Reboilers revamps

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Refineries, gas processing and petrochemical plants are frequently oriented at debottlenecking and upgrading existing equipment. Projects associated with these activities require focus on quantifying existing equipment performance, alternative flow schemes, and reliable revamp design. All phases of a debottlenecking process design must be addressed to meet both the low cost and reliable objective.

While increased capacity can sometimes be gained by changes in operating conditions, more often equipment changes and capital cost will be required. These changes can be minimised by a thorough knowledge of the plant and through its limitations, but also thorough application of new technologies, such as Twisted Tube® heat exchangers (TT® HEX). With significant thermal/hydraulic benefits, combined with no need for modifications of existing piping, this technology is often the cheapest and most cost effective way to debottleneck the plant.

This article highlights specific fluid flow characteristics of a Twisted Tube® replacement bundle operating in parallel configuration with an existing conventional exchanger and its impact on the performance of a kettle reboiler unit. The reboiler design faced the unique obstacle that process stream flows to both exchangers are not equal. Evaluation of the measured outlet temperatures confirmed the tube and shell side flows are not equal, and that the exact imbalance could be reasonably well determined. The performance data confirm this reboiler system was design accurately, resulting in efficient use of exchange surface area. Understanding how the integrated system works and modifying the system appropriately maximises the performance and economic benefits. This application confirmed that in maximising the performance of revamped kettles, debottlenecking analysis should consider combining existing shells with the high performance bundles.

Kettle reboilers

The TEMA K shell, a 'kettle reboiler', is used in distillation processes to vaporise a portion of the bottom liquid for fractionation. The vapour generated in a kettle, along with the vapour in the feed, creates the distillate product as well as the required reflux. U-bundles are typically used with K shell designs and are considered as the workhorse of the petrochemical industry. The liquid level in a K shell exchanger covers the tube bundle and fills the smaller diameter end of the shell. A wier plate at the far end of the entrance nozzle controls the level by liquid overflow. To insure against excessive liquid entrainment and carry through with the vapour stream, the expanded dome area facilitates vapour disengagement. Liquid carry through can also be minimised by installing various types of demister devices at the vapour exit nozzle. Several excellent reviews of designs of reboilers, including kettles, are available[3,4]. In addition, software based routines are available from HTRI or HTFS.

Kettle revamps

Kettle reboilers, sometimes mistakenly called pool boilers, are an important part of distillation plants. They handle process flow fluctuations and higher heat flux better than other reboiler designs, but have a greater tendency to foul on the process side. Thus, the objectives of kettle upgrades could be increased capacity, extended runtime, or both.

Although kettle reboilers usually operate at a relatively constant vaporisation rate, they are typically not easy to upgrade. The available options are:

- Increasing surface area.
- Increasing MTD:
  - Increasing the temperature of the heat source.
  - Decreasing the temperature of the process side (by reducing the column pressure).

Practical limits of the conventional equipment reduce the upgrade potential of existing units and in most cases only new, larger equipment could be used. In addition, increasing capacity by boosting available MTD usually has an adverse effect on effective runtime of equipment. It is commonly assumed that the overall heat transfer coefficient is a variable gradually and slowly changing with system properties. This would imply that as the temperature difference increases, while holding the area constant, duty should also increase. However, experience shows that this is not always true. In kettles, when the MTD has been increased the duty might decrease. This is a common problem in units where an increase in a duty has been based on a change to hotter heating medium than previously used.

The future improvements in both increased energy efficiency and extended runtimes will likely come from the use of closer temperature approaches. As the temperature difference required to instigate nucleate boiling could be high, conventional exchangers will in most cases pose a severe limitation. One option is the use of special boiling surfaces. However, these are expensive and investments hard to justify. In addition, their use is further limited by adverse effects in most fouling applications.

One promising alternative to increase capacity and runtime of equipment is based on use of Twisted Tube® technology. This type of kettle has an added advantage of allowing the boiling to be controlled by varying the temperature of the utility used. The technology brings significant thermal/hydraulic benefits, combined with no need for modifications of existing shells, piping and foundation. Claims are supported by operating experience in a large number of plant installations, including kettles. Revamping with Twisted Tube heat exchangers is often the cheapest and most cost effective way to debottleneck the plant.

