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EFFECT OF FOULING AND CLEANING ON THE THERMAL PERFORMANCE OF WELDED PLATE HEAT EXCHANGER IN AN OFFSHORE REBOILER APPLICATION

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ABSTRACT

The thermal and service performance of a forced circulation reboiler in the MEG regeneration unit was tested. The tests were performed using a welded plate heat exchanger (GEABloc with double-dimple plates) at non-fouling and fouling conditions. Fouling was induced by adding salts to the MEG solution that precipitate as $CaCO_3$. The reboiler could be scaled with water-salt solution at lower initial $CaCO_3$ super-saturation ratio, over many days to build a uniform $CaCO_3$ layer. Subsequently MEG regeneration test was performed over scaled heat exchanger. The scaling test was performed with minimum MEG flow of 4.0 m^3/h and maximum hot oil flow of 9.5 m^3/h. More deposits were formed on the plate pack of the reboiler which caused the performance of the unit to decline. The overall heat transfer coefficient (OHTC) was decreased from 246 W/m²C to 234 W/m²C while the surface margin was decreased from 26.7% to 5.1%.

INTRODUCTION

Heat transfer equipment plays a significant role in the oil and gas production and processing. For many years the standard shell and tube heat exchangers (S&T) were the only reliable and suitable for these applications (Nesta and Bennett, 2005). However, over the last three decades this view has changed. Alternative technologies consisting mainly of plate heat exchangers (PHE) have entered the market and solidified their successful benefits. Today, in offshore applications, PHE technology is highly established and must not be ignored.

Since the end of the 1980s, welded plate heat exchangers have taken over various operations in oil and gas applications. They proved to be highly favorable for several reasons (Bani Kananeh and Peschel, 2012):

- Highly compact, reduced dimension (footprint and height).
- Higher heat transfer coefficients, enhance thermal efficiency.
- Higher turbulence and wall shear stress (self-cleaning effect), lower tendency to fouling
- Relatively easy and fast to clean and repair, lower maintenance costs.

A welded plate heat exchanger, GEABloc, is used in the oil and gas sector. One of these applications is in the mono-ethylene glycol (MEG) regeneration system. MEG used for hydrate inhibition in closed loop pipelines will gradually become contaminated. If the impurities are not treated and removed in a controlled manner, regular replacement or continuous maintenance becomes necessary in order to avoid excessive scaling and corrosion in the regeneration and injection systems. A conventional MEG regeneration system that simply boils off water and skims off hydrocarbons results in all of the other pollutants accumulating in the MEG. The MEG will then become saturated with these components and precipitation will commence, beginning with scaling, which takes place on heated surfaces (like heat exchangers) and at the injection point. This causes operational problems and the need for cleanout of the system, which results in frequent shutdowns. As a worst case, gas production may be affected (Haque, 2012). The recycle heater uses usually S&T and spiral-type heat exchangers to heat the high-flow salty recycled MEG (Nazzer, 2006). However, a GEABloc welded PHE operates the same application yet with three to five times higher wall shear stress values. Consequently, it lowers fouling rate, minimizes maintenance costs, extends service intervals and increases the heat exchanger's availability.

The objective of the project is to test the thermal and service performance of a forced circulation reboiler in the MEG regeneration unit. The experiments are performed with a welded plate heat exchanger (GEABloc with double-dimple plates).

PROCESS DESCRIPTION

The tests were done in a MEG Reclaimer Pilot Plant, but the conditions were selected to simulate a MEG reboiler. The plant is not equipped with a distillation column or an outlet for lean MEG product. It was run with circulation through the heat exchanger and the flash separator, with evaporation of MEG and water and a rich MEG feed that resulted in ca. 90 wt% MEG in the circulated liquid at steady state conditions. The reclaimer was run at a vacuum pressure of about 0.95 bara. The reclaimed MEG vapors were condensed in a vapor condenser and then pumped back to the lean glycol side of glycol regeneration. The schematic of the process used for performing the experiments is shown in Figure 1.

