Maintenance of Heat-Transfer Equipment Enhances Operational Efficiency

By Ed Curran, CEO, Curran International

Companies that take care of the finer details in properly maintaining, coating and cleaning their heat-transfer equipment (HTE), known as heat exchangers, can realize significant cost savings -- in reduced downtime and depreciation on capital equipment, improved energy efficiency, and stronger feed outputs. Inefficient heat transfer in heat exchangers is a common bottleneck that plagues refineries and energy operations around the world, requiring no small amount of attention and, at times, and greater-than-anticipated expense.

In petrochemical refineries, heat exchangers play a mission-critical role in cooling and processing the feedstock. It is of paramount importance to preserve these systems to ensure they operate at maximum efficiency and prolong their working lives through good maintenance practices. Since the cost of poorly performing heat-transfer equipment can cost well into the millions, many operators have found that it is usually preferable to maintain maximum operation efficiency and extend the life of the tubes through coating their inner diameters with phenolic materials especially suited for this purpose.

While the type of steel pipe and tubular inner diameter (ID) coatings may differ between oilfield, refinery and pipeline applications, this preventive coatings approach holds many advantages, and can save millions in operational costs over time.

In the past, coating inner diameter piping had to be done in special shops, and could not be done onsite. That meant each heat exchange had to be completely disassembled, shipped and then reassembled; it precluded the largest units from being transported at all. Progress in techniques has enabled in situ application to be a common practice by now, and coatings are optimized to match the type of steel of the tubes for best effect. Coatings can consist of polyamides, fluorinated products, phenolics and novolacs, depending on the base material to which they are applied.

Before coatings, the only way to extend tube lives involved chemical cleaning and mechanical cleaning or upgrading to expensive alloys. The chemical cleaning actually produces toxic H_2S gas and hazardous waste, and removing oxides also causes further corrosion due to structural degradation.

A Case for Operational Efficiency

One Gulf Coast refinery tracked its heat exchanger costs over a 12-year period. Measuring outages per month for cleaning or leaks at six-month intervals from January 1993 through January 2005, the company saw visible improvement in reduced monthly outages which ranged as high 17 or more per month until after July 2001, when they dropped to fewer than two per month.

See Appendix A – *Graphic 1 "Cooling Water Coated Steel Bundle Leak Run Chart" showing the drop in Monthly Leak Rates after coatings in heat exchangers operating at a Gulf Coast Refinery.*

The number of service years between leaks (see Appendix A, Graphic 2) 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.

This represents an improvement of 120 fewer service outages and 72 fewer repairs per year. With the cost of an outage at approximately $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. These estimated cost savings do not even account for the price of bundle retubings or higher alloy replacements, at $500,000 (estimated) per incident, but that should also be considered in the assessment. Additionally, the greatest potential economic benefit is maintaining optimal or additional process throughput which, while harder to quantify, can quickly add vast amounts of net revenue to an existing unit.

The following two case histories represent the known examples of process improvements

In another part of the same company's refinery operations, the C-4 recovery unit, there were several heat exchangers (Feed Flash Condenser, Deethanizer Overhead Condenser, Ammonia Condenser), that historically had been "bad actors." The heat exchanger tubes were suffering severe fouling, corrosion and pitting, which plagued unit reliability and cost by frequent outages for leak repair and cleaning which cut bask feed rates to the CAT crackers. Of the six exchangers chosen for coatings, two exchangers required complete retubing before coating. The other four were three years old at the time, but had ~50% remaining tube wall, so the company opted to apply coatings to all six heat exchangers to prevent further corrosion from sulfate-reducing bacteria and to decrease fouling from calcium deposits. By coating all the exchangers, they could use preventive maintenance to reduce further stoppages for leak repairs, retubings, and cleaning cycles.

The results realized in taking the preventive measure of tube I.D. coatings for their six heat exchangers included improved CAT gas cooling in the heat exchangers, which ran at more than 230 lbs in the older equipment before retubing and coating. After the coated exchangers were put in service, the coolant fluid pressure dropped 10% and remained steady within a range of 190 to 200 lbs. The additional cooling eliminated all gas recycling and kept the unit at 96% recovery rate even in the hottest summer months. This netted an additional recovery of 1000 bpd. Previous cleaning cycles for each exchanger averaged six months at 4 days each, and lost production of 10,000 bpd. They now have more than 9 years of service and have never been taken out of service for cleaning.

