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EMBAFFLE[®] HEAT EXCHANGER IN FOULING OPERATION

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ABSTRACT

EMbaffle Technology is a patented shell and tube heat exchanger technology, originated by Shell Global Solutions International. The technology was originally developed for fouling abatement of crude preheaters.

In fouling services, dead zones of the conventional segmental baffle design reduce the performance of the exchanger with pressure drop increasing during operation.

In the EMbaffle design the tubes are supported by a grid, allowing the fluid to flow parallel to the tubes, thus avoiding dead zones. This has resulted in significantly higher performances. EMbaffle technology is applied in many different crude unit applications. This article presents two cases of performance monitoring of EMbaffle technology in crude units, the 2-pass shrouded design and the 3-pass design. The design, installation, performance monitoring, clean-out and condition monitoring are discussed.

INTRODUCTION

EMbaffle technology was originally developed to enhance the shell side heat transfer and to reduce fouling in heat exchange applications in refineries and petrochemical plants. By creating a uniform flow in the bundle dead zones are omitted. By supporting the tubes using expanded metal grid (fig. 1, 2) the boundary layer is continuously reduced due to the cross flow component initiated by the shape of the grid and due to the local increased velocity due to the reduced flow area in the grid (fig. 3), thus enhancing the heat transfer (Oakley, S et al, 2009). Extensive CFD analysis and research in test facilities of both HTRI and TUV-NEL have been executed to derive the heat transfer and pressure loss correlations which are now embedded in HTRI's Xist. Analysing the data from clean fluid cases show higher heat transfer rates and lower pressure losses at similar velocities compared to segmental heat exchangers.

Through this approach the balance between fouling disposition and removal will result in a lower fouling layer than in conventional heat exchangers. Increasing the number of baffles will lead to further fouling reduction. The hydraulic resistance is significantly reduced as the fluid flow has no turns to make. This allows for design optimization. The technology was patented by Shell Global Solutions International BV, further improved by EMbaffle BV and is now part of Brembana & Rolle Group.



Fig. 1 Expanded metal grid that allows parallel flow with boundary layer reduction



Fig. 2 Design of the EMbaffle heat exchanger



Fig. 3 Disturbance of the boundary layer by the EMbaffles

FOULING MONITORING OF EMBAFFLE TECHNOLOGY IN CRUDE UNITS

The purpose of this article is primarily to share the experience with the EMbaffle technology in fouling applications. The performance comparison of the different technologies by both OHTC and fouling rate over time are presented.

The fouling model has the following form:

$$U(t) = U_{\infty} + (U_0 - U_{\infty}) \cdot e^{-\left\lfloor \frac{t - t_0}{t_f} \right\rfloor}$$
(1)

The fouling factor is derived from:

$$R(t) = \frac{1}{U(t)} - \frac{1}{\alpha_i} \cdot \frac{d_o}{d_i} - \frac{d_o}{2 \cdot \lambda} \cdot \ln(\frac{d_o}{d_i}) - \frac{1}{\alpha_o}$$
(2)

The U is derived from the measured Overall Heat Transfer Coefficient using:

$$U(t) = \frac{Q(t)}{A \cdot \Delta T_{\text{ln}}} \tag{3}$$

$$Q(t) = m(t) \cdot C_p \cdot \left(T_{out} - T_{in}\right) \tag{4}$$

The wall heat transfer coefficient α , derived from the design value, is compensated for differences in flow, with the Prandl number is small and where the shell side factor (0.6) is used to be able to compare with the conventional shell side heat transfer, so

$$\alpha_{i}(t) = \alpha_{i,design} \cdot \left(\frac{m_{i}(t)}{m_{i,design}}\right)^{0.8}$$
⁽⁵⁾

and

$$\alpha_o(t) = \alpha_{o,design} \cdot \left(\frac{m_s(t)}{m_{s,design}}\right)^{0.6}$$
(6)

PERFORMANCE MONITORING IN PLANT APPLICATIONS

Although the EMbaffle technology has been applied in different crude units, for a number of reasons the performance of only a few applications have been analysed.

Sufficient process data are needed and often not enough data points are available.

Lack of data available is one of the major difficulties in performance monitoring of heat exchangers in fouling services, as instrumentation is designed to operate the plant and not to monitor the performance. Usually this is resolved by filling in the missing data using mass and heat balance over sections or over the complete unit, which introduces measuring errors. (Partly) evaporation in some of the exchangers may increase the challenge in closing the mass and heat balances. Also instrumentation may deviate away from its calibrated value or even stop functioning during a certain period of time. In some cases installing additional instrumentation may solve this issue, but at serious costs. Also the use of a high end software tool enables enhanced data reconciliation (Hoeve et al, 2007) and analysis.

Further a good comparison with the conventional heat exchanger is needed. Ideally a conventional and a novel technology are operated in pure parallel flow where velocities are maintained at the same level. Just installing both the segmental and the EMbaffle heat exchanger in parallel would mean insufficient data to distinguish between the two exchangers. Also due to the different pressure loss flow adjustment will be needed. Alternatively the two technologies are compared in two sequential runs in time.

Finally the fluid properties should be known. In practice crudes are blended and properties may change over time. Apart from instrumentation, also the crude composition may have changed when comparing exchangers in different runs.

In contrast to this, the fouling is monitored over a longer period and comparison is more pointing to a trend than concluding on strict numbers.

In the past years we have been able to study a few cases. Two of the monitored cases will be further explained in this article.

