not areas where geothermal brines can be utilized for district heating. However, for other applications there appears to be an overwhelming interest.

These applications refer to the evaporation of liquids at the shell side by cooling the geothermal brine in the tubes. In spite of the high fouling tendencies of many such brines, the fluidized bed heat exchanger has the potential to remain clean over long operating periods.

Evaporation of liquids at the shell side could apply to:

1) The production of steam for domestic purposes.

2) Evaporation of ammonia (NH_3) for low temperature power generation.

This paper will only discuss the first option, i. e. production of steam for domestic purposes.

Before discussing the benefits of this application, it is necessary to explain the fluidized bed heat exchanger.

2. PRINCIPLE OF THE FLUIDIZED BED HEAT EXCHANGER

2.1 INTRODUCTION

A typical configuration of a non-fouling fluidized bed heat exchanger is shown in figure 1.

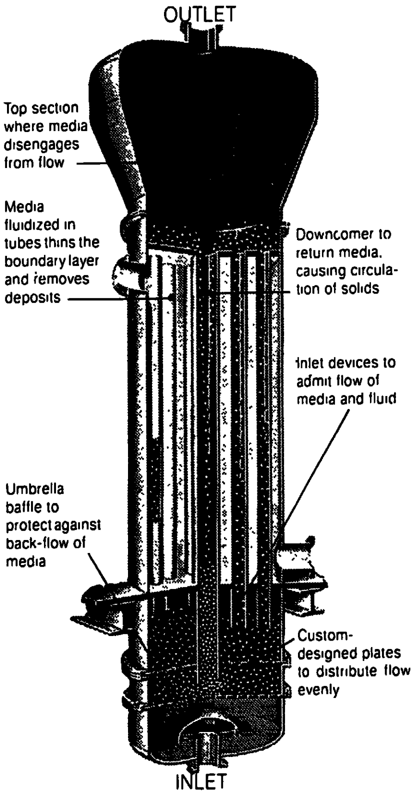


Figure 1: Fluidized Bed Heat Exchanger

The liquid which causes severe fouling at the surface of conventional heat exchangers is supplied to the inlet channel of the fluidized bed heat exchanger. A unique flow distribution system in the inlet channel provides for the uniform distribution of liquid and solid particles throughout the internal surface of the tube bundle.

The solid particles in the tubes are maintained in a fluidized state and exert a scouring or polishing effect on the wall of the heat exchanger tubes. Continuous agitation of the liquid boundary layer adjacent to the tube wall results in high levels of turbulence and stable (non-declining) heat transfer rates. The turbulent action at the tube wall also inhibits precipitation, as deposits are removed at an early stage and discharged with the liquid through the outlet channel. Within the outlet channel the solid particles disengage from the liquid and are returned to the inlet channel through a down comer tube (or tubes) and the cycle is repeated.

2.2 HEAT TRANSFER PERFORMANCE

A typical characteristic of the fluidized bed heat exchanger is it's ability to maintain an excellent wall-to-liquid film coefficient with a relatively low liquid velocity in the tubes. Operating with water, at a temperature level of approximately 100°C, the coefficients vary from 9,000 W/m^2 to 16,000 W/m^2 at liquid velocities from 0.25 m/s to 0.6 m/s. The selection of design velocity is heavily influenced by the size of the particles and the density of the particle material. Typical examples of particles often used are 2 or 3 mm glass spheres or chopped metal wire with a diameter (and equal length) of 2 to 3 mm.

Additional information concerning design details and theory on heat transfer characteristics of a fluidized bed heat exchanger are presented in references 1 and 2. These references also explain the various shell-side designs and numerous applications where this innovative heat exchanger has been applied.

2.3 PUMPING POWER REQUIREMENTS

Pumping power requirements to transport the liquid in the tubes and to maintain the particles in a fluidized state depend on the weight of the fluidized bed.

For glass particles the pressure drop associated with the bed height corresponds to approximately 0.2 m water column per meter of tube length; for steel particles this pressure drop will amount to 0.2 m water column per meter of tube length.

Due to the low velocities in the tubes, the total tube length is short and seldom exceeds 10 meters. Consequently, the total pressure drop through the tubes is quite modest and constant, even while operating under the most severe fouling conditions.

