CHEMICAL ENGINEERING

Operations & Maintenance

Get More Life Out Of Heat Exchangers

Putting sleeves into the tubes of tubular exchangers can reduce erosion, enable reactivation of tubes disabled by perforations or worn walls, or bridge discrete points damaged by cracks

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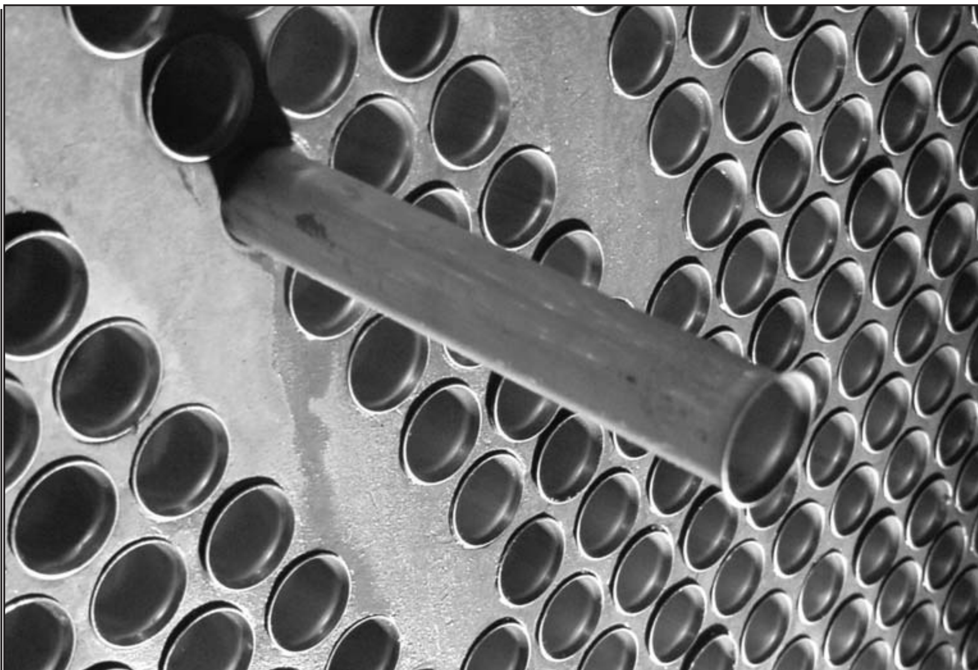


Heat exchanger sleeving, a money-saving technology generally associated with the electric power industry, is drawing increasing interest from engineers in the chemical process industries (CPI), as well.

Sleeving consists of expanding thin tubes (sleeves) into the tubes of a heat exchanger. The expanding process produces a residual, interfacial fit pressure between the outside surface of the sleeve and the inside surface of the tube. The sleeves may be short, for instance about 6 to 16 in., or may extend for the full straight length of the tubes. Typical sleeve thicknesses are 0.01 to 0.03 in., depending upon material of construction and thickness of the original tubes. In addition to the expansion step, sometimes the inner end of the sleeves is welded to the inside wall of the tube.

In tubular heat transfer equipment in power plants, sleeving has long been used for one or more of these purposes:

- To reduce the prospect of inlet-end tube erosion (short sleeves for this purpose are also called ferrules, and their use is called ferruling)
- To restore tubes to service that had been plugged by plant personnel because of known perforations in discrete, identifiable locations
- To restore tubes to service that had been plugged because their walls had become excessively thin
- To bridge failