

## The Benefits of Tube ID Coatings in Heat-Transfer Applications

When heat exchanger fouling is causing operational disruption and downtime at the expense of your business, lost opportunity costs only continue to grow. Companies that pay attention to the small details involved in the proper maintenance, coating and cleaning tubular systems can realize significant cost savings in reduced downtime, improved energy efficiency and stronger feed outputs. Inefficient heat transfer in heat exchangers – the spherical bundle of hundreds of equal-length, small-diameter tubes most widely used in large-scale heating and cooling systems, power utilities and in chemical refineries – plays a critical role in adversely impacting business operations and bottom-line results.

In many cases, the losses from inefficient heat-transfer applications can amount to tens or even hundreds of thousands of dollars per day. Depending on the size of the business, however, it is possible to save millions, even billions a year by deploying appropriate maintenance techniques for tubular systems. One company in particular saved an average \$1 million per month in lost production in a single alkylation unit. By taking advantage of proper coatings and cleaning processes, you can dramatically enhance system performance and operational efficiency. Good tubular maintenance leads to long-term reliability and a host of additional benefits.

### Why Use Coatings?

Corrosive and mineral laden fluids that come into contact with heat transfer surfaces have always plagued heat-exchanger equipment. Historically, water treatment and periodic cleaning by hydroblasting managed this process, but the results were not always optimal. Now, refineries and utilities are applying polymer coatings to the tubular inner and outer diameters (ID and OD) of the heat-transfer apparatus. This practice has evolved and matured into a cost-effective remedy to reduce typical fouling and corrosion problems intrinsic to heat-exchange equipment. Improvements in coating materials, surface preparation, application and thermal conductivity, plus owner-operator data collection and analysis, have propelled tubular coatings toward viable heat transfer equipment (HTE) problem solving.

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, it was the industry's best option until the mid-1980s. By that time, utility companies in Italy began experimenting with air-atomized spray applications of epoxy phenolic developed by their engineers. They hoped to alleviate the huge volume of effluent discharge contaminating the cooling water inlets with a rich broth of bacterial nutrients at several power stations. This was causing excessive biological fouling in the main steam-condenser tubes, adversely affecting condenser efficiency and power-generation capacity.

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By coating the copper-nickel tube interior with the epoxy phenolic compound, the Italians achieved excellent results and improved fouling and corrosion resistance to the main condensers, which actually restored the generating units to normal operating capacity.

Across the Atlantic, a Florida-based utility was experiencing rapid-through wall leaks two years after a retubing. In 1990, in collaboration with the [Electric Power Research Institute](#) (EPRI), they initiated a joint study to investigate alternatives to expensive retubing. Together, both organizations experimented with coating the tube ID with epoxies as a best practice. They brought the Italian engineers to Crystal River, Florida, to demonstrate their technology at a corporate power-generation site. The joint testing revealed some invaluable findings about tubular coating materials, surface preparation and cleanliness. It also confirmed that a uniform layer of coating was an effective solution. However, further improvements were still needed, and EPRI embarked on a more in-depth study. They looked at all possible methods and noted the following findings.

### **Tube Surface Preparation**

First, tubes were cleaned and profiled using typical sandblast nozzles held up against the tube ends and directing the grit into and through the tube. The 36-foot (12-meter) tubes had to be cleaned from each side, which consumed large amounts of grit as well as time and labor, but still left the center sections of the tubes insufficiently clean for the long-term. A US-based coatings application firm developed and experimented with several new grit-blasting methods such as lance blasting, radial-pattern blasting, swirl blasting and high-velocity grit blasting (HVGB).

In 1993, an EPRI demonstration project successfully proved the efficacy of lance blasting. However, it was cumbersome to manage the length of the lances, which ranged between 20 and 40 feet (6-13 meters). There were also safety issues, as the metal lances tended to wear through at the hose-to-lance transition coupling after eight hours of cleaning. Radial nozzles mounted on the end of lances also suffered excessive wear and tear, not to mention mechanical damage from insertion into the tube ends. It was clear that grit-blasting procedures needed further development and improvements.