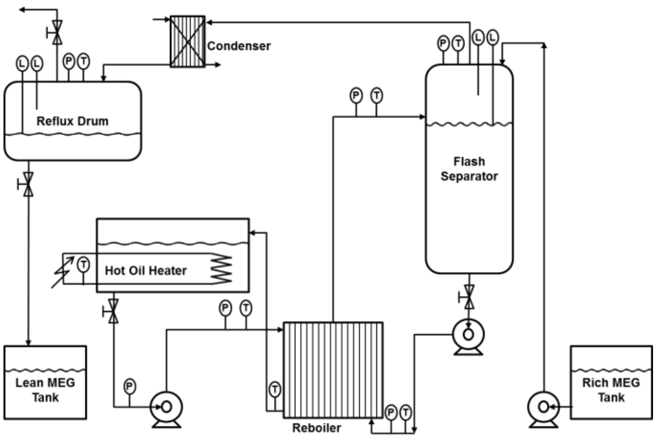

Fig. 1 Process flow diagram for MEG regeneration with PHE reboiler (Fjords Processing AS).

The reboiler is a welded plate heat exchanger (GEABloc) with double-dimple plates. The basic design of GEABloc is illustrated in Figure 2. The unit has 80 plates with 8 passes on the hot oil side and one pass on the MEG side. MEG solution flows in vertical channels in order to reduce pressure drop.

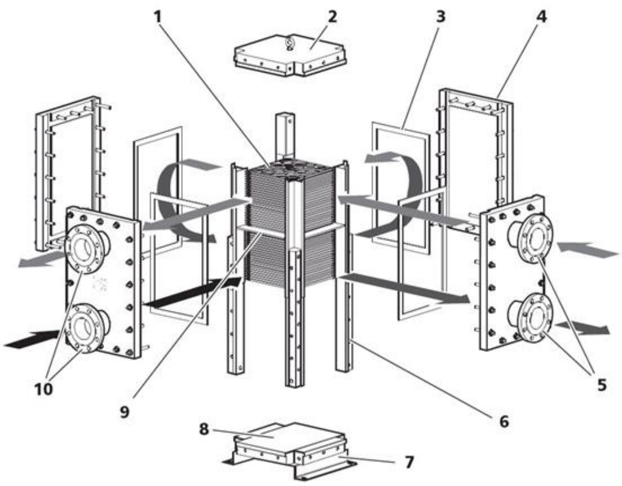

Fig. 2 GEABloc welded plate heat exchanger reboiler. 1 Plate pack, 2 Top head, 3 Panel gasket, 4 Panel, 5 Primary side connection, 6 Column, 7 Support, 8 Bottom head, 9 Baffle/guide plate, 10 Secondary side connection. (GEA Ecoflex GmbH)

GEABloc plate heat exchanger is constructed of welded heat transfer plates. The individual plates are TIG (Tungsten Inert Gas) welded alternately on the two longitudinal sides and at the corners. The two pressure-resistant channels are separated from one another inside the unit, with a special design at the corners. The plate pack is installed between four columns, four bolted panels and the top/bottom head plates, thereby forming a compact plate heat exchanger with two circuits. In the plate pack, the media flows in cross flow direction. The entire unit consists of a counter-current flow arrangement. Furthermore, the heat transfer plates are corrugated to induce high turbulence and minimize fouling. The turbulent flow creates high shear stress on the walls, which in turn, literally scrubs deposits and fouling from the heat transfer surface. This is also known as the 'self-cleaning effect'. Consequently, the lowered fouling rate minimizes maintenance costs, extends service intervals and increases the heat exchanger's availability.

The double dimple plates create a unique tubular profile which is easy to clean. They are needed for high volume flows with low pressure drop, viscous fluid or for fluids with high fouling tendency as they can be easily cleaned. Figure 3 shows the view through the double-dimple plate pack. These corrugations offer sufficiently large spaces; high-pressure cleaning is possible from any direction.

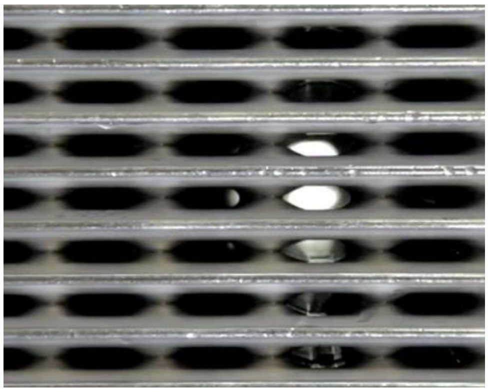

Fig. 3 GEABloc double dimple plates.

