NEW TECHNOLOGIES PROVIDE EFFECTIVE MITIGATION OF FLOW-INDUCED VIBRATION IN HEAT EXCHANGERS

Amar S. Wanni, Thomas M. Rudy and Zdenka F. Ruzek
ExxonMobil Research and Engineering, Fairfax, VA, U.S.A.

ABSTRACT

Plant operators often attempt to increase capacity with minimal expenditure on equipment. Such increases in plant capacity, sometimes referred to as capacity creep or debottlenecking, usually result in higher flow rates through the system. In the shell-and-tube heat exchangers, the increased capacity may result in a flow rate that causes flow-induced vibration (FIV) failures if the existing exchangers are used. Alternatively, new larger shell-and-tube exchangers or more expensive bundles need to be installed.

ExxonMobil has developed and patented a suite of anti-vibration technologies (AVT) that can be retrofit into existing exchangers to mitigate vibration. In grassroots applications, these technologies can be used to reduce the size of exchangers, or to reduce pressure drop in gas-compression circuits.

This paper describes this new suite of vibration mitigation technologies in general, and presents applications involving four different scenarios: (a) Repair an existing failed exchanger bundle, (b) Optimize a new design, (c) Retrofit for a capacity creep project, and (d) Debottleneck a gas compression loop.

1. INTRODUCTION

Technological advances, including catalyst and control technologies, allow operators to increase plant capacity by simply increasing flow through existing process equipment. Also, as a result of research, new design correlations enable the design of smaller exchangers that require less space. Higher flow rates and smaller exchangers usually result in higher velocities in the exchangers.

Although a higher velocity results in a higher pressure drop, research has shown that it often has the advantage of reducing fouling. However, on the negative side, higher velocity increases the potential for tube vibration on the shell side of the exchanger. The usual reaction to this condition is to design a new, larger exchanger or a new bundle with additional baffles that requires increased shell side pressure drop.

Potentially damaging flow conditions are regularly either predicted to occur at the increased flow conditions of a capacity creep project, or actually do occur and cause a failure in the operating unit. In either case, a larger exchanger as a replacement could pose space problems and usually results in modifications to piping and structural members, etc. These modifications and the associated downtime are costly.

ExxonMobil Anti-Vibration Technologies (AVT) can be used to address existing or potential vibration problems.

ExxonMobil has licensed these technologies to six qualified heat exchanger vendors to make them available to customers worldwide. These technologies have been applied in more than 100 different exchangers at more than 20 plant sites, both within ExxonMobil and at third parties, since our first application in 2003.

There are several different application scenarios where the AVT can be applied. These include both retrofit and new designs.

As a retrofit, the AVT can be applied to mitigate an existing vibration problem that has caused tube failure or to prevent a problem that is predicted to occur at a debottleneck condition. For either of these cases, the AVT provides a very cost-effective solution.

If there has been a tube failure, the operating condition can be analyzed to determine the necessary tube support, a new bundle built with AVT installed, and the replacement bundle reinstalled in the same shell. We have come across situations where several tubes have failed during operation, but the exchanger was put back in operation after plugging of the failed tubes. If the failure was indeed caused by an FIV condition, this "plug-and-run" approach leads to further tube failures within several weeks or even in a matter of days. This is because, often, a whole region of the bundle is vulnerable to FIV. Therefore, it is always prudent to carry out a root cause failure analysis and provide vibration mitigation as necessary.

For the case of predicted vibration at a debottleneck condition, the existing bundle can be analyzed to determine the necessary extra tube support. Then the bundle can be removed, the AVT installed in less than a day, and the bundle reinstalled into the same shell. In both cases, the existing shell is reused, saving significant cost to the plant.

Another scenario for application of AVT is one where pressure drop reduction through the exchanger is desired. In this case, changing from a baffled exchanger (segmental or double-segmental) to a longitudinal flow configuration may be very beneficial. Depending on the stream and the impact on the heat transfer performance that results from the switch to longitudinal flow on the shellside, the designer may consider a simultaneous change from bare to finned tubes. We have had several such successful applications in gas-compression circuits.

For a new exchanger design, the optimum heat transfer design point, although within the allowable pressure drop limit, may not be acceptable because a vibration analysis may predict a potential problem. The conventional solution for such a case is to reduce the shell side velocity, which results in an off-optimum design. The lower velocity will reduce the heat transfer performance and produce a larger and more costly exchanger. However, application of DTS™ technology can remove the vibration potential and allow the optimum design to be used.

1.1 DTS™ Technology

DTS™ technology consists of dimpled and corrugated straight metal strips that are inserted into a heat exchanger bundle to reduce vibration by stiffening the bundle. As shown in Figure 1, the corrugations on each strip act as a wedge to slightly deflect the tubes. The dimples on one end of each thin strip provide a locking mechanism to hold the strip in place. DTS strips are inserted in alternate lanes, only in the regions of the bundle that have loose tubes or that a vibration analysis calculation predicts a high risk of damage.