CASE EMBAFFLE IN CRUDE PREHEATER: SHROUDED DESIGN

In this case the segmental baffled bundle was replaced by the EMbaffle bundle. No modifications to the existing shell neither to the piping were made (Mulder et al, 2005). The design was optimised to a two shell side pass design (fig. 4). Since the shell was designed for a single shell side bundle (E-shell), the 2-pass bundle was shrouded to guide the fluid from shell inlet to the bundle inlet at the opposite side of the exchanger. The shrouded design resulted in around 20% lower available heat transfer surface (fig. 5).

To be able to compare the performance with the conventional technology the following adjustments were made:

- Physical adjustment of the shell side velocity by throttling the valve. Due to the lower shell pressure loss the flow increase would prevent a proper comparison.
- Numerical adjustments of the tube side velocity as the number of tube passes were reduced for unit pressure constraints. (using Eq. 5)
- Numerical adjustment of the heat transfer area in the OHTC calculation



Fig. 4 Two pass design under construction



Fig. 5 Insertion of the shrouded EMbaffle exchanger in the existing shell

This resulted in the OHTC plots as shown in figure 6 and figure 7.



Fig. 6 OHTC plot for the segmental baffle heat exchanger bundle



Fig. 7 OHTC plot for the EMbaffle heat exchanger bundle

The results show a higher performance and a lower fouling rate of the EMbaffle compared to the segmental run. To compare the performance of the 2 cases the method of optimum clean out time is used where the optimum run time of the heat exchanger is based on cost evaluation, i.e. cost of decreased performance versus the cost of a clean-out. This results in an almost twice longer optimum run time for the EMbaffle (fig 8).



Fig. 8 Optimum clean-out frequencies of the segmental and the EMbaffle technology

Also the fouling was evaluated, using the method described above. The large variation in the early phase of both the segmental as of the EMbaffle run is reflected in the first part of the fouling plot. On the longer run the fouling of the EMbaffle is increasing relatively slowly (fig 9).



Fig. 9 Comparison of the fouling factors of the EMbaffle and the segmental baffle heat exchangers

CASE EMBAFFLE IN CRUDE PREHEATER WITH 3-PASS DESIGN

The shell-side 2-pass design was optimized into the shell-side 3-pass design to utilise the available pressure loss, to increase the heat transfer area (by filling the available shell area with tubes) and also to allow bundle replacement in E-shells with no shell or piping modification (fig. 10).

This resulted in only a few percentage of lower heat transfer area compared to the segmental baffle design, while maintaining the shell side velocities. The tube side pass number remains unchanged to the segmental design.

The higher shell velocities result in a further reduction of the fouling layer.

The reviewed case was a good opportunity, as this section of the crude preheat train was equipped with sufficient instrumentation to allow performance analysis.



Fig. 10 Three pass design under construction

The graphs in figure 11 show the OHTC values of both the EMbaffle and the segmental run.



Fig. 11 OHTC comparison of the segmental and the EMbaffle technology



Fig. 12 Fouling rate comparison of the segmental and the EMbaffle technology

The fouling of the segmental heat exchanger at the start of the run is higher than 0, indicating that the bundle performed at start lower than the design value, possibly due to insufficient clean-out or different crude properties (fig. 12). The data are taken from two sequential runs and no information is available of the clean-out of the bundle prior to this run.

The fouling rate of the EMbaffle bundle starts as expected and slowly progresses. A start of the fouling at 0 would show the difference in trend between the 2 technologies.

CLEANING

The cleaning method for EMbaffle bundles is the same as used for the conventional bundles with similar clean-out times and results. Many clean-outs have been attended to understand the impact of the clean-out process. With modern clean-out equipment allowing manipulating of bundle and cleaning nozzle in all positions, the EMbaffle bundle is cleaned well. This was supported by boroscope inspection. The pictures below show shell side clean-out of the 2-pass shrouded design. (fig. 13, 14)



Fig. 13 Cleanout of the 2-pass shrouded EMbaffle design



Fig. 14 Result of the cleanout. EMbaffle bundle after cleanout.



Fig. 15 Inspection of the 2-pass bundle

CONDITION ASSESSMENT

The condition of the EMbaffle heat exchanger has been assessed over the years. Potential risks such as damage or failure of components have been identified and analysed. Mechanical analyses show the feasibility of grid in baffles of 2 meters diameter and above.

Field inspection included visual and boroscope inspection and eddy current testing (fig. 15). No tube or grid failure or damage was detected.

CONCLUSION

The performance of the EMbaffle has benefits over the segmental design. In all aspects, performance, clean-out and condition the technology has shown to be proven over the years.

NOMENCLATURE

- A heat transfer area $[m^2]$
- C_p heat capacity [J/kg]
- *d* tube diameter [m]
- m(t) mass flow as a function of time [kg/sec]
- m_{design} mass flow of the rated exchanger [kg]
- Q(t) heat transferred as a function of time [W]
- R(t) actual fouling as a function of time [m² K/W]
- t_f fouling rate [days]
- *t* variable time
- t_0 start time of the run
- ΔT_{ln} logarithmic temperature difference [°C]
- U(t) actual OHTC changing in time [W/m²K]
- U_{∞} equilibrium OHTC [W/m² K]
- U_0 initial OHTC [W/m² K]
- α heat transfer coefficient, adjusted for the actual mass flow rate [W/m²K]
- λ heat conduction coefficient of the tube wall [W/m K]

Subscript

- i inside
- o outside
- s shell side
- t tube side
- 0 (zero) initial

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