The Case for Protective Coatings
Cutting Corrosion and Fouling in Heat-Transfer Equipment

By Edward Curran, CEO, Curran International

Tube corrosion, fouling and leakage in heat-transfer equipment running in refinery environments creates unfavorable conditions that can seep across the entire business. Inefficient heat transfer in heat exchangers is a common logjam that affects chemical and energy operations around the world, often requiring much greater expense than anticipated.

There is a novel way to cut plant and equipment downtime, curb depreciation on capital assets, recover energy efficiency, and achieve fewer stoppages for routine maintenance. One small preventative measure can make a huge difference in raising maintenance standards, facility and equipment reliability, operational efficiency and production capacity. All of these factors contribute to higher margins for the business.

That particular step consists of applying polymer coatings to the inner diameters (ID) of the steel tubes in heat-transfer equipment, such as heat exchangers, condensers or other types of equipment running cooling water or process fluids through a tubular system to achieve a temperature decrease/increase in petrochemical feedstock or pressurized gases. The advantages of coating metallic tubing rather than leaving it bare in these conditions are numerous. They provide benefits that stretch beyond corrosion and fouling protection for heat-exchanger maintenance.

The return on investment in cost savings for one small ounce of prevention can be worth millions per year. One Gulf Coast refinery estimated it saved $30,000 per day in reliable production, reduced downtime and lower energy costs, amounting to nearly $9 million per year after coating the tubular systems in their heat exchangers. Additionally, the costs they saved in not retubing each exchanger increase by an additional $3 million per year compared to historical retubing cycles. Bare steel needs to be cleaned and replaced much more frequently than tubes with protective coating treatment.

The Power of Polymers

Heat exchangers are mission-critical equipment used routinely in the energy and chemicals industries, particularly in petrochemical refineries. A heat exchanger is an apparatus comprised of spherical bundles of hundreds of equal-length, small-diameter tubes that run cooling water or liquid to reduce the temperature of the feedstock. Heat exchangers that run cooling water are the most likely candidates for protective tubular coatings.

Water is corrosive to metallic tubes, and is also susceptible to fouling and bacterial contamination that eats away at the exchanger tubes’ inner and outer surfaces. Leaks and damage, pitting and obstructive buildup all require frequent maintenance and stoppages for cleaning. Stoppages for tube cleaning occur roughly five times more often, on average, if the tubes remain bare, or uncoated. Additionally, the bare tubes erode faster than coated tubes, and their useful life is diminished, requiring costly retubing of the heat-transfer equipment as it ages.

In chemical process plants, it is of vital importance to preserve these systems and prolong their working lives through good maintenance practices. Since the cost of entirely retubing a large piece of heat-transfer equipment climbs well into the tens or hundreds of thousands, it is far more preferable to extend the life of the tubes through coating their inner diameters with phenolic or epoxy materials especially suited for the base metal and the function of the heat exchanger. This practice is not new for shop applied linings, but can now be applied on site. It remains an option that may not be commonly known or utilized but has a tremendous potential for solving common heat exchanger problems.

Why Coatings?

Fluids, by their very nature, have always posed a difficulty for efficiently running heat-exchanger equipment as they come into contact with the metallic tube surfaces. Traditionally, water treatment and periodic cleaning by hydroblasting managed the cleaning process, but the results were not always optimal. Increasingly, users are applying polymer coatings to the tubular inner and outer diameters (ID and OD) of the heat-transfer apparatus.

Over the years, this practice has evolved and matured into a cost-effective remedy to reduce typical fouling and corrosion problems intrinsic to this equipment. Improvements in materials, surface preparation, application techniques and thermal conductivity, plus owner-operator data collection and analysis, have established tubular coatings as viable heat-transfer equipment (HTE) problem solvers.
A German chemical company first developed phenolic materials for tube ID coatings in the 1950s . Applied by a fill, drain and rotate method in a specialized shop, this was the industry’s best option until the mid-1980s. Around that time, companies in Italy began experimenting with air-atomized spray applications of epoxy-phenolic developed by their engineers. By coating the tube ID with the epoxy phenolic compound, the Italians achieved excellent results and improved fouling and corrosion resistance to the main condensers, actually restoring the units to their normal operating capacity.

Today, ID coatings are considered the most cost effective practice for extending the performance and lifecycle of a heat-transfer system. It took decades of trial and error to find the right solutions for each ID, bare metal, and chemical coating compound to optimize the practice for each and every application.

The Chemistry of Corrosion

Microorganisms that draw nutrients from cooling water inside tubes cause bacterial build-up and fouling, and represent the most common way that corrosion cells are created inside condensers and heat exchangers. The bacteria breed quickly in the nutrient-rich environment, enhanced by certain chemical processes and the lack of light inside the tubes.

