HEAT EXCHANGER TUBE RESTORATION

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Many failures of heat exchanger tubes occur within the first six inches. Inlet-end erosion, impingement attack, stress corrosion cracking, pitting and crevice corrosion are typical damage/failure mechanisms encountered in the chemical, petrochemical and oil refining industries.

The presentation will discuss a cost effective, in-situ tube restoration technique, consisting of installing thin-walled metallic inserts or “shields” that are mechanically expanded into the affected tube ends. Since their introduction in 1976, metallic tube shields have successfully restored and protected damaged heat exchanger tubes at a fractional cost of retubing. Materials utilized for I.D. tube shields cover a wide range of copper-base, iron-base, and nickel-base alloys. The technique for affixing tube shields is also being incorporated into the design of new heat exchangers.

This restoration technique and its advantages are compared with traditional tube protection/restoration methods employing thick metal ferrules, ceramic ferrules and epoxy coatings. Unlike any of these, rolled-in metallic shields have the unique capability of restoring perforated tubes to full service.

Introduction

It is common experience that many failures of shell-and-tube heat exchanger tubing in the chemical, petrochemical and oil refining industries occur within the first six inches of the bundle. Frequently encountered forms of such tube end damage are erosion, impingement attack, stress corrosion cracking and pitting/crevice corrosion. The damage variously manifests itself as tube thinning, grooving, localized pitting and cracking, all of which can ultimately lead to leakage and tube failure.

In the past, the accepted solution for repairing this highly localized tube damage has been full retubing, even though usually more than 95% of the tube bundle length remains largely
unaffected. In some instances, the bundle can be salvaged by shortening the exchanger, provided a smaller heat transfer area is acceptable. However, either of these radical solutions is very costly and time consuming.

With the objective of dealing with these shortcomings, a new restoration technique was developed in the mid-1970's. It makes use of rolled-in metallic inserts, variously referred to as I.D. tube shields. This versatile in-situ restoration method has been successfully extended to installing full length tube “liners” for instances of more extensive tube damage.

The characteristics and capabilities of metallic tube inserts are described below. Also, briefly covered for sake of completeness are tube restoration/protection methods that make use of non-metallic materials.

**Common Heat Exchanger Tube Failure Mechanisms**

Inlet-end erosion is a common problem with carbon steel and copper alloy cooler, process heat exchanger and condenser tubes, caused by the kinetic force of the fluid (typically cooling water), particularly if it contains entrained abrasive solids. Changes in flow direction, eddying and air bubbles combine to create highly turbulent conditions at tube inlets, resulting in impairment of protective passive films on the tube I.D. About six inches into the tube, turbulent flow conditions change to laminar flow, and fluid erosivity is sharply reduced. Other factors that can contribute to high turbulence are unfavorable design configurations of the waterbox (channel) and inlet piping.

With fluids containing corrosive constituents, tube wastage can be greatly exacerbated. This so-called erosion-corrosion is a synergistic phenomenon wherein the combined action of erosion and chemical attack are greater than their separate effects. Erosion-corrosion is most commonly caused by corrosive process fluids. However, it can also occur with waters, as for example with brasses exposed to sulfide and/or ammonia contaminated cooling waters.

Stress Corrosion Cracking (SCC) is another common failure mode in heat exchanger tubes. It is caused by the combined action of tensile stress and corrosion. SCC frequently occurs in the rolled area immediately beyond the tubesheet, especially with overrolling. SCC is metal-
environment specific. Well-known forms are ammonia SCC of copper base alloys, chloride SCC of austenitic stainless steels and alkali SCC (caustic embrittlement) of carbon and alloy steels.

Other types of corrosion encountered in tube ends and at tube-to-tubesheet joints are pitting attack and crevice corrosion. Crevice corrosion is a virulent form of deep local penetration, experienced most often with austenitic (Cr-Ni) stainless steels exposed to chlorides. Both SCC and crevice corrosion are greatly accelerated at elevated temperatures. Damage at this critical location of the inlet tubesheet and tube ends can also be caused by mechanical factors (e.g. improper tube expansion) and by poorly executed tube-to-tubesheet welds.

I.D. Tube Shields

Metallic thin-walled inserts or “shields” were introduced in 1976. This restoration process protects, restores and seals the damaged tube ends. The shields are manufactured to specific dimensions while retaining ductility required for expansion. A thin-walled construction, I.D. chamfer of the outlet end and metal-to-metal expansion eliminates the chance of end step erosion, a common occurrence with other tube inserts.

As in the case of the heat exchanger tubing, selecting the proper shield alloy is critical. Material can be selected from a range of different alloys, depending on existing tube material, the service of the heat exchanger and the failure mechanism. Choices of shield material range from copper alloys (Cu-Ni and brass), conventional stainless steel (austenitic, ferritic, martensitic, duplex), superaustenitic stainless steels (6 Moly alloys) and nickel-base alloys (e.g. Alloy 400, Alloy C-276). This allows the plant to select an alloy to combat a specific failure mechanism such as chloride pitting, stress corrosion cracking, ammonia grooving, etc.

The installation process is carried out in-situ beginning with wire brushing tube I.D.’s to allow for a pressure tight seal. After the tubes are blown clear with compressed air, I.D. measurements are taken to determine expansion requirements. Shields are then inserted into each tube end. The flared end of the shield is expanded to a torque setting by use of a conventional tube expander, while the downstream end is expanded using a mechanical setting, therefore avoiding
any possibility of over-expansion. The final step is to flare the shields so that they conform to the tubesheet profile.