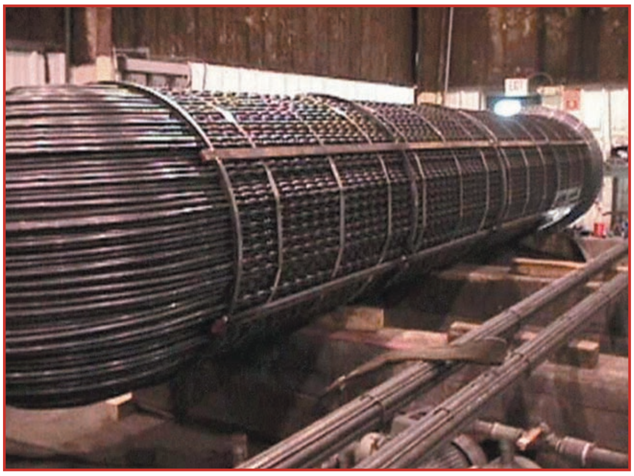

Figure 1. A Twisted Tube replacement bundle for a kettle reboiler application.

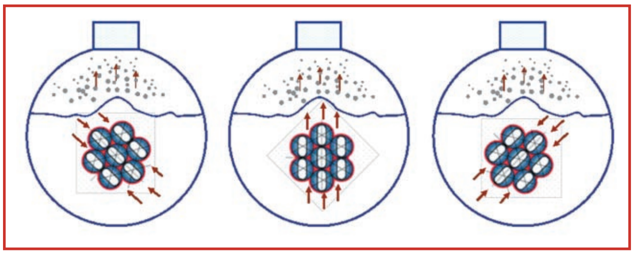

Figure 2. Twisted Tube geometry.

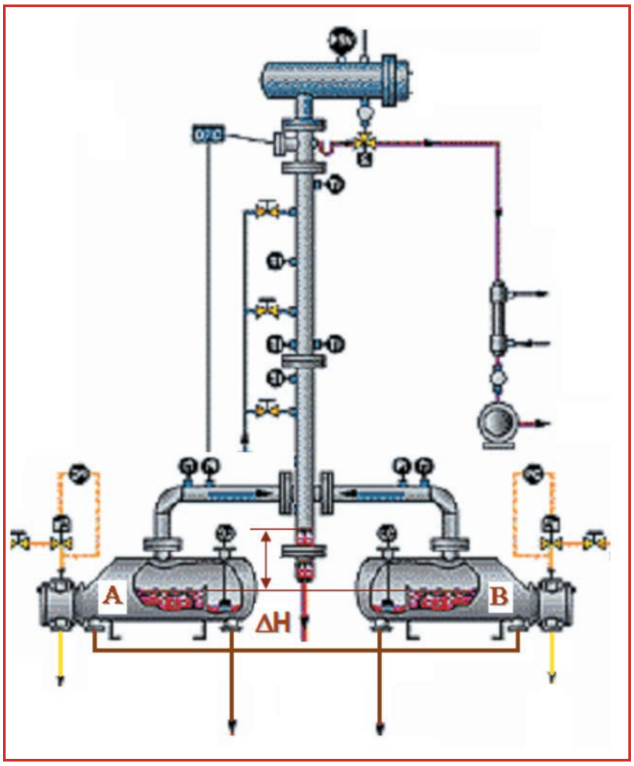

Figure 3. Conventional system, Kettle A, and Twisted Tube system, Kettle B.

New technology

Twisted Tube devices consist of helically twisted, double radius oval tubes, welded by their round ends to tubesheet. Tubes contact one another at their wider sides, six times over the length of one twist pitch, which makes the unit practically vibration free. Due to the ability to provide increased surface area, low pressure drop, and high heat transfer coefficient, Twisted Tube technology is becoming a common tool for solving problems in capacity upgrades and fouling mitigation cases. Figure 1 shows a Twisted Tube replacement bundle for a kettle reboiler application.

The bundle enhances heat transfer, tube side and shell side. The tube side fluid becomes swirled and is affected by increased turbulence and secondary circulation. In the course of the shell side flow over tubes circulation and mixing is generated. A simple use of twisted tubes instead of plane, rounded tubes is equivalent to a 30% reduction of the heat exchanger size while keeping a similar heat exchanger duty. Due to the lack of physical approach, considering enhanced mechanisms in boiling, and in kettle reboilers in particular, is not a simple task. However, it is clear that improved performance can be attributed to a larger wetted surface area and to an enhanced natural convection and recirculation inside Twisted Tube bundles.

Ju'Aymah Gas Plant (JGP) installation

In May 2005, JGP became the first facility in the Middle East to install a Twisted Tube bundle in a reboiler service. The objective of the installation was to extend the mean runtime between reboiler fouling and debottleneck depropaniser column capacity. Initial startup quickly revealed that Twisted Tube bundle was operating at considerably lower steam pressure, indicating potential longer runtime. Data available in the open literature indicate that the most probable cause of the fall off in conventional kettle reboilers is due to insufficient liquid recirculation through the bundle. This limit is not related to the boiling crises observed in pool boiling experiments. Kettles are not pool boiling devices and their operation is limited by the flow boiling critical flux. With fresh liquid entering the bundle from five directions, Twisted Tube bundle geometry (Figure 2) provides better recircualtion rate compared with only three in the conventional configuration. In contrast to the common design approach, which typically focuses on heat transfer aspects, kettle design requires putting thermal/hydraulic parts together and examining the thermo-siphon loop as a whole.

The hydraulic analysis of the thermo-siphon loops at Ju'Aymah Gas Plant quickly revealed that actual capacity was limited by the piping around the reboiler, particularly the vapour return line. Recirculation around the kettle is driven by the density difference between the outlet line and the inlet line. Figure 3 shows the system: conventional, Kettle A, Twisted Tube, Kettle B.

The system pressure balances based on the total driving head for flow must equal the total resistance to flow:

$$\left(\lambda_{vr}\cdot\frac{L_{vr}}{D_{vr}}+\xi_{v\_sum}\right)\cdot\frac{\left(\frac{4\cdot VFR}{\pi\cdot D_{vr}^{2}\cdot\rho_v}\right)^2}{\frac{2(\rho_l-\rho_v)}{\rho_v}\cdot g}+\left(\lambda_l\cdot\frac{L_{dc}}{D_{dc}}+\xi_{l\_sum}\right)\cdot\frac{\left(\frac{4\cdot LFR}{\pi\cdot D_{dc}^{2}\cdot\rho_l}\right)^2}{2\cdot g}=\Delta H_l$$

For most systems (and it proved to be the case here), the pressure drops in the inlet piping and the kettle are small compared with the driving force and the pressure drop in the vapour return pipe. Solving the above equation for liquid feed rate showed that the maximum capacity of each reboiler is limited to 1 346 050 lb/hr and this fact requires careful consideration in any future capacity upgrades.

Performance evaluation

As JGP did not have all operating data required to calculate heat transfer coefficients on a daily basis, reboiler performance and fouling was assessed or 'trended' using indirect process parameters such as opening of the flow control valve (FCV) steam or the pressure of the reboiler steam condensate drum. In the short term, operating variables such as column feed rates, feed composition and light key bottom specification can affect the results; however, over an extended period, FCV opening and condensate pressure provided

Table 1. Comparison of JGP reboilers performance

Reboiler	Starting pressure (psig)	Start of run date	Rate of pressure increase (psig/day)	Days in operation	Pressure as of 1 June 2006 (psig)
E-122B Twisted Tube	40	5 May 2005	0.049	365	54
E-122A acid cleaned	46	16 May 2006	0.090	16	48
E-222B acid cleaned	60	10 May 2005	0.085	364	60
E-222A acid cleaned	35	10 January 2006	0.058	143	45
E-322A decontaminated	120 - 130	7 October 2005	0.172	190	156*
E-322B decontaminated	85	22 September 2005	0.182	254	135

** Exchanger was removed from service on 13 April 2006*

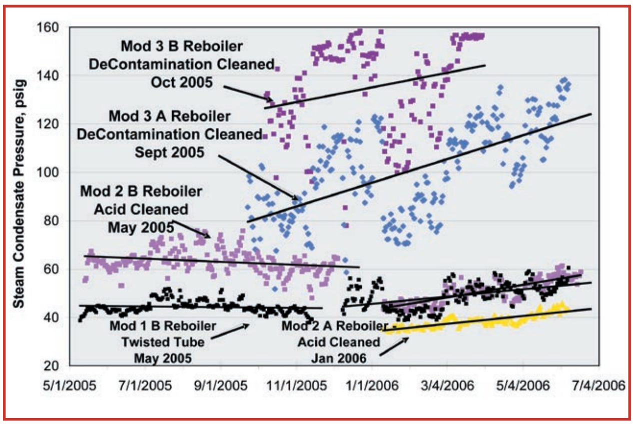

Figure 4. Comparison of JGP DeC3 reboilers.