2.4 WEAR

Wear of the tubes and particle material has always been the subject of much attention, and has been investigated for different materials and various applications.

Stainless steel (304 and 316) and graphite have shown excellent wear resistance in many different industrial applications, even when the particles are made of highly abrasive chopped wire. As far as the particles are concerned, neither glass nor chopped metal wire have shown any signs of extensive wear. Proper design of the distribution system can prevent or minimize wear.

It may also be worthwhile to state at this time that since the wall is cleaned by the scouring action of the particles, the particles also clean themselves and remain free of any deposits.

THE FLUIDIZED BED HEAT EXCHANGER IN GEOTHERMAL APPLICATIONS

3.1 HISTORY

The first contact with geothermal application dates from 1982. In that year the first two tests at different geothermal sites in Iceland were carried out. Both tests were successful, and as a result the fluidized bed heat exchanger is now wildly accepted in Iceland.

It was discovered in Iceland that cooling of some of the geothermal brines resulted in heavy silica deposits being formed on the heat transfer surface. It is not uncommon for a conventional heat exchanger to become fully blocked with deposits in a couple of days, after having lost its thermal efficiency in a matter of hours.

Figure 2 shows a piece of stainless steel which was kept in geothermal brine for approximately 100 hours resulting in a silica scale of 2 mm thickness.

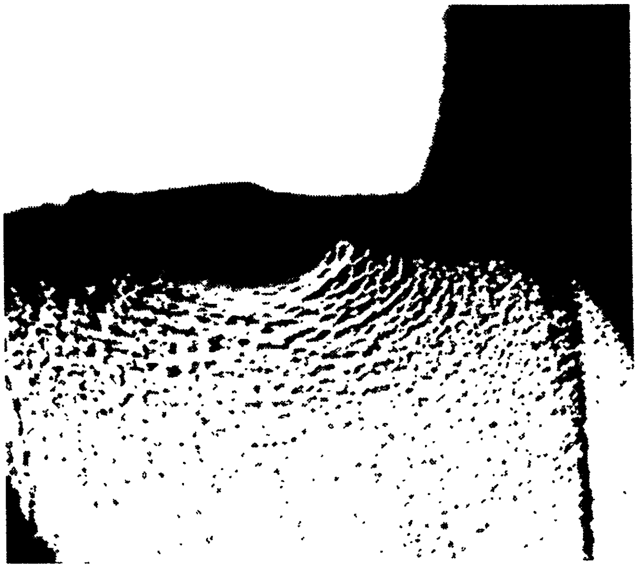


Figure 2: Silica scale formed in Geothermal Brine

Figure 3 shows the clean inside surface of the tubes of an experimental fluidized bed heat exchanger which has operated on the same brine for many thousands of hours.

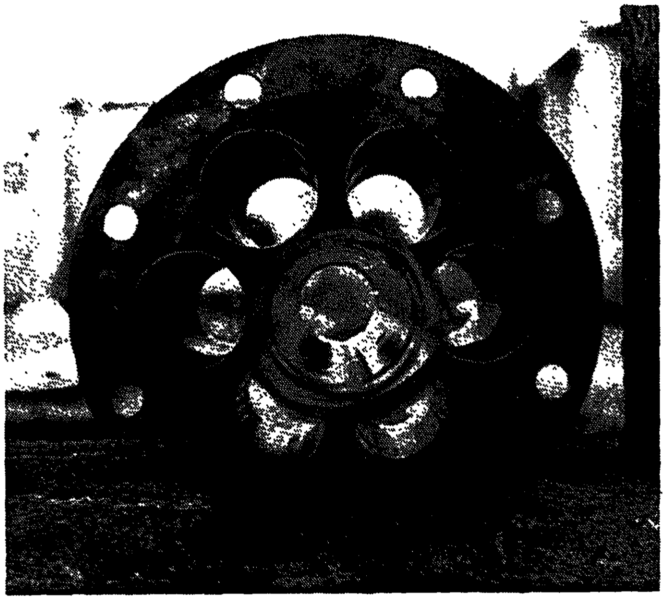


Figure 3: Fluidized Bed Heat Exchanger operating on Geothermal Brine

Figure 4 shows two fluidized bed heat exchangers at a large testing site and delivered to Iceland in 1984.

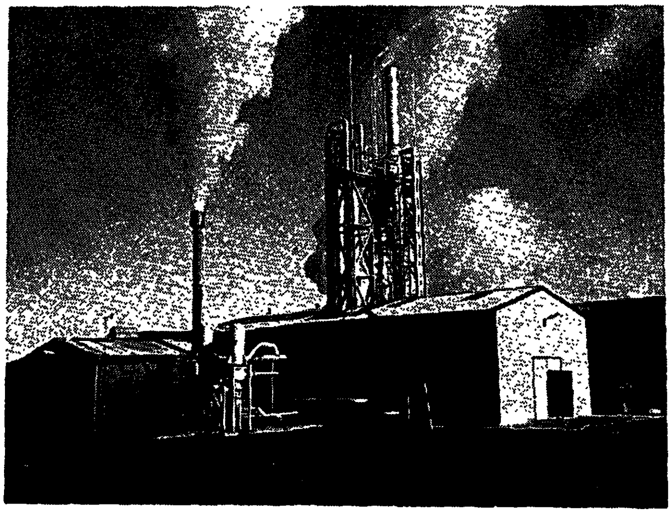


Figure 4: Fluidized Bed Heat Exchangers operating on Geothermal Brine in Iceland

In 1990, the last two fluidized bed heat exchangers were put into operation in Nesjavellir for the Reykjavik District Heating Company (Hitaveita Reykjavikur), see also reference 3. These exchangers cool 16.67 Kg/S of severe fouling brine from 198°C to 30°C. At the shell-side 50 Kg/S of well water is heated from 40°C to 50°C.

Overall,heat transfer coefficients average 27.50 W/m^{2}K and a reduction of these values due to fouling has not been observed.

The cooled brine is discharged on the porous lava near the site. Re-injection of the cooled brine is not preferred because the re-injection holes might become clogged by the scraped off deposits and the chemical reactivity of the brine caused by it's potentially slight super-saturation, which then could produce still more deposits on the way down the re-injection holes.

3.2 CURRENT SITUATION

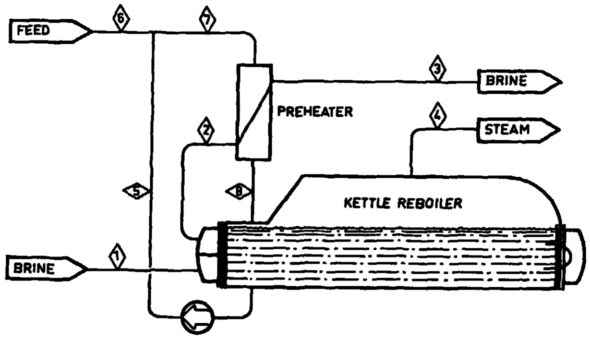
A Mexican company is involved in the investigation of various plans which could result in a better and more efficient utilization of the geothermal brine in one of the Mexican fields.

One of their ideas is based on the application of fluidized bed heat exchangers for the production of steam for domestic purposes by cooling geothermal brine.

However, before they considered the fluidized bed heat exchanger, they first evaluated their ideas based on existing and conventional technology. Therefore, they planned to use a conventional kettle re-boiler for the production of 1.74 Kg/S of steam per hour of 9.6 Bar and 178.3°C while cooling 59.44 Kg/S geothermal brine at a pressure of 13.2 Bar from 192.2°C to 178.9°C.

In series with the kettle re-boiler a preheater is required for heating 1.74 Kg/S of steam condensate from 90.6°C to 178.3°C by cooling the total geothermal brine flow (i.e. 59.4 Kg/S) further from 178.9°C to 176.5.°C.

Figure 5 explains this conventional design.



	1	2	3	4	5	6	7	8
FLOW Kg/s	59.44	59.44	59.44	1.74	13.4	1.74	45.14	1.74
TEMPERATUUR °C	192.2	178.9	176.5	178.3	178.3	90.6	168.2	178.3
PRESSURE BAR	13.2	-	-	9.6	>9.6	>9.6	>9.6	>9.6

Figure 5: System with conventional reboiler

According to the above plans, the steam is produced at a higher pressure than strictly required for domestic purposes. This is necessary to maintain, in the re-boiler, brine temperatures above the temperature where fouling can be expected by the precipitation of solids dissolved in the brine. For this re-boiler a "lowest brine temperature" near the tube-wall of

$$\frac{178.3^\circ C + 178.9^\circ C}{2} = 178.6^\circ C$$

will occur during normal operation.