Shields have been installed in high pressure units (4200 psi) and high temperature service (1200°F). In some cases, though not typical, shields have been able to “bridge” tubes that have been completely severed. Tube restoration by means of roller-expanded metallic inserts is a cost-effective repair method offering the following favorable features and capabilities:

- Restore and protect the damaged tube ends.
- Extend bundle life at a fraction of the cost of retubing.
- Return plugged, leaking tubes to service.
- Provide pressure tightness.
- Restore tube-to-tubesheet joint strength.
- Enable the tubes to maintain mechanical cleaning capabilities.
- Increase safety
- Reduce potential for emissions
- Eliminate end-step erosion
- Reduce outage time.

Because of the thin-wall construction and the expansion of the shield, tube openings are reduced by only a fraction compared to considerably thicker metal ferrules.

**Full-Length Tube Liners**

Based on the success of the shields for the repair of tube end damage, a similar repair technique was developed to restore tubes that had sustained damage over their entire length. This repair involves the installation of full-length tube liners. Due to I.D. pitting, O.D. grooving, full-length thinning and impingement damage, these tubes were plugged and no longer in service.
As the heat exchanger ages, the amount of plugged tubes begins to affect the efficiency of the unit and increases the flow rates in the remainder of the tubes. With 10% of the tubes plugged, historically the unit becomes a candidate for a full retube project. In cases like this, the installation of full-length liners to repair the plugged tubes becomes an attractive alternative. By restoring the plugged tubes to duty, years of additional service can be provided.

The process of tube lining begins with the tube plugs being removed and the tubes prepared with a thorough cleaning. Cleaning methods include wire brush, bristle brush, metal tube scrapers and hydroblasting. Tubes are cleaned of debris and the liner (a thin-walled tube) is installed. A bleed chuck is clamped on one end and the pumping chuck is placed on the other end. The tube is filled with water and the air is bled out. The chucks seal the tube and the hydroexpansion pump pressurizes the water in the tube.

As the pump reaches the yield point of the material, the liner begins to expand. When the liner has achieved a metal-to-metal fit within the damaged tube, it is allowed to remain pressurized for a short period of time. Pressure is then released and the tube is allowed to drain. The expanded liner is cut off and milled flush to the tubesheet. The liners are then roller expanded into the tubesheets to a set wall-reduction specification. The previously plugged and condemned tubes are now restored and returned to circulation.

**Thick Metal Ferrules**

Thick-walled metal ferrules have been quite common in oil refineries for many, many years, as a protector against inlet-end erosion. They’re normally rolled into the existing tubes – for the first inch only – or tack welded to the tubesheet.

Unfortunately, these ferrules brought with them their own drawbacks. The wall thickness, which is typically 0.065”, drastically reduces the tube opening in some instances by nearly 30% of the original design. Other problems associated with thick metal ferrules:
• Do not restore plugged/leaking tubes to service.

• Do not fit properly in eroded tubes.

• Prevent proper mechanical tube cleaning.

• Promote crevice corrosion.

• Cannot be installed into outlet tube ends.

*Ceramic Ferrules*

Ceramic Ferrules are employed in conjunction with refractory lined inlet tubesheets and serve the dual function of providing both thermal and erosion/corrosion protection within tubesheet holes and tube ends. They are employed exclusively for high temperature applications such as firetube boilers, waste heat boilers and gas/gas exchangers. Ceramic ferrules are installed by wrapping or sleeving them with ceramic fibre, which centers and cushions the ferrule. An additional purpose is to reduce thermal shock and to accommodate for differential thermal expansion between the ceramic and the parent tube.

Ceramic ferrules are offered in a number of sizes and shapes, and several different materials including alumina, zirconia and silicon carbide. The most commonly used material is 85% alumina. Higher alumina ferrules are stronger, denser and more heat and erosion resistant, but are considerably more prone to thermal shock cracking.

Ceramic ferrules find application almost exclusively in new units where they are integrated into the original design of the heat exchanger. Retrofitting ceramic ferrules is a burdensome procedure since it necessitates installation/replacement of tubesheet refractory. Ceramic ferrules are therefore more appropriately considered a design feature rather than a restoration measure.

*Epoxy Coatings*

Application of synthetic resin and epoxy coatings has recently emerged as a method for in situ restoring eroded/corroded I.D. surfaces of heat exchanger tubing, as well as for protecting new bundles. Coating systems applied are phenolics, epoxy phenolics and fluoropolymers. Coating performance and life is critically dependent on meticulous surface preparation and coating
application, particularly on pitted surfaces, and requires specially developed devices. Coatings also have strict limitations regarding temperature and corrosive environments.

Coatings on heat exchangers are also applied by dipping, which enables internal and external coating of tubes as well as tubesheets and baffles. Dating back over half a century, this form of corrosion protection, utilizing baked phenolic coatings, has been effectively used on selected exchangers. The drawback is that immersion coating application can only be done in the workshop. Consequently, this technique is essentially limited to new exchangers, and strictly speaking, is not a restoration method.

**Summary**

Heat exchanger bundles in the chemical process industry frequently experience severe erosion/corrosion damage at the tube ends. Thin-walled metallic tube inserts (I.D. tube shields) installed by roller expanding have been effectively used for over 25 years for restoring damaged tubes and returning the condenser tubes to full active service.

Compared to traditional tube restoration/protection methods employing thick metal/ceramic ferrules and epoxy coating, metallic inserts alone possess the capability of repairing leaking tubes. The wide range of alloys suitable for tube shield/liners enables cost-effective life extension of heat exchanger bundles in severely corrosive and high temperature/pressure services.