Each corrosion cell creates a pit – a place for bacteria to further multiply and hide – that leads to intricate bacterial structures that rapidly advance corrosion to inefficient and even dangerous blockages. Such bacterial pits can cause electrochemical changes inside tubes that exacerbate the damage.

Another common cause for tube pitting and corrosion is activated films that can galvanize inside the tube from sulfide or manganese influences. If these potentials differ from the base metal, the reaction can cause pitting, which invites severe biologic decay and faster deterioration of the tubing. Leaks and bottlenecks in the tubing can seriously jeopardize the efficiency of the heat-transfer apparatus. Polymer coatings are inert to these types of chemical or biological attack and can restore the integrity of tubes that have had substantial wall loss.

Generally, tube pitting can be corrected in several ways: cleaning, chemical treatment and retubing. But none of these options is as viable or cost-effective as coatings.

Cleaning

Because of the bacterial component of pitting, removal of tube deposits and adoption of better methods for tube cleaning can halt deterioration, or at least stabilize the rate. Deep pits can be identified through eddy testing and preventatively plugged prior to cleaning. Rough cleaning can be accomplished by brushes and scrapers, or by using hydrolyzing or sponge balls. Tubes need to be decontaminated as well. Low chloride potable water that has been demineralized, or water conditioned with a chloride neutralizer can flush out contaminating chlorides. Finally, abrasive blasting to remove the last vestiges of contamination in the tubing should then be deployed.

Chemical Treatment

Biocides or oxidizing agents can be used on the tubes to control biological activity. Biostats can be used after a biocide treatment to control future growth, a milder form of chemical control. In recent years, chemical treatment has fallen out of favor due to the toxic nature of the chemicals used.

Retubing

If severe pitting cannot be alleviated, complete retubing of the heat exchanger may be called for, particularly in older equipment that has run for consecutive years. Choosing a more appropriate tube material or accelerating maintenance can stave off recurring fouling and corrosive conditions; however, this option is extremely costly and may have to be done several times to prolong the working life of the apparatus. The bare tube surface will inevitably sustain pitting and bacterial build-up as long as they remain uncoated.

What about Heat Transfer?

Decades of service history and studies have proven that coatings can significantly improve heat transfer and overall performance. While the thermal conductivity of the coating alone is less than that of the metallic parent tube, this is offset by several factors.

The first factor is normal design consideration. Generally, heat exchangers are designed with a fouling factor of .001 or .002 BTU. Adding a coating to the tube ID impacts the thermal duty by a factor of .0006-8 BTU at fully dry film thickness, which is well below the pre-calculated design. Applying the coating can either totally eliminate the subsequent fouling or greatly reduce the accumulation of typical micro or macro fouling, mitigating the initial design consideration.

The second major factor is boundary layer-drag reduction. It is known that for an exchanger, about 70 percent of its total heat transfer resistance is a result of boundary layer drag. Tube wall friction due to fouling reduces designed flow and creates an insulating barrier of low velocity fluid. Polymer coatings reduce the friction at the tube wall substantially by a factor of 40, compared to metallurgy. Less friction decreases the boundary layer drag and substantially opens up the flow profile.

In observations at two separate refinery applications, data showed flow rate improvements of 80 and 100 percent in coated tubes compared to new “bare” tubes in the same fluid train. This increase in flow and the low surface energy of the coating contributes to the improved overall thermal efficiency of the heat exchanger in fluid service.

Coated tubes have also maintained 100% of their heat transfer efficiency over years of service without cleaning cycles In a separate industry study documenting delta t on water side and process side temperatures on a monthly basis , taking place over a 5year period coated heat exchangers remained at optimal thermal duty; whereas the bare tubes actually lost heat transferability over that period – dropping to below 50 percent on the same scale.

SIDEBAR:

Tips and Traps for Success

Carbon steel is a lowest cost material available for exchanger tubing, as much as 1/4 the cost compared to nickel and chrom/moly alloy materials, i.e., admiralty brass, 70/30 or duplex stainless steel. The inherent passivation of these high alloy materials in cooling water provides advantages when compared to the oxidation of carbon steel.

To maintain optimal performance of low-cost carbon steel tubes, cooling water flow rates, Ph levels and temperature must be maintained through an operating unit that may have many pieces of equipment tied to the same loop. It is common for refineries and chemical plants to promote an alloy upgrade as a replacement for carbon steel exchangers when aggressive fouling and corrosion impacts production units. The consideration of tube ID coating fits as a lower cost alternative to "alloy upgrade" for many carbon steel exchangers in cooling water service.

Polymer linings, such as high baked phenolics, phenol epoxy and novolacs epoxy, are commonly used in "product" environments, such as tankage, transport containers, and vessels. In ambient temperature conditions these linings provide resistance in wide range inorganic and organic acids, solvents, and hydrocarbons. Typical applications call for coating films to be applied at 10- 20 mils, and materials are often loaded with glass or ceramic pigments to inhibit porosity over time.

