

# One Small Step in Maintenance Can Save Millions in Operating Costs

*By Ed Curran, CEO, Curran International*

Tube corrosion, fouling and leakage in the heat-transfer equipment in refinery operations creates adverse circumstances in one area that often trickle through your entire business organization. Inefficient heat transfer in heat exchangers is a common bottleneck that affects refineries and energy operations around the world, requiring no small amount of attention and, at times, greater-than-anticipated expense.

There is one sure way to reduce plant and equipment downtime, slow depreciation on capital assets, improve energy efficiency, and attain fewer stoppages for routine repairs. One small step taken as a preventive measure can make a huge difference and raise the bar for maintenance standards, improve equipment reliability, enhance operational efficiencies, increase production capacity and - ultimately - yield higher margins for your business.

That small step consists of applying polymer coatings to the inner diameters (ID) of the steel tubes in your refinery heat-transfer equipment. This can provide benefits that go far beyond mere corrosion protection and basic tube maintenance.

The return on investment in cost savings for one small ounce of prevention can be worth millions per year. One US Gulf Coast refinery estimated it saved \$30,000 per month in reliable production, reduced downtime and lower energy costs, amounting to nearly \$2 million within the five years after coating the tubular systems in their heat exchangers. But the costs they saved in not retubing each exchanger increase by an additional \$3 million per retubing incident. Bare steel or costly alloy tubes need to be cleaned and replaced much more frequently than tubes with protective coating treatment.

## **The “Heat” of the Matter**

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 wear down faster than coated tubes, and their useful life is diminished, requiring costly retubing of the heat-transfer equipment as it ages.

In refineries, 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 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, but it remains an option that may not be commonly known.

### **The History of 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 a best 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.

### **Case Studies: Before and After Coatings**

A U.S.-based refinery tracked its heat exchanger costs over a 12-year period. Measuring leaks per month at six-month intervals from January 1993 through January 2005, the company saw dramatic improvement in reduced heat exchanger outages which averaged nearly 20 per month before coatings ("BC"). After completing a significant amount of coating the heat exchanger tubes in 2000, the refinery put the equipment back in action. By the following year, unplanned cleanings had dropped to an average of fewer than two per month and remained so through the rest of the tracking period.

The number of service years between leaks also increased significantly during this time, particularly from January 2002 to March 2004 and beyond. The number of years between service maintenance for leaks was trending toward 20, compared to "BC" days, when the number of service stoppages was as frequent as five or six times per year or, at best, every six months. Outages per month decreased to a mean of less than five *after* coatings, from a mean of nearly 15 per month "BC."

This represents a trend of 120 fewer service outages and 72 fewer repairs per year. With the cost of an outage at approximately \$5,000 per heat exchanger, the savings in outages amounts to \$600,000 per year, per exchanger. In addition, repair and replacement costs run as high as \$20,000 per tube bundle (in each heat exchanger). Total savings including retubing (replacement) costs and fewer outages on a single heat exchanger amount to 800,000 or more. If the tubes remained uncoated, the operator must retube approximately every three years.

The cost of coatings is normally a 25-50% of the cost of retubing, and once you recoat the tubes after their first ten-year lifecycle, they remain functional in perpetuity, requiring minimal maintenance. Over a 12-year period, the costs saved by coating the tubes initially could be as much as \$8 million or more.

With coatings and proper maintenance procedures now in place, this refinery is actually saving close to \$1.4 million per year. Combined, the outage and repair savings are around \$2 million per year. All in all, it pays to coat your pipes.

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At a different refinery, several heat exchangers in the catalytic cracker recovery unit's refrigeration section also required maintenance. They were operating inefficiently, 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, repairs, replacements and the need for any retubings – and the unit would see better performance from the equipment in the refrigeration area.

Since corrosion causes leaks and fouling reduces pressure generated by the systems in which the exchangers operate, the tube bundles in the exchangers were given three coats of polymer each, after being pre-treated with grit blasting to ensure their inner surfaces were prepared per NACE-1 standards for white metal cleanliness. Grit blasting also creates a more surface area so the coatings can achieve a better bond to the carbon-steel tubes when applied.

In the past, coating inner diameter piping had to be done in special shops, and could not be done onsite. That meant each heat exchanger had to be completely disassembled, shipped and then reassembled. This inconvenience and expense usually precluded the largest units from being transported or treated at all. However, techniques have progressed, enabling *in situ* application to take place under most circumstances. Coatings are applied with special equipment adapted to operate in tight areas, using a type of spray nozzle that can reach into the deepest, longest tubing from almost any narrow angle.

Tube coatings usually consist of polyamides, fluorinated products, phenolics and novolacs, depending on the base material to which they are applied. Coated tubes actually maintain a fairly steady level of heat transfer properties over time, contrary to conventional wisdom.

Before coatings, the only way to extend bare-tube performance life involved regular chemical cleaning and mechanical cleaning. The chemical cleaning actually produces toxic H<sub>2</sub>S gas and hazardous waste, and removing oxides also causes further corrosion due to structural degradation rendered to the tubes in the process.

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 PPI (pounds per inch). The two older heat exchangers ran at more than 230 PPI before retubing and coating. Afterwards, the pressure drop remained steady within a range of 190 to 200 PPI, a desirable metric in its consistency. During their first three years of “bare” pipe service, the four younger exchangers experienced an increase of pressure drop by 15 PPI per year. Once the tubes were coated, the pressure performance stabilized.

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

### **Tubular Surface Preparation**

While the grit cleaning method has been widely adapted for heat-exchanger tube cleaning, the question of tube wall erosion due to the cleaning procedures has also been raised and studied by certain end users and industry organizations. Using 90/10 Cu/Ni (copper-to-nickel) tubes to test the benchmark, the average dwell time is 30 seconds for grit-cleaning tubes to NACE 1, the standard for white-metal cleanliness. Next, grit-blasting tubes six-feet in length in two repeated tests for three minutes each yielded no measurable wall loss. This test of erosive potential from the cleaning method has been repeated many times and up to 10 minutes dwell time with no measurable wall loss.

Another vast improvement in surface preparation has evolved in the use of high-resolution video probes to verify grit-blasting cleanliness. It is now easier to identify residual scale and surface cleanliness and match it to an industry standard.

### ***In Situ* Application Advantages**

Earlier application methods by fill, drain and rotate worked well enough but could not be done on-site, or *in situ*. These also required high-solvent loading to control thickness and prevent coating set-up before solvent flash-off. Since solvents are recognized as being hazardous environmental contaminants, such practices are being phased out.

Application method refinements with a spray application approach apply a reliable, uniform layer of coating. Current application equipment can actually coat up to four tubes at a time at speeds of 6-feet per second (2-meters/second). Spray methods also allow for application of different coatings and solids content to 100 percent. Typically, there is a less than 1.5-mils (37.5-microns) differential in dry-film thickness for the tube ID circumference. Coatings can be applied to a pinhole-free condition and verified with a full-length holiday test designed specifically for tube ID.

The advantage of being able to apply coatings to tubes *in situ* may justify further explanation, though it should be intuitively apparent. In many refineries or plants,

condensers or heat-transfer equipment is enormous in size and weighs several tons. This makes it virtually impossible to remove and transfer for in-shop application, not to mention extremely costly if such a transfer were even possible. The development of flex lance coating equipment allows for on-site coating applications to some of the most roust equipment, and with the same quality mentioned above.

### **Common Coating Materials**

Polymer materials for heat-transfer equipment as a group are limited generally by materials that are functional at less than 12 mils (300  $\mu$ m) dry-film thickness, to avoid impacting heat transfer. Common coatings falling into this category and used for the heat exchanger ID coating include baked phenolics, epoxy phenolics, vitons, novolacs and thermoplastics. Coatings are chosen according to the service temperature and conditions in which they are to be applied, and how the application will occur -- for example, whether it is field (*in situ*) or shop-applied.

### **Thermal Conductivity**

Polymer tube linings have always suffered from a perception of heat transfer penalties due to their lower thermal conductivities vis-à-vis metallurgy, but case history has demonstrated just the opposite. Tube coatings can actually enhance heat transfer and overall performance to a significant degree. While the thermal conductivity of the coating is much less than the parent tube, its impact is offset by several factors.

The first factor covers normal design considerations. 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 full-dry film thickness, which is well below the precalculated design. Applying the coating either totally eliminates the subsequent fouling or greatly reduces the accumulation of typical micro-/macro-fouling, mitigating the initial design consideration.

The second major factor is the boundary layer-drag reduction. Fully 70 percent of total heat transfer resistance (HTR) across a heat exchanger tube is the slow-moving fluid coming into contact with the tube wall. Tube wall friction reduces this flow and creates an insulating barrier of low velocity fluid. Polymer coatings reduce the surface tension at the tube wall substantially, by a factor of 30 to 40 dynes per  $\text{cm}^2$  compared to bare steel in a non-oxidized or new condition.

Reducing friction reduces the boundary layer drag and substantially opens up the flow profile. Two separate studies show flow rate improvements of 80 to 100 percent with polymer coatings compared to new uncoated tubes in the same fluid train. This increase in flow and low surface energy of the coating contributes to the improved overall thermal efficiency of the heat exchanger in fluid service.

### **Quality Assurance**

Applying polymer coatings to the ID of heat transfer equipment can provide benefits such as increase duty heat transfer, eliminate corrosion, reduce or eliminate micro- and macro-fouling, improve the cleaning cycle, and enhance or improve perpetual equipment life with recoating.

Certain extreme chemical exposures, temperatures and high fluid or gas velocities can limit the efficacy of coatings. However, great benefits can be realized through applying coatings in the acceptable temperature and exposure that corresponds to the coating properties, guided by quality assurance (QA) techniques. While coating the ID of small-diameter and long-length tubes is effective, a full QA of every phase of surface preparation, coating application, and holiday testing can be adapted from today's current immersion lining standards.

Blotter tests or black light examination can confirm or eliminate the presence of hydrocarbons. Video scopes can verify and test surface cleanliness for grit blasting. Chloride testing is also viable, but usually on tube sheet areas. The most limited QA issue concerns DFT (dry film thickness) readings. Current instrumentation can only reach six inches (150mm) into the tube-end to verify adherence to the specification. If additional verification is needed, sample tubes can be coated, split and measured for verification of minimum DFT throughout the tube. Holiday testing can then be accomplished with high or low-voltage methods, adapted to reach all the way through the tube, with the sponges/brushes sized to fit snugly into the tube ID.

### **Bottom-Line Benefits**

Applying polymer coatings to the inner diameter of tubes in heat transfer equipment operating in refineries can provide benefits that increase heat transfer duty, eliminate corrosion, reduce or eliminate micro- and macro-fouling, improve cleaning cycles, and allow for perpetual equipment life with recoating. There are now more approaches to produce the desired outcomes and reduce the losses incurred through inefficient heat transfer in petrochemical refining.

The methodology 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 refinery operators around the world.

For more information about coatings applications, contact [www.curranintl.com](http://www.curranintl.com).

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*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.*