A gas dynamics lab at a university in the northeastern U.S. had previously researched the grit-blast nozzle design. They were provided data to develop a new design for a grit-blasting nozzle specifically to clean tube IDs. Typical sandblast nozzles attained an air speed of 1115 ft/s (340 m/s) and grit velocity of 440 ft/s (130 m/s), which was inadequate to maintain the grit velocity (kinetic energy) needed to clean tubes more than 10-feet (3-meters) long. The new design increased air speed to mach2 2230 ft/s (680 m/s) and grit velocity to x 796 ft/s (243 m/s). This increased the kinetic energy in the grit particles by 81 percent, and proved highly effective as a tube ID cleaning method. Grit blasting using this special sandblast nozzle has since become the standard cleaning method for tubes prior to coating. To date, millions of tubes have been cleaned to white metal for surface preparation prior to coating.

Unlike hydroblasting, this cleaning process is highly predictable in getting the cleanliness results acceptable for the varied inspection methods. Video probe inspections also verify tube cleanliness, helping companies comply with the rigorous standards demanded by the industry. Inspections have always sought reliable, verifiable and predictable methods to ensure these cleanliness standards are met and applied consistently.

Grit blasting has proven so effective that it is now widely used to clean tubes with tenaciously adhered deposits that UHP (ultra-high pressure) water jetting could not

remove. An entire industry has grown out of the need to clean tubes prior to LOTIS, IRIS, RFET, and other NDT inspections.

### **Erosion Potential**

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 initially by EPRI. Using 90/10 Cu/Ni (copper/nickel) tubes to test the benchmark, the average dwell time is 30 seconds for grit-cleaning tubes to NACE 1, which is the standard for white metal cleanliness. After repeated tests of up to 10 minutes' dwell time, no measurable wall loss occurred.

A helpful advance in surface preparation occurred in the use of high-resolution video probes to verify tube interior cleanliness for grit blasting. The latest video probes can now identify extremely small surface imperfections, making it easier to spot residual scale and confirm surface cleanliness, matching it to the industry standard.

### **Application Development**

Earlier application methods by fill, drain and rotate worked well enough but could not be done on-site, *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 the 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.

### **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 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, bisphenol A and F 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 or shop-applied. [Table X provides a basic evaluation of coatings and their suitability.](#)

[\[Need to add this graphic\]](#)

Tube interior coatings can be inspected with similar tank lining methods adapted specifically for small ID tubes. Blotter tests of black light examination can confirm or eliminate the presence of hydrocarbons. 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.

### 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. Decades of service history have shown that 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.

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The second major factor is the boundary layer-drag reduction. ~~About 70 percent of total heat transfer resistance (HTR) across a heat exchanger tube is the result of boundary layer drag.~~ 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 ~~40 dynes per cm<sup>2</sup>~~ compared to metallurgy 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.

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See Table X.

### A Case for Cost Savings

One Gulf Coast 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 visible improvement in reduced unplanned cleanings (UCLs), ranging as high as 17 a month and higher until after July 2001, to less than two per month.

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The number of service years between leaks also dramatically increased during the period, particularly from January 2002 to March 2004 and beyond. The number of years between service maintenance for leaks was trending toward ~~20 years~~, according to the data, whereas in earlier days, before coatings, the number of service stoppages was ~~averaging 6.5 times per month~~. Outages per month have dropped to a mean of less than ~~one in recent years, as the most problematic exchangers have been coated~~.

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This represents a trend of 120 fewer service outages and 72 fewer repairs per year. With the cost of an outage at \$5,000 per heat-exchanger bundle, that translates to savings in outages of \$600,000 per year. In addition, repair and replacement costs run as high as \$20,000 per bundle. With coatings and proper maintenance procedures now in place, this refinery is saving approximately \$1.4 million per year. Combined, the outage and repair savings exceed \$2 million in savings per year. But the estimated cost savings do

| not account for the price of bundle retubing, at an estimated \$500,000. All in all, it pays to coat your tubes.

### **Best Practices**

Applying polymer coatings to the ID of heat transfer equipment can provide benefits such as increased heat transfer duty, eliminate corrosion, reduce or eliminate micro- and macro-fouling and associated cleaning cycles, increase process throughput, and provide 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. Coating the ID of small-diameter and long-length tubes is working effectively, a full QA of every phase of surface preparation, coating application, and holiday testing can be adapted from today's current immersion lining standards.

The methodology is now well proven and utilized by the world's largest companies. Now there are more approaches to produce the desired outcomes and reduce the losses incurred through inefficient heat transfer in power generation and petrochemical refining. The best approach is to consider the various conditions and use the most efficient method to clean and coat the tubular systems. For more information about best practices, contact [www.curranintl.com](http://www.curranintl.com).