Specify the right fin type for air-cooled heat exchangers

Improved design selection can mitigate corrosion attacks on equipment and avoid tube failure

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Air-cooled heat exchangers (ACHEs) enhance heat transfer through fins. They are extensively used to remove heat from process fluids (liquid or gas) by transferring it (heat) to atmosphere. The process includes conduction from the fluid through the tube to the fin and convection from the fin to atmosphere.

Corrosion is a leading factor that degrades ACHEs' performance. Operating in harsh environments, air-borne contaminants mix with rainwater, seep into the tube-to-fin bond and corrode the tube and fin materials. Consequently, heat transfer efficiency degrades over time; tube failure often shortens the exchanger's service life. Depending on the process fluids and operating environment, users must specify and demand the best type of finning for ACHEs. Several examples describe the types of finning available and their performance under various processing conditions.

Loss of performance. When using ACHEs, the heat encounters a series of thermal resistances as it flows from the fluid to atmosphere. These resistances are listed in Table 1. Whenever the performance of an ACHE has degraded, it can be traced to either reduced airflow or increases in one or more of the thermal resistances listed in Table 1. Items 1, 3, 4, 6 and 7 are basically fixed characteristics and not subject to change over time. However, items 2, 5 and 8 can change with time.

Table 1. Thermal resistance found in ACHE applications

1. Thermal conductivity of the fluid
2. Internal fouling resistance
3. In-tube "film" resistance
4. Thermal resistance of the tube metal
5. Tube-to-fin bond resistance
6. Thermal resistance of the fin metal
7. External "film" resistance
8. External fouling resistance

Correction possibilities. Where reduced airflow degrades performance, external cleaning of fins or servicing of fan and/or drive can improve heat-transfer efficiency. External cleaning of fins reduces both external fouling resistance (item 8) as well as aerodynamic resistance. An increase in in-tube fouling resistance (item 2) can often be corrected by cleaning. When performance degradation results from increased tube-to-fin bond resistance (item 5), there is no remedial solution for this progressive failure except for tube replacement.

Conditions affecting tube-to-fin bond resistance are the most important factors in the fin's effectiveness to transfer heat from the tube to air. All heat movement from the tube to the fin passes through the tube-to-fin bond resistance, located at the fin "root."

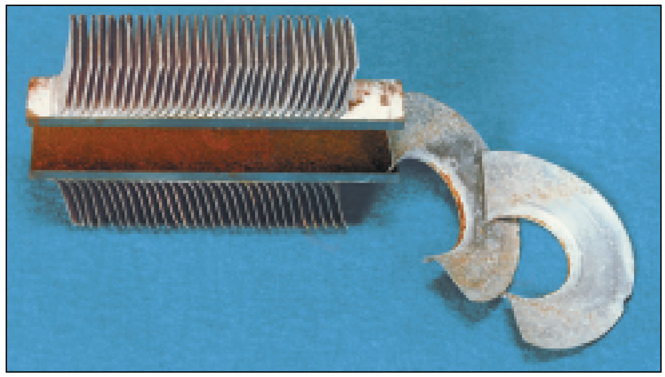

Fig. 1. Cut away view of the wrap-on fin for an ACHE.

"Root" of the problem. The two basic causes of increased thermal resistance at the tube-to-fin bond are: 1) corrosion at the fin base or root, and 2) loss of contact or bond pressure. Both conditions generally can occur over time. These problems are not likely to appear in a newly installed ACHE, regardless of the finning type.

Fin-root corrosion occurs when airborne contaminants, such as salt found in all coastal or marine environments, mix with rainwater. This seeps into the tube-to-fin bond, thus causing chemical reactions to occur at the fin root where the temperature is highest. Consequently, decomposition of the fin material and formation of metallic salts and oxides create a thermal insulation between the tube and fin at its root. Where electrolytic potential difference exists between tube and fin materials, corrosion is greatly accelerated.

The loss of tube-to-fin contact or bond pressure occurs, most frequently and rapidly, in cyclical ACHE services. Heat from the process fluid causes the tube to expand. This expansion, in turn, stresses the "hoop" of the fin. When the ACHE is out of service, the tube contracts and relieves the stress on the fin material. Fin material, being less resilient than the tube, tends to stretch and loosen progressively over time.

Fin types. Three basic fin types are used for ACHE tubes. They are wrap-on, embedded and extruded and are applied to fluid handling tubes as follows:

Wrap-on fins are attached by feeding a thin strip of heat conducting metal (usually aluminum) into a

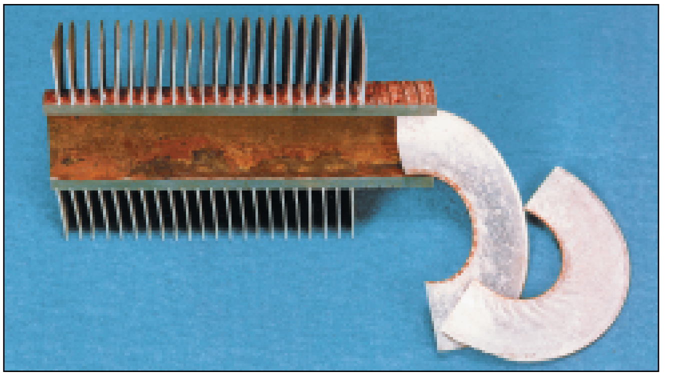

Fig. 2. Cut away view of the embedded fin for an ACHE.

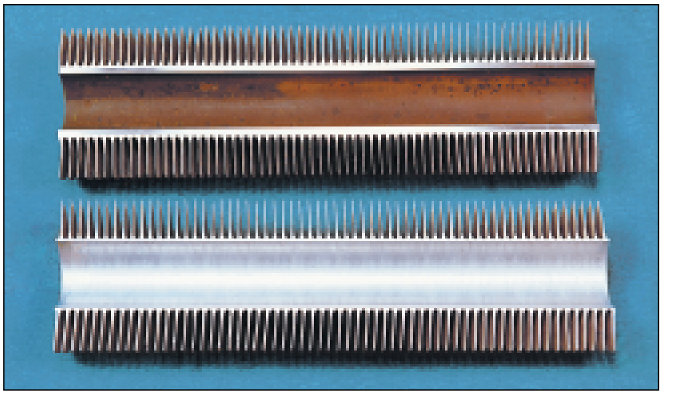

Fig. 3. Cut away view of the extruded fin for an ACHE.

machine, which first forms a small "foot" at one edge of the strip. This foot is usually a single 90° bend ("L" base) or a double 90°–180° bend ("T" base) at the fin root. The strip is then wound tightly around the tube. Tension of the fin strip is retained by stapling or clamping it with a collar at both ends of the tube (Fig. 1).

Embedded fins are applied by first plowing or rolling a continuous spiraling groove into the outer surface of the tube. This wall thickness must allow for the groove depth. A strip of fin material is then wound on edge into this groove. Following strip insertion in a continuous process, the machine peens or rolls the tube material adjacent to the groove tight against the inserted fin root. The tube material must tightly grip the fin root to ensure good heat transfer (Fig. 2). Such gripping can only by confirmed through a specified pull test.

Extruded fins are applied by forming the fins from the parent metal of a tubular aluminum sleeve into which the fluid handling tube has been inserted. The telescoped tube and aluminum sleeve combination is fed into a machine with rotating dies, which extrude or literally squeeze the fins out in a close spiral from the aluminum sleeve. This extrusion raises the fins to a required height, leaving a substantial thickness of aluminum totally encasing the fluid-handling tube (Fig. 3).

Differences. *Wrap-on fins* are, generally, the least expensive. Aluminum is the most common ACHE fin material; however, wrap-on fins can be constructed from a variety of materials. Equally important, *wrap-on fins* are the most susceptible to fin-root corrosion. Various methods attempt to protect wrap-on fins from root corrosion such as overlapping "L" or "T" base fins. Unfortunately, none of these methods produce a completely watertight seal between the fin material and tube. If corrosive liquids seep beneath the fins anywhere along the tube's length, corrosion will spread, thus leading to permanent failure of the tube-to-fin bond.

Embedded fins are also available in a variety of materials. In most cases, they have about the same initial cost as wrap-on fins. However, in applications when expensive alloy fluid handling tubes are required, the total cost can be greater than wrap-on fins and can even cost as much as extruded type. This expense is due to the additional wall thickness needed in the fluid-handling tube to accommodate the fin groove.

Root corrosion is less pronounced with embedded fins than with wrap-on fins, but it can still occur. The edge winding of the fin material strip produces considerable stress in that material. Edge winding causes one edge of the strip to be stretched while the other edge is compressed. The strip becomes tapered in thickness from ID to OD. At the ID, the material is linearly compressed, not uniformly, but in a repeating set of waves. Where the strip is thinner, it is not gripped as tightly in the grove as where the material is thicker. In the loosely gripped areas, liquid can enter this groove and allow corrosion to occur. Conversely, thermal stretching and loosening of fins is minimized in embedded fin tubes, when the fins are applied under strict quality control requiring a specified pull test procedure. Also, embedded fins can handle higher temperatures than the other types.

Extruded fins are initially the most expensive of the three fin types and are only available in aluminum. The additional expense comes entirely from the greater quantity (weight) of fin material (aluminum) required. When operated within design temperature limits, extruded fin tubes have the most stable performance over time of the three fin types. The pressure required to extrude fins from the aluminum sleeve ($1,200^+$ psi) creates a "pressure bond" between the two materials that guarantees efficient heat transfer. They are extremely resistant to corrosion at the fin root, as the aluminum fin material completely encloses the metal of the tube, except at the very ends of the finning where tube-coating methods can be applied.

Solutions. There is no repair for ACHEs with loose or root corroded fins short of re-tubing or replacement. Performance will continue to degrade as long as it remains in service. Those problems can be avoided, however, through initial fin type selection. When specifying the fin type for an ACHE, three major factors should be considered. They include the environment for the installation, operating temperature of the unit and the required service life.

In most refineries and chemical plants, and all coastal or marine locations, air contaminants exist when combined with rainwater, produce a corrosive electrolytic solution. Airborne concentrations of these contaminants can be extremely low, yet still result in a corrosion problem. ACHEs usually operate continuously, and the fin-root area contains millions of minute crevices where contaminants can collect and concentrate.

Initial-vs-lifetime cost. In the refining and petrochemical industry, long-term equipment reliability is crucial for return on investment. Lost production from equipment degradation or unplanned shutdowns can ruin a process unit's balance sheet.

The cost difference between extruded and wrap-on finning, although relatively small, is not a figure that can always be ignored. However, when evaluated over the operating life of the unit, and avoidance potential shutdowns and lost production, it becomes a classic case of "pay now or pay later." The "now" is usually much less expensive than the "later." As a "rule of thumb" when selecting fin types, evaluation over a minimum of five years is recommended. With very few exceptions, when an ACHE is planned for an operating life of five years or more, extruded fins will be economically justified over wrap-on. An exception to this rule might be considered under these conditions:

1. In low-process temperature, noncyclical services without airborne contaminants
2. In depleting services where the cooling demands naturally decrease over time (such as certain oil or gas production applications)
3. In "temporary" applications where the desired operating life of the ACHE is short (less than five years)
4. Combinations of the above.

Improving performance. Definite performance differences of various ACHE fin types have been proven scientifically.[1] Deviations of ACHE performance increases over time, especially when operating and environmental conditions that degrade the heat transfer efficiency at the fin root. Once degradation has begun, it cannot be reversed; it proceeds progressively. Only complete tube replacement can restore performance on a degraded ACHE. The corresponding differences in the cost for ACHE fin types varies directly with the quality of the product. Most leading ACHE manufacturers offer all three types of finning. The end user must determine, specify and demand the type of finning for each application.

LITERATURE CITED

[1] Smith, E. C., A. Y. Gunter, and S. P. Victory, "Fin Tube Performance," *Chemical Engineering Progress*, July 1966.

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