The performance of the heat exchanger was tested with approximately 90 wt% MEG at non-fouling and fouling conditions. The theoretical boiling temperature for a salt free solution is about 135°C. Fouling was induced by adding salts that precipitate as $CaCO_3$. The scale tests were performed with a solution composed of 90 wt% MEG (salt free basis), 10 wt% water and various amounts of $CaCO_3$. The pressure was maintained at ca. 0.95 bara by a vacuum pump placed downstream the condenser. The cold side was heated using hot oil (Therminol 55) at an inlet temperature of about 155°C. After certain time of operation, the heat exchanger was opened for inspection and cleaning. The panels were dismantled and the plate pack was cleaned using a weak acid solution. The scaling was followed by analyses of alkalinity and Ca^{2+} concentration. The alkalinity was determined by acid titration and Ca^{2+} concentration by EDTA titration.

The inlet and outlet temperatures on both sides were measured using Pt-100. All Pt-100 elements used for temperature readings in the tests were calibrated before the tests. The volumetric flow rate on the hot oil side was measured using a vortex flow meter while the inlet flow rate on the MEG side was controlled by a calibrated pump which is frequency controlled. The vaporization rate from the reboiler was calculated from the measured condensate mass out of the condenser divided by time. The inlet pressure on both sides was measured using pressure transmitters and the differential pressure on the cold side was also measured.

It is to be mentioned here that the tests were performed under oxygen free conditions in order to avoid any corrosion problems.

RESULTS & DISCUSSION

The heat exchanger was firstly tested at non-fouling conditions, on one hand to compare the performance of the heat exchanger to the design conditions and on the other hand, to compare the performance of the heat exchanger to the scaling conditions.

The first scaling test was performed for 5 days with continuous addition of $CaCO_3$. The Ca^{2+} was added in the MEG feed while the CO_3^{2-} was added as a 15wt% Na_2CO_3 solution in water. In total up to 20 wt% of calcium carbonate has been added. On the last day an increased pressure drop was observed on the MEG side. The heat exchanger was opened for inspection and some deposits of calcium carbonate were found (everything what is white on the plate pack), as can be shown in Fig. 3. In the middle of the heat exchanger is one bigger crystal. It is turned out to be the only big crystal which was found in the whole exchanger.

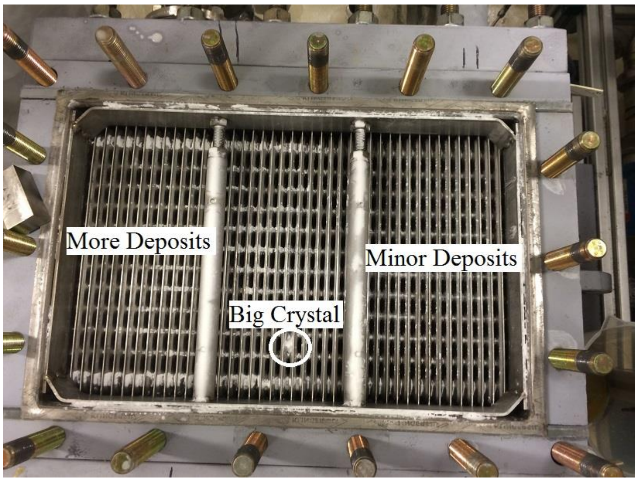

Fig. 3 Deposits formed on the heat exchanger plate pack.

More $CaCO_3$ deposits were accumulated on left side of the plate pack than on right side. This can be explained due to the higher wall temperature where the hot oil inlet is. In Figure 4, more deposits on the panel in the area at the hot side inlet can also be seen.

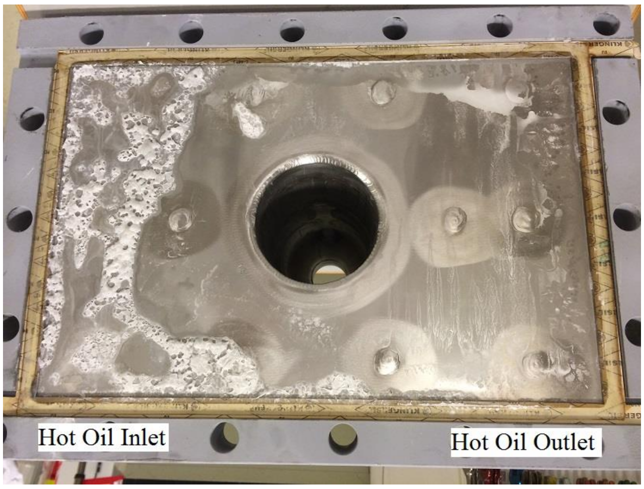

Fig. 4 Deposits formed on the heat exchanger panel.

As a result, the deposits were not enough to make any valid conclusions. This can be due to the fact that most of the precipitation happened in the bulk of the liquid. As long as particles will be present in the bulk of the liquid it would be difficult to scale the heat exchanger.

The heat exchanger was cleaned using an acid solution and a second test run was performed but not with MEG. Otherwise, the heat exchanger was firstly pre-scaled. The pre-scaling was performed with water solutions. Water-salt solution ($CaCl_2.2H_2O$ and Na_2CO_3 solution) was discarded many times and for longer time from the process side (heat exchanger and tank) to limit the bulk particle formation and particle growth at the expense of scaling. The pre-scaling period was 4 weeks and was run continuously during day time. The bulk fluid temperature was set to about 40 °C. The temperature was then increased to get a faster scaling rate. At first the temperature was only increased during day time, but after 17 days it was attempted to run continuously, first at 60, then at 75, 80, 85 and 90 °C. The heat exchanger was opened at the end of the test and there was evident scaling. The plate pack was covered uniformly with about 0.5 mm deposits layer as shown in Figure 5. XRD analyses showed that it was $CaCO_3$.

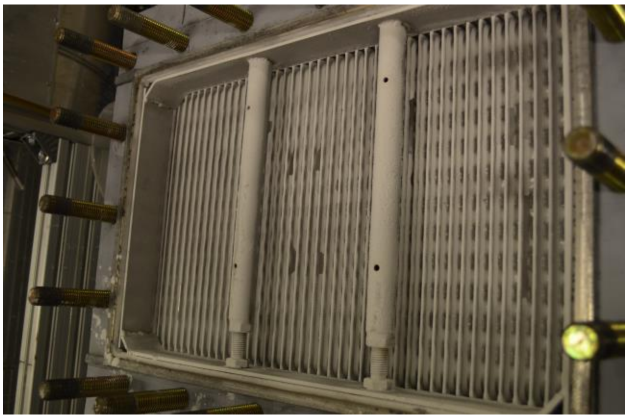

Fig. 5 Deposits formed on the heat exchanger plate pack after water-salt scaling.

The scaled reboiler was then tested with 25% MEG in the feed in order to maintain the MEG concentration in the reclaimer at about 90 wt%. The scaling rate was increased by increasing the wall temperature on the MEG side. This could be achieved by increasing the hot oil flow rate to maximum and decreasing the MEG flow rate to minimum such that the MEG side coefficient falls relative to the oil side coefficient. Test was performed with flows of 4.0 m^3/h on the MEG side and 9.5 m^3/h on the hot oil side. The test was run for 7.75 hours. More deposits were formed on the plate pack as can be seen in Figure 6.

Fig. 6 Deposits formed on the heat exchanger plate pack after MEG solution scaling.

It can be clearly seen that quite a bit of scale has been removed, possibly due to thermal effect on the material and shear due to flow. The reboiler was cleaned with an acid solution and Figure 6 shows the plate pack after acid wash. The plate pack seems to be very good after the scaling tests and no corrosion was observed.

Fig. 7 Heat exchanger plate pack after acid wash.

The non-fouling results are compared to fouling results in Table 1. Deposits accumulated inside the heat exchanger channels caused the performance of the unit to decline. The overall heat transfer coefficient (OHTC) as well as the surface margin was decreased. This can be explained due to thermal resistance of the scaled layer accumulated over the plates.

Table 1. Performance of reboiler under non-fouling and fouling conditions

	Non-fouling	Fouling
MEG flow rate (m3/h)	4.0	4.0
Hot oil flow rate (m^3/h)	9.5	9.5
OHTC (W/m²C)	246	234
Surface margin (%)	26.7	5.1

CONCLUSIONS

1. GEABloc plate heat exchanger with double dimple plates was used as a reboiler in the mono-ethylene glycol (MEG) regeneration pilot plant system. With its free-flow channels cleaning-in-place of the plate pack was successfully conducted.
2. The performance of the reboiler was tested with MEG solution at non-fouling and fouling conditions. Fouling was induced by adding salts that precipitate as $CaCO_3$.
3. Scaling of the reboiler could be achieved by building a uniform $CaCO_3$ layer in water at low supersatuation ratios for $CaCO_3$ and subsequently by running the test under MEG regeneration mode by recycling the MEG solution.
4. The overall heat transfer coefficient (OHTC) was decreased from 246 W/m²C to 234 W/m²C while the surface margin was decreased from 26.7% to 5.1%.

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