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Improving the Operational Performance of Existing Heat Exchangers used in the Hydrocarbon Processing Industries.

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Abstract The selection of equipment type, design, and geometry specification in the field of heat exchangers may be considered to be quite a simple task, using relatively accurate performance predictions based on well proven methodologies. In reality and for many cases this concept of assumed accuracy can be far from the truth. Limitations include the inherent in-accuracy of the fundamental data available, anomalies in predicting specific fluid flow dynamics, effects of wall friction causing fluid maldistribution, 2-Phase flow instabilities together with transient and unstable temperature gradients. It follows from the above that often heat exchangers do not meet performance requirements at the beginning or fail to maintain performance level over time. These often critical processing limitations become substantial challenges to plant engineers.
Tube-side heat transfer enhancement technology in the form of Wire Matrix Technology (hiTRAN Thermal System) has been available for more than 35years to improve the thermal performance of tubular heat exchangers. Increased focus is now given for the use of this technology in exchangers with operational problems in new and retrofit designs. Aside from the obvious potential of increased duty and therefore increased exchanger efficiency, applying this technology can also often provide improved operability as will be shown for specific operation conditions.

Keywords: hiTRAN, Maldistribution, Vapouriser, Laminar Flow

1. Introduction

1. Reducing the adverse effects of uneven fluid distribution.

Design calculation of the thermal performance of tubular heat exchanger does in general assume an even fluid distribution within a tube bundle but also within a single tube. For certain operating conditions this is not necessarily the case and can lead to underperforming units. This enhancement technology can be useful to solve those issues.

1.1 Bundle fluid maldistribution

Severe maldistribution of the tube side flow within a bundle can result in an underperforming heat exchanger. Low flow regions within the bundle are also more prone to fouling, resulting in an even worse performance. Geometrical aspects like large bundle diameter, single pass configurations, small nozzle sizes and axial nozzle location, in conjunction with low frictional tube side pressure drop contribute to an uneven fluid distribution. In a revamp the geometrical conditions are difficult to alter, whereas the low frictional pressure offers the possibility to use hiTRAN® Thermal Systems technology. The matrix density and also installation length can be adapted to the level of pressure drop required to remedy poor distribution. With this flexibility it is even possible to fine-tune the frictional pressure drop requirements over the cross-section of a bundle by varying Element geometries. In addition to the improved distribution the Elements also contribute to an improved tube side coefficient.

1.2 Tube fluid maldistribution

In laminar flow the heat transfer is often dominated by mixed convection. In mixed convection, a secondary flow profile caused by density differences is superimposed on the forced velocity profile in the flow direction [1](Oliver, 1962), [2](Ghajar & Tam, 1995), [3](Metais & Eckert, 1964). Under these conditions natural convection superimposed on the main flow causes a rise of less dense fluid towards the upper tube region, whereas the more dense fluid accumulates at the bottom of the tube. Computational fluid dynamic (CFD) can be used in order to simulate such behavior. As a result of the natural convection effects the temperature over the cross section of the tube can become stratified. This flow stratification has an impact on the predictability of heat transfer, since the temperature of the fluid at tube bottom area approaches the temperature of the cooling fluid outside of the tube. This in effect equates to a loss in heat transfer area, since here the temperatures pinches. Due to the complex flow patterns, the extent of this pinch area is difficult to predict and can severely limit heat transfer performance [4](Dooley, 2010). For this reason heat transfer in mixed convection flow is difficult to correlate. Again CFD simulation was employed in order to investigate the impact of fluid mixing on flow stratification with hiTRAN® Thermal Systems. The simulations show a flow pattern over the cross section of the tube which is substantially different to the plain empty tube. Due to the mixing action of the Element, temperature differences between adjacent fluid layers are much smaller. No stagnant velocity zones towards the bottom of the tube are present when operating with hiTRAN® Thermal Systems in laminar flow. Apart from the much improved heat transfer, prediction with correlations is more accurate due to the removal of thermal stratification.

1.3 Thermodynamic non equilibrium in stratified two phase flow

Another form of fluid mal distribution within the tubes can be encountered in two phase flow heat transfer. In gravity controlled two phase flow regimes the liquid phase will accumulate towards the bottom of the horizontal tube.