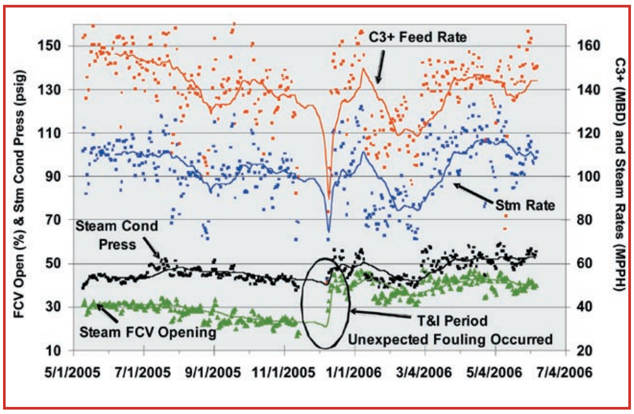

Figure 5. Performance of Twisted Tube during first 13 months of service.

reliable fouling rate trends. In addition, the fact that JGP is operating three parallel fractionation trains further helped in the analysis of reboiler fouling.

Other parameters such as steam rate to each reboiler were also evaluated; however, pressure readings and valve openings are significantly more accurate with fewer variations and therefore easier to analyse. In this analysis, both the opening of the steam FCV and the pressure of the steam condensate drum had definite upper limits; 100% for the FCV and 155 - 160 psig for the steam condensate drum.

Fouling in kettle reboilers is common and unfortunately not well understood. Understanding of many fouling mechanisms is incomplete, and the ability to predict fouling rates limited. However, this application proved that fouling rate within Twisted Tube bundles has been reduced and that, compared with conventional bundles, even fouled exchanger performance is superior. Although it remains unclear how to cast the observed improvements into quantitative correlations, it is encouraging to see that the same mechanisms that enhance thermal performance also reduce fouling tendancy.

Figure 4 provides a comparison of the fouling rates for five reboilers; two that were acid cleaned, two decontamination cleaned, and finally, the Twisted Tube. The trend line is a linear correlation of the operating data depicting the fouling rate. The Figure shows that the Twisted Tube still has the lowest rate of fouling, which was expected as it contains 45% more surface area than the other bundles. The acid cleaned bundles show the next lowest rate of fouling and highest performance, and then finally the bundles that were decontamination cleaned.

It is important to notice that the start of run pressure is significantly lower in some reboilers, indicating more available surface area and higher cleaning efficiency. As there is an upper limit on condensate pressure (steam pressure is approximately 160 psig), low condensate pressure at startup should translate into longer runtimes.

Table 1 provides a comparison of JGP reboilers performance, including the fouling rates since the Twisted Tube bundle was installed in May 2005. This is the same period that JGP began to trial restoration of reboiler performance by acid cleaning. From the Table it can be observed that the Twisted Tube bundle has the lowest fouling rate. Again, considering that the Twisted Tube bundle has significantly more surface area, the runtime should be greater. The remaining factor to be determined is whether the unique configuration of the Twisted Tube bundle contributes to lower fouling factors.

Conclusion

In general, the Twisted Tube bundle has performed well over the last 13 months. It has been demonstrated that they offer some valuable characteristics previously unavailable in kettle reboiler applications. Figure 5 shows a trend (30 day moving average) for the C3+ feed rate, steam rate to the Twisted Tube bundle, steam condensate drum pressure and steam FCV opening.

During initial startup, the condensate pressure was 43 - 45 psig and has since approached 60 - 63 psig. FCV opening started out at 30% and has recently been in the 40 - 45% range, both indicating an acceptable rate of fouling.

As expected, there is a good correlation between C3+ feed and steam rates; however, compared with the condensate drum pressure and valve opening the variations are quite large. In addition, during short periods, there is a good correlation between feed rates, valve opening, and condensate drum pressure.

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