In the preheater the brine will be even lowered further in temperature. Taking into account a condensate inlet temperature of 168.2°C and a brine outlet temperature of 176.5°C a "lowest brine temperature" near the tube-wall during normal operation of

$$\frac{176.5^\circ C + 168.2^\circ C}{2} = 172.4^\circ C$$

can be expected.

Considering the fact that the re-boiler has been designed for a very close approach in temperatures, there appear to be serious fear for scale at brine temperatures lower than 178.6°C. The preheater operates at even lower brine temperatures. As a consequence it could be necessary to install two preheaters in parallel one of which is operational while the other is being cleaned.

From the above, it follows that a conventional system remains sensitive to fouling, which becomes more of a problem if the brine is cooled to lower temperatures.

Figure 6 explains the system based on the fluidized bed technology. Preheater and evaporator (re-boiler) are integrated in one single vertical fluidized bed heat exchanger with an overall height of approximately 12 meters.

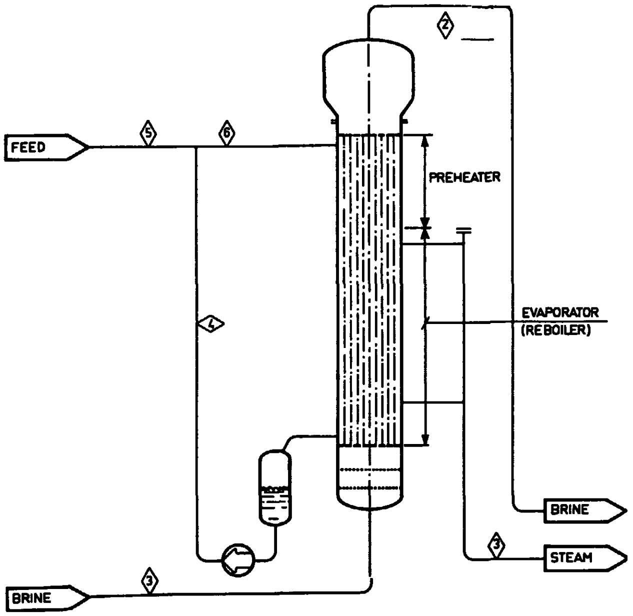


Figure 6: System with Fluidized Bed reboiler

	1	2	3	4	5	6
FLOW Kg/s	42.74	42.74	1.69	11.04	1.69	12.73
TEMPERATUUR °C	192.2	170.3	160.0	160.0	90.6	150.8
PRESSURE BAR	13.2	10.0	6.2	>6.2	>6.2	>6.2

At the shell-side, preheating and partial evaporation takes place from a circulating flow of condensate which runs down the tubes as a falling film and amounts to 12.73Kg/S. The condensate feed to the system corresponds to 1.69 Kg/S at 90.6°C and equals the steam production of 1.69 Kg/S at a pressure of 6.2 bar and a temperature of 160.0°C based on the same heat load of 3,500 kW as for the conventional design.

Steam pressure corresponds to the value required for domestic purposes. Because the brine experiences a larger temperature drop from 192.2°C to 170.3°C, only 42.74 Kg/S of brine is required for a steam production of 1.69 Kg/S which corresponds to the heat load of 3,500 kW.

In comparison with the conventional design, this corresponds to a reduction of the brine flow of :

$$\frac{59.44^\circ C - 42.74^\circ C}{59.44^\circ C} \times 100\% = 28\%$$

which explains the better utilization of geothermal brine in fluidized bed systems compared to conventional technology.

In case even lower steam pressures would be sufficient, much larger savings on brine could be achieved.

The larger temperature drop of the brine in the fluidized bed exchanger gives a much lower "lowest brine temperature" near the tube-wall of the re-boiler section of:

$$\underline{160.0^\circ C + 173.7^\circ C} = 166.8^\circ C$$

compared to 178.6°C for the conventional design.

For the preheater section of the fluidized bed exchanger, the lowest brine temperature near the tube-wall is:

$$\frac{170.3^\circ C + 150.5^\circ C}{2} = 160.4^\circ C$$

compared with

$$\frac{176.5^\circ C + 168.2^\circ C}{2} = 172.4^\circ C$$

for the conventional design.