In **Figure 1** the flow conditions in a 20mm transparent tube are shown with an air water mixture. The two phases are separated and flow with different velocities of 3.3m/sec (Re~11000) for the gas and < 0.1m/sec (Re ~1000) for the water. There is little interaction between the water and gas phases. Those situations can be found often towards the end of a condensation process in a horizontal tube. In multicomponent condensation the gas and vapour phase have to be cooled in order to maintain the condensation process but due to the low Reynolds numbers the cooling potential is limited. In addition due to the limited interaction between gas and liquid phases non-condensable components will accumulate at the interface and limit the mass transfer in turn limiting the condensation process. In general heat exchanger design programs assume equilibrium conditions for their calculations and in such situations temperatures can be very different for the phases causing insecurity when designing for those scenarios. As shown in **Figure 1** the technology improves the interfacial mixing and mass transfer. In addition the heat transfer and therefore the cooling duty will increase considerably in the liquid and vapour phases. Since those situations are often encountered towards the exit of condensers, Wire Matrix Systems may be installed as a partial length to limit the pressure drop penalty which can be important for such applications.

2. Operational benefits in terms of more stable operation

Creating flow stability in shell and tube heat exchangers using enhancement techniques can also be a practical option for improvement.

2.1 Operation in transitional and film boiling flow regime

Vaporizers which operate under dry wall conditions can be difficult to predict since the mechanism for the onset of transitional and film boiling are poorly understood. hiTRAN® Thermal Systems technology can be used to debottleneck poor performing vaporizers where the cause is dry wall condition. Experimental research shows increased critical heat flux values for the onset of film boiling when compared with empty tube conditions [5](Mergerlin, Murphy, & Bergles, 1974).

In cases where film boiling is sustained even in the presence of enhancement, it can be expected that the heat transfer rates in the vapour blanket are increased.

Feedback from industrial applications does confirm these assumptions. This is illustrated in a real case study, a BEU 2 pass TEMA type shell and tube heat exchanger (702 tubes, 4m length) with ethylene evaporating on the tube side. The exchanger originally performed below specification. After retrofitting the exchanger with hiTRAN® elements the increase in performance indicated suppression of film boiling with much higher heat transfer.

2.2 Reduction of mist flow in vaporizers

Droplet carry-over can lead to operational problems with rotating process equipment. Mist flow in vaporizers is where remaining liquid is dispersed as small droplets in the vapour stream. The saturation temperature of the droplet increases with decreasing radius and makes it therefore more difficult to evaporate small droplets. In addition the velocity-slip between the vapour and the droplet decreases with smaller droplet size. A smaller velocity difference in turn reduces the interfacial heat transfer. This means that for small droplets the vaporization is mainly controlled by the temperature difference between droplet and vapour. Since hiTRAN® Thermal Systems increases the single phase heat transfer in gas flows several fold the superheat can be increased substantial for a given tube length compared to an empty tube. This superheat relative to the droplets is beneficial in vapourising the remaining liquid.

Additionally Wire Matrix Systems can have a demister effect agglomerating droplets and therefore increasing the relative velocity between vapour and droplets, increasing therefore the heat transfer at the interface. In revamp applications it is often advised to install the wire matrix only over a short flow length where droplet carry over is most likely, this will help to reduce the additional pressure drop after the revamp.

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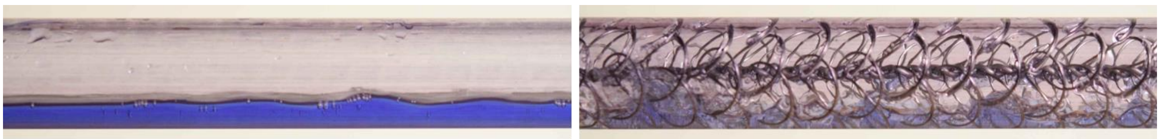

Figure 1*: Wavy stratified two phase flow at mass flux of 50kg/m^{2}sec and gas mass fraction of 0.18 in transparent tube; left plain empty, right hiTRAN® enhanced.*

***Table 1**: Revamp of ethylene vaporizer with hiTRAN®.*

	Plain empty	**hiTRAN® (after retrofit)**
Flow rate [kg/sec]	14.5	21.1
Temp. in/out [°C]	-100 / - 1 (saturated)	-100 / 30 (superheated)
Pressure in / out [bar]	40 / 39.9	40 / 39.7
Heat transfer [W/m^{2}K]	613	2390
Heat duty [kW]	261	618