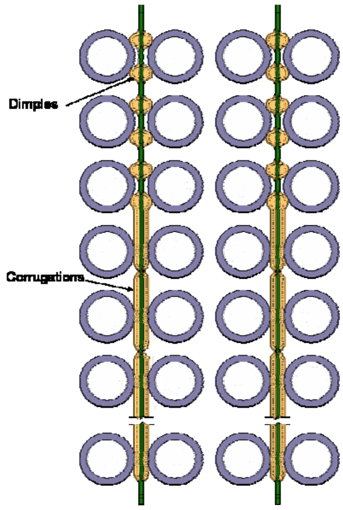

Figure 1: *Schematic of DTS Strips Installed in a Bundle.*

Figure 2: *DTS Strips Applied as U-Bend Stiffener.*

The strips can be used in all common tube layouts and can be fabricated from many different metals. We have successfully made them from SS304, Titanium, Duplex, Carbon Steel, Monel, and Brass.

Another excellent application of DTS is as a U-Bend stiffener. Figure 2 shows one of a number of such applications where we have applied the DTS as a U-Bend stiffener. Whether in a straight tube or U-Bend application, DTS can either be installed in a new or existing bundle.

1.2 STS™ Technology

STS™ technology, as shown in Figure 3, is corrugated pairs of identical thin metal strips that are welded together and inserted into alternate tube lanes in a heat exchanger bundle in a similar manner to DTS. The "saddle" portion of the STS, however, provides a wide contact area against the tubes instead of a point contact.

The tube deflection support provided by the STS is especially beneficial for use with integral-fin tubes made of softer metals such as carbon steel and brass because the saddles contact multiple fins to prevent any fin damage. STS technology is limited to 90- and 45-degree layouts. The STS geometry also provides a very low profile for axial flow bundle configurations such as our SBX™ bundle configuration described next. We have applied STS in gas compression feed preheater applications in the SBX technology.

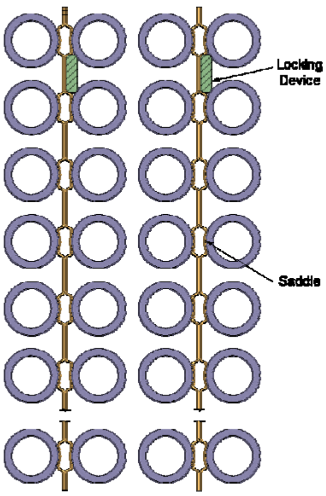

Figure 3: *Schematic of STS Strips Inserted in Tube Bundle.*

1.3 SBX™ Technology

The SBX™ technology is an axial-flow exchanger. Its bundle consists of a relatively small number of horizontal and vertical tube support stations, along with a number of strategically placed DTS or STS strips, thereby providing low-pressure drop and vibration-free operation.

Figure 4 shows an SBX bundle that was designed for a gas-compression circuit in a chemical plant. By retrofitting the existing shell with an SBX bundle having integral-fin tubes, the plant was able to reduce the pressure drop from 16 to 4 psi (110 to 28 kPa) while maintaining the existing feed preheat duty. The significant savings captured from reduced operating expense (reduced pressure drop) and capital avoidance (used existing shell/foundation/piping) more than offset the cost of the finned tubes.