In spite of lower brine temperatures near the tube-wall, the fluidized particles in the tubes, which for this particular application consist of cut metal wire with a diameter equal to length of 2.0 mm, prevent the tubes from fouling.

For both designs the cooled brine is not re-injected, but discharged in ponds for similar reasons already explained in sub-paragraph 3.1.

3.3 COMPARISON OF CONVENTIONAL VERSUS FLUIDIZED BED DESIGN

Table 1 presents a detailed comparison of both designs.

	UNITS	CONVENTIONAL DESIGN	FLUIDIZED BED DESIGN
AMOUNT OF STEAM PRODUCED	Kg/s	1.74	1.69
STEAM PRESSURE	BAR	9.6	6.2
STEAM TEMPERATURE	°C	178.3	160.0
BRINE FLOW	Kg/s	59.44	42.74
INLET TEMPERATURE OF BRINE	°C	192.2	192.2
OUTLET TEMPERATURE OF BRINE	°C	176.5	170.3
REBOILER			
HEAT LOAD	kW	3508	3508
LOG. MEAN TEMPERATURE DIFFERENCE	°C	4.2	19.3
OVERALL HEAT TRANSFER COEFFICIENT	W/m^2K	1158	3304
SURFACE AREA	m^2	716	55
LOWEST BRINE TEMPERATURE NEAR THE TUBE-WALL	°C	±178.6	±166.8
PREHEATER			
HEAT LOAD	kW	635	646
LOG.MEAN TEMPERATURE DIFFERENCE	°C	2.9	14.7
OVERALL HEAT TRANSFER COEFFICIENT	W/m^2K	1500	2585
SURFACE AREA	m^2	145	17
LOWEST BRINE TEMPERATURE NEAR THE TUBE-WALL	°C	±172.4	±160.4

Table 1: Comparison of conventionsl design versus Fluidized Bed design

The fear for fouling caused by scale formation on the tube-wall pushes the conventional design into a direction where actually the steam is generated at a higher pressure than required.

Only this approach guarantees sufficiently high brine temperatures which then should prevent the system from fouling. However, it also requires a larger brine flow for the same heat load.

Considering the fact that after passage through the re-boiler, the cooled brine is discharged in ponds and therefore wasted, the conclusion is evident that the fluidized bed system utilized the brine more efficiently because it requires less to achieve the same goal.

The consequences of the above approach are devastating with respect to the installed heat transfer surfaces required for the conventional design. This is primarily due to the differences in logarithmic mean temperature difference between both designs, and to a certain extent by the better heat transfer mechanisms for the fluidized bed system which are not affected by fouling factors at the brine-side.

Of course, for the conventional design there is always the possibility to increase the brine outlet temperature while maintaining the same heat load and so improving the logarithmic temperature difference. However, this means more brine is required and is contradictory to the efficient use of the brine.

For the fluidized bed design all brine temperatures are lower. Because deposits are removed by the scouring action of the particles, fouling of the tubes is very unlikely.

Considering the experiences in Iceland, it is very possible that far lower brine temperatures can be handled in fluidized bed exchangers. This could make the difference in potential between conventional technology and fluidized bed technology even greater.

4. CONCLUSION

This article explains the non-fouling fluidized bed heat exchanger when applied as a re-boiler for the generation of steam by cooling severely fouling geothermal brines.

Any comparison with conventional technology is in favor of the fluidized bed exchanger.

It is very likely that the fluidized bed technology offers new exciting possibilities for a broader and more efficient use of severely fouling geothermal brines.

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BIOGRAPHICAL INFORMATION

Dick G. Klaren is the Director of ESKLA BV in the Netherlands. He obtained his technical education in the Netherlands, The Federal Republic of Germany and the United States. In 1975 he received his Doctorate Degree from Delft University for a thesis in which he explained the principle of the fluidized bed heat exchanger for applications involving severe fouling liquids. His innovative work in this field has resulted in numerous publications and more than 100 patents granted in twenty countries. Currently Dr. Klaren is responsible for the continued program of research and development associated with the non-fouling fluidized bed exchanger and related technologies and marketing support.