At a west coast US refinery, the alky effluent refrigerant condensers had historically created bottlenecks for the Butane gas cycle. New or "just cleaned" exchangers would start with flow rates of 5,000 gpm and quickly depreciate from fouling within six months to 700 gpm. This forced the 6,000hp compressor to recycle 30% or 2,000hp of the Butane Unit. Two exchangers were ID coated in 2004. Since installation the exchangers have maintained flow rates of 5,000 gpm. Back pressure on the compressor has dropped 5 PSI and all gas recycling has been eliminated even on 100F days. The unit has now raised production from 13,000bdp to 16500bdp consistently over the last three years.

Since corrosion causes leaks and fouling reduces pressure across the exchangers, 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 greater surface area so the coatings can achieve the maximum chemical bond to the carbon-steel tubes when applied.

The plant expects a 10 year minimum coating life, barring some minor tube-sheet touchups during maintenance periods. After a decade, the tube bundles can be grit-blasted and recoated if needed. The life expectancy of the heat-transfer equipment is expected to exceed 20 years and can be continued indefinitely with repeated coating applications.

Heat-Exchanger Performance in other Energy Operations

Heat exchanger performance can have a significant impact on bottom-line results. With proper care and maintenance of the apparatus, using appropriate coatings and cleaning processes to enhance and extend the active life, operators can realize a score of benefits that positively impact the life span of the project, production, plant or pipeline.

In the oilfield, the petroleum and natural gas must be separated, and the crude could contain contaminants such as hydrogen sulfide (H_2S) turning it “sour.” Heat exchangers are used to cool the crude, as it is being separated and stored. The crude oil is transported to the processing plant from the storage tank, where it undergoes treatment that involves cooling with a heat exchanger during the separation process to remove the H_2S and water. Because of the highly corrosive nature of the H_2S, the steel material of the pipes must be of a sufficient quality to resist corrosion, and the coatings applied must be resistant to higher-heat temperatures.

Even expensive steel alloys can deteriorate from corrosion in the oilfield’s heat exchanger tubes. By coating their carbon steel tubular systems, operators can generally expect better corrosion protection compared to that of non-coated (mild) carbon steel, and by doing so, both the upstream oilfield and downstream petrochemical operators can realize reduced operating costs.

In gas pipeline transmission, natural gas is compressed and cooled at approximately every 100 miles at compression stations, to keep the pressure high enough to ensure its movement to the destination. The compression stations restore the gas’ loss of pressure due to friction along the pipelines. Once the gas is recompressed, it is run through a heat exchanger to cool it down but maintains the sufficiently high pressure – 1000 to1500 PSI (pounds per square inch) is the upper limit -- so it can be transported. Smaller diameter pipes can support higher pressures, as their wall thickness is much greater, but the high heat requires appropriate steel and epoxy coatings to resist deterioration over time.

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 operation, however, it is possible to save millions, even billions a year by deploying appropriate maintenance techniques for tubular systems. One company managed to save 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.

Callout Box:

The History of Coatings

Fluids that come into contact with tubular 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, 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 heat-exchange equipment. Improvements in materials, surface preparation, application 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, it was the industry's best option until the mid-1980s. By 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, which actually restored the generating units to normal operating capacity.

Today, ID coatings are commonly considered a best practice for extending the performance and lifecycle of a heat-transfer system. It took decades of trial and error in upstream, midstream and downstream applications to find the right solutions for each ID, bare metal, and chemical coating compound to optimize the practice for each and every condition and situation.

Coating Materials

Decades of service history have shown that tube coatings can actually enhance heat transfer and overall performance to a significant degree.

Common coatings 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 or shop-applied.

One of the best known coatings for oilfield applications is a thermoplastic, polyphenylene sulfide (PPS), which is widely used for injection molded parts in oilfield equipment, as well as in cookware, automotive engine parts, circuit boards, aerospace and in commercial and residential heater exhaust components. It is a viable thin-film corrosion barrier for tubular products that can function well even at high temperatures, exceeding 400 degrees F (200°C). It provides excellent protection to carbon steel substrates and serves as a good alternative to an alloy. This is being developed and utilized as the next generation of heat exchanger coating for heat transfer equipment. PPS can be combined with PTFE and other pigments to create a thermally conductive, self healing, thin film thermoplastic that can operate at 400F continuously.

Insert graphic 1, Appendix B – Table of coatings and their suitability.
Polymer tube linings have always suffered from the perception of heat transfer penalties due to their lower thermal conductivities vis-à-vis metallurgy.
While the thermal conductivity of the coating is 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 certain fouling factor (.001 or .002 btu/hr) coating to the tube ID impacts the thermal duty by a factor of .0006-8 btu/hr l-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. Friction at the tube wall 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 cm^2, compared to bare steel or metal alloy in a non-oxidized or new condition. Reducing friction reduces the boundary layer drag and substantially opens up the flow profile.

Bottom-Line Benefits

Applying polymer coatings to the ID of heat transfer equipment in petrochemical refineries can provide benefits that increase heat transfer duty, eliminate corrosion, reduce or eliminate micro- and macro-fouling, improve the cleaning cycle, and allow for perpetual equipment life with recoating.

The efficacy of coatings is somewhat limited by certain chemical exposures, elevated temperatures, and high fluid or gas velocities. 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 conceptually 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.

Video scopes can verify and test surface cleanliness for grit blasting. Chloride testing is also viable, but usually on tube sheet areas. Blotter tests or black light examinations can confirm or eliminate the presence of hydrocarbons. The most limited quality assurance (QA) issue revolves around DFT (dry film thickness) readings. Current instrumentation can only reach six inches 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 a low-voltage, wet sponge method, adapted to, extended and led to reach all the way through the tube, with the sponge sized to fit snugly into the tube ID.

There are now more approaches to produce the desired outcomes and reduce the losses incurred through inefficient heat transfer in oilfield applications, pipeline transmission and chemical refining. The best starting point is to consider the various conditions and use the most efficient methods to clean and coat the tubular systems. By taking care of the small details -- adhering to best practices found by the energy industry over decades of development and testing, and deploying correct procedures to coat and clean tubular systems in heat-transfer equipment – the results will speak for themselves.

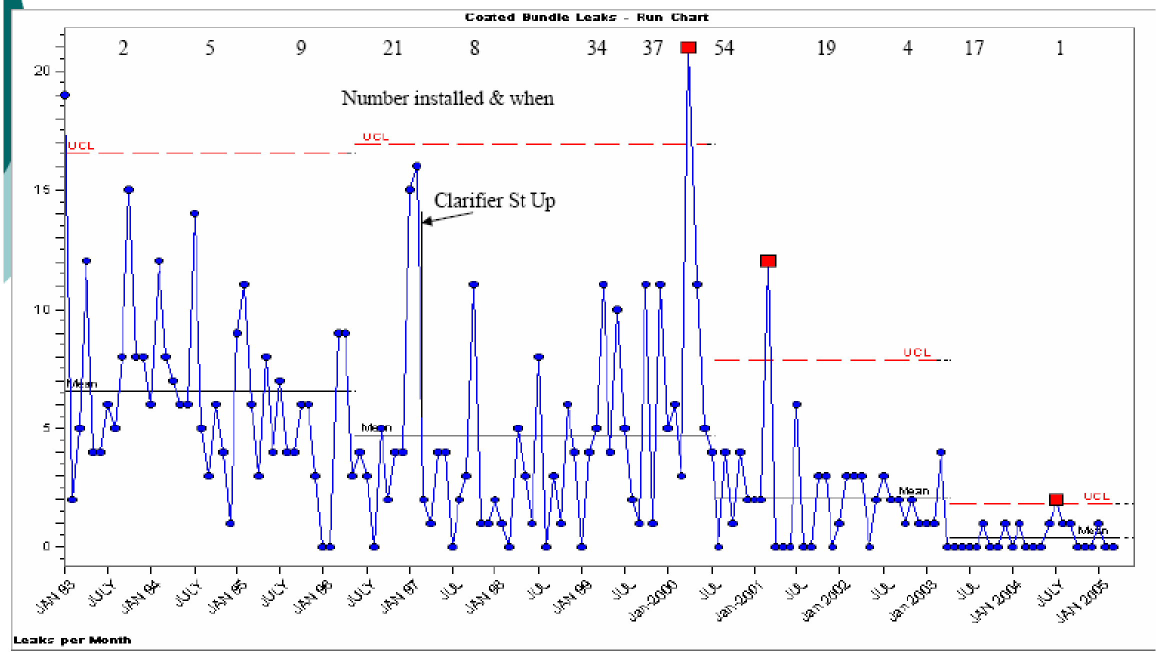
Reduced downtime, slower depreciation on capital, assets and equipment, fewer stoppages due to repairs or outages and better maintenance procedures all contribute to improved operational efficiency, gains in production capacity and, ultimately, higher margins for the business. One small ounce of prevention in coating your heat-transfer equipment tubes can yield giant-sized returns on your capital investment.

For more information about best practices, contact www.curranintl.com.

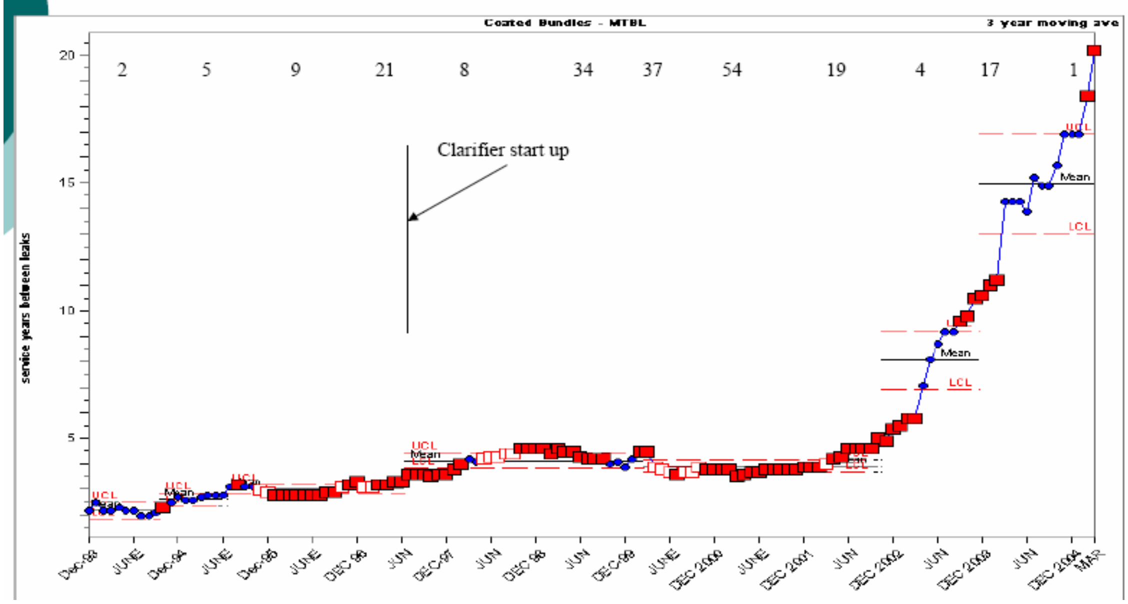
Curran International specializes in advising on and applying the correct ID and OD coatings for smaller diameter tubular systems such as those found in the heat transfer equipment operating at petrochemical refineries, in the oilfield and in pipeline recompression stations.

APPENDIX A: Graphic 1 - Unplanned Cleanings Chart

LKC Cooling Water Coated Steel Bundle Leak Run Chart



LKC Coated C Steel Cooling Water Bundle MTBL



Graphic # 2 (Optional, showing the number of svc yrs between leaks growing)

APPENDIX B, Graphic 1

Curran international
Applying coating solutions

Exchanger thin-film coatings:

7435/36 Phenolic Epoxy

•Phenol epoxy resin, amine adduct cured - used for cooling water tube ID applications
•Resistance to organic acids, solvents, hydrocarbons, alcohols
•Immersion resistance to 250°F; dry resistance to 350°F
•Field or shop applied; DFT IDs 6-9 mils; 12-16 mils heads, components.

4310 Novolac Epoxy

•100% solids novolac – modified cycloaliphatic amine hardener
•Ph 0.5 – 14; Resistance to inorganic acids, alcohols, and hydrocarbons
•Immersion resistance 250°F, "dry" limits to 375°F
•U-tube coating avg DFT 8-12 mils; may be applied to 80 mils DFT

Curralon – PPS

•Commercially developed with DOE – wide chemical resistance
•Field applications to >350°F, lab tested at 550°F brine
•Shop applied thermo-melt – new fabrication

Saekaphen (GmbH) – Licensed Applicator

•Globally recognized formulator of thin film tubular linings
•Acid to alkaline resistant linings, immersion service to 200°C
•Shop applied only, new fabrication, heat cured

Protective Lining Systems:

•Epoxy, vinyl esters, glass flake, ceramic filled systems
•Airless, plural, troweled, or roller/brush systems
•Pressure vessels, waterboxes, tubesheets, transport tanks
•Electric arc and flame spray "metallized" linings, turnkey field or shop applications
•Rubber Linings, neoprene, turnkey application capabilities
•Low EMR, approved at XOM, Citgo, Valero, Chevron, Motiva, ConocoPhillips, Shell

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