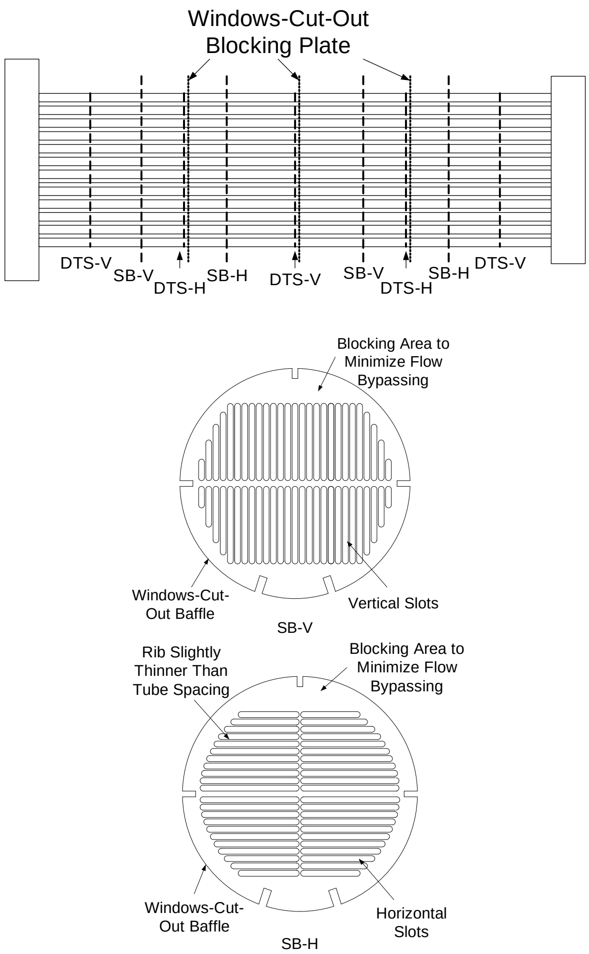

Figure 4: *Schematic of an SBX Bundle.*

2.1 Repair of Existing Exchanger After Tube Vibration Failure

Shortly after the start-up of a new LNG plant, several kettle reboilers suffered vibration-induced tube failures because of insufficient tube support. The bundles were opened and inspectors identified that more than 10 percent of the tubes had significant tube fretting at the baffle hole locations and some tubes had completely holed through. The plant was able to minimize expensive downtime by plugging of the fretted tubes and stabilized the remaining tubes by installing DTS.

The locations and the quantity for the DTS strips were determined through a detailed vibration analysis. The vibration analysis indicated a very high probability of Fluidelastic Instability at the top twelve rows of bundle where the failures had occurred. The Fluidelastic Instability Ratio (FIR) was calculated to be greater than 4 for the current conditions and was reduced to 0.2 after the DTS installation. Generally a value of less than 0.8 is recommended for new exchangers.

The exchangers have continued in successful operation for more than four years after the restart. Overall, the plant realized significant savings of potential lost opportunity cost from unplanned downtime and cost of purchasing replacement bundles.

2.2 Design of a New Heat Exchanger to Capture Optimum Heat Transfer

Sometimes the optimum design (i.e., the smallest exchanger size) for a specified heat transfer, subject to the allowable pressure drop limit, will not be acceptable because of a potential vibration problem. Often, the conventional solution is to reduce the shell side velocity by changing baffle type, spacing, or increasing the shell size. This will result in an off-optimum design (lower heat transfer performance and a more costly exchanger). In this situation, the designer may use the DTS strips strategically in the vulnerable regions of the bundle and stay with the original optimum design.

Table 1 summarizes the results for application of DTS to enable the optimum design of an overhead condenser. During the design phase, an optimum design was identified with a pair of 36-inch (914 mm) shells. The pressure drop limit was satisfied, but a vibration problem was identified. In order to remove the vibration problem, the design would have been modified to require a pair of 44-inch (1118 mm) shells with NTIW baffles. Instead, with the application of DTS to mitigate the vibration problem, the smaller exchanger was feasible.

Table 1: Summary of Design with DTS for Optimum Heat Transfer Conditions.

Exchanger: TEMA AES Condensing Service	**Conventional Design (with no vibration)**	**Optimum Design with DTS**
	44" x 192" (1.118 m x 4.88 m) **Plain Tubes** NTIW/Seg 2p / 1s	**36"** x 192" (0.914 m x 4.88 m) **Plain Tubes** Double seg 2p / 1s
Duty (MBtu/hr)/ (MW)	17.7 (5.19)	17.7 (5.19)
Shell side Δp (psi)/(kPa)	1.8 (12.4)	1.4 (10)

For new projects, DTS Technology allows the design at the optimum performance for heat duty and pressure drop thereby saving significant capital and operating costs.

2.3 Application of DTS Retrofit into a Treat Gas Heater

In the following application, DTS strips were retrofit into an existing bundle in order to mitigate a vibration problem in one heat exchanger in an expansion project for a gas cracker. A detailed vibration analysis showed that serious tube vibration was highly probable for a project that would increase the flow through the exchanger by 9% and heat duty by 30%.

Table 2 shows the data and installation details of this application of DTS Technology. Although the pressure drop, as shown in Table 2, was acceptable for the flow rate increase through the exchanger (8.4 to 10.0 psi, or 58 to 68.9 kPa), a detailed vibration analysis predicted serious vibration problems at the inlet and outlet spans in this TEMA BEU exchanger.

Table 2: Details of DTS application for Treat Gas Heater.

<table>
<tr><td rowspan="2">Feed / Effluent Heat Exchanger</td><td colspan="3">• TEMA BEU
• 33” x 126” (838 mm x 3.2 m), 1” (25.4 mm) tubes
• 1180 ft2 (109.6 m2)
• Segmented baffles</td></tr>
<tr><td>Design Conditions</td><td>30% Capacity Creep without DTS</td><td>30% Capacity Creep with DTS</td></tr>
<tr><td>Duty (MBtu/hr)/ (MW)</td><td>49.4 (14.5)</td><td>64.2 (18.8)</td><td>64.2 (18.8)</td></tr>
<tr><td>Δp (psi)/ (kPa)</td><td>8.4 (58)</td><td>10.0 (68.9)</td><td>10.2 (70.3)</td></tr>
<tr><td>Vibration Problems?</td><td>No</td><td>Yes</td><td>No</td></tr>
</table>

The most expensive solution would have been to design a new, larger heat exchanger that would have required more space, piping changes, and a different foundation; the re-designed bundle without the use of DTS strips was estimated to have a shell ID of 44" (1118 mm). However, as also shown in Table 2, a detailed vibration analysis for the same bundle after the installation of DTS in the inlet and outlet regions predicted that the vibration potential would be eliminated. The desired 30% capacity increase was achieved with the existing exchanger with only a minimal increase in pressure drop (10.2 psi / 70.3 kPa versus 10.0 psi / 68.9 kPa).

This example shows that DTS technology is well suited for capacity-creep projects because it spares significant costs of new, larger heat exchangers, piping, foundation, and other project costs associated with the purchase of a new heat exchanger. The retrofit of the DTS was done on site during the turnaround. The technology is especially suited to debottlenecking condensers, reboilers, and feed/effluent exchangers where vibration problems are often encountered during a capacity increase review.

2.4 Application of SBX to Debottleneck a Gas Loop with an Axial-Flow Exchanger

In the compression loop of an existing chemical plant the pressure drop became limiting as throughput was increased. Additionally a vibration problem developed in the existing exchangers that resulted in a tube failure. After a vibration analysis was completed, it was decided to replace the existing baffled, exchanger with an SBX, axial flow bundle.

Table 3 summarizes the results of this application. The replacement SBX bundle was designed with integral-fin tubes to maintain the duty of the original bare-tube bundle.

Table 3: Summary of SBX application to reduce pressure drop in a compressor loop.

Exchanger: TEMA AEU Feed Preheat w/ Steam	**Original bundle (at debottleneck conditions)**	**SBX Bundle**
25"x126" (6.35 m x 3.2 m) Shell	1200 ft2 (111 m2) 0.75" (19 mm) plain tubes Segmental baffles	2140 ft2 (199 m2) 0.75" (19 mm) finned tubes No baffles (axial flow)
Duty (MBtu/hr)/ (MW)	97.6 (28.6)	103 (30.1)
Δp (psi)/(kPa)	16 (110)	3.5 (24)
Vibration Problem?	Yes	No

A significant savings in operating expense is predicted based on the reduction in pressure drop from 16 psi (110 kPa) to 3.5 psi (24 kPa). Additionally, the plant saved the capital expense of modifications to the shell/foundation/piping that would have been required if a larger exchanger was used. These savings more than offset the additional cost of the finned tubes.

3. CONCLUSIONS

The three ExxonMobil technologies described in this paper are commercially proven. In many cases, installation of the AVT technology resulted in significant savings and prevented costly downtimes.

Heat Transfer Research, Inc (HTRI) will provide modeling capability within their Xvib program to include ExxonMobil AVT technology as an option when evaluating vibration potential in shell-and-tube heat exchangers. This feature will be available in Xchanger Suite 6 in the second half of 2008.

Advantages of DTS and STS Technologies:

- Completely eliminate tube chatter and stiffen the tubes.
- Very unlikely for tube supports to be dislodged or displaced during bundle handling, operation or during cleaning; this is a common problem experienced by other technologies on the market.
- Suitable for vertical bundles as well – other technologies on market are questionable.
- Modified DTS offers an easier and lower-cost vibration mitigation option for U-bend region.
- DTS or STS strips are inserted only in alternate tube lanes so that any increase in shell side pressure drop is minimal - other technologies available on market require devices to be inserted in each tube lane.
- U-bend DTS suitable for new U-tube bundles to reduce labor cost and fabrication time.

Advantages of SBX Technology:

- Provides a low-cost alternative for exchangers with axial flow on shell side.
- Minimizes fabrication time through laser- or water-cutting of slots.
- Tube chatter is completely eliminated through the use of DTS or STS, which are used to stiffen bundle.
- Avoids tube vibration damage.
- Leads to a substantial reduction in shell side pressure drop.

These anti-vibration technologies are available from a limited number of licensed heat exchanger manufacturers worldwide. The current licensees have been trained to provide the vibration analyses, quality manufacturing, and expert installation of the technologies. They can install these technologies either in their shop or at the customer's plant with minimal space and crew requirements.

For additional information, contact:
zdenka.f.ruzek@exxonmobil.com
or
the licensees directly:
www.ohmstede.net or bried@ohmstede.net
www.leffer.de or info@leffer.de
www.knm-group.com or jennlai@knm-group.com
www.larsentoubro.com or
Ramesh.nv@hed.ltindia.com
www.dkme.com or muhur@dkme.com
www.kureko.co.jp or ohsima@kureko.co.jp