In heat exchangers, operating temperature and pressure are part of the equation when evaluating coating applications. The limits of high performance epoxy coatings in immersion service - neutral Ph water - are about 300F and about 400F in "dry" service conditions.

Selecting a lining material for thin-film applications suitable for cooling water service requires that a material provide the following mechanical characteristics:

- Homogenous coverage at films less than 12 mils,
- Adhesion resistance >2500 PSI,

- Resistance to thermal cycling and conditions exceeding operating temperatures, and
- Superior release of foulant such as calcium and sulphite deposits

The chemical and heat resistance properties of these linings is improved through a heat cure of the application - up to 400F for baked phenolics and to 250F for epoxy applications.

While exchangers in cooling water "tubeside" service typically have operating temperatures well within the limits of the coating, "product" side temperature conditions, and flow rates should be considered. Plant maintenance "steam out" will impact coating integrity if temperatures exceed out of service or dry "tubeside" coating limits.

A common size for heat exchanger tubing is 3/4" or 1.00" OD (outer diameter) tubes; the general limits of coating and full inspection of tube ID (inner diameter) coating is about 0.250" internal diameter. Tubes lengths to 60'long have been fully coated using an airless spray technique; "U" tube and hair pin design exchangers can be coated.

It is important to have all of the coated surfaces inspected for discontinuities, or "holidays." NACE has a procedure for a low voltage spark test for thin film coatings (<20 mils). This procedure uses a "fish tape" to wipe a wet sponge through each exchanger tube, a "beep" signals a "holiday," which the applicator should repair and recheck using the same procedure.

END SIDEBAR

It can Pay to Coat Your Tubes

The cost of coatings is easily a quarter of the cost of retubing, and once the tubes are recoated after their first ten-year period, they remain functional in perpetuity, requiring minimal maintenance for the rest of the life of the heat exchanger. Over a 12-year period, the costs saved by coating the tubes in a single heat exchanger could be as high as $8 million or more.

At a petrochemical refinery, six heat exchangers in the catalytic cracker recovery unit’s refrigeration section required maintenance. They were not operating efficiently, and upon examination, the diagnosis was severe tube corrosion and pitting. Two of the six exchangers required complete retubings due to age and damage over time. The four remaining exchangers had only been operating for three years, but still had telltale wear and tear, corrosion and pitting.

The refinery management opted to apply coatings to all six exchangers to prevent further damage and to decrease fouling from sulfate-reducing bacteria. By coating all the equipment, preventive maintenance in future would suffice to reduce stoppages, leak repairs, replacements and the need for any retubings – and the unit would see better performance from the equipment in the refrigeration area.

The results the refinery realized in taking the preventive measure of coating the tubes in six of their heat exchangers included improved pressure, measured in psi (pounds per square inch). The two older heat exchangers ran at more than 230 psi before retubing and coating. Afterwards, the coolant fluid pressure dropped 10% and remained steady within a range of 190 to 200 p.s.i, a desirable metric in its consistency. The additional cooling eliminated all gas recycling and kept the unit at a 96% recovery rate, even in the hottest summer months. Additional recovery netted 1000 BPD. Previous cleaning cycles for each exchanger averaged six months at 4 months each, and lost production of 10,000 BPD. During their first three years of “bare” pipe service, the four younger exchangers experienced an increase of pressure drop by 15 p.s.i per year. Once the tubes were coated, the pressure performance stabilized.

The refinery expects a 10-year minimum coating life for the exchangers, barring some minor tube-sheet touchups during maintenance periods. After a decade, the tube bundles may need to be grit-blasted and recoated if needed, but the life expectancy of the heat-transfer equipment is expected to exceed 20 years, conservatively, and the maintenance required is extremely minimal compared to the bare pipe alternative.

The Bottom Line

The methodology of tube coating is well proven and utilized by many of the world’s largest companies. There are now more approaches to produce the desired outcomes and reduce the losses incurred through inefficient heat transfer in petrochemical refining. The best way to start is to consider the various conditions and identify the most efficient method to clean and coat the tubular systems.

By taking care of the small details – paying attention to your tubes – you can save enormous expense in unnecessary maintenance, energy costs and enhanced operational efficiency over the lifetime of your heat exchanger equipment. One small step in tube coatings is a giant step forward for heat-transfer technology around the world.

For more information about coatings applications, contact www.curranintl.com.

Curran International is a coatings application provider, specializing in advising and applying the coatings for smaller diameter tubular systems such as those found in the heat transfer equipment at petrochemical refineries. In addition, Curran International manages cleaning of heat-transfer equipment at refineries for industry inspections, and advises on best practices for cleaning and coating tubular systems in heat-transfer equipment used in ships and in upstream and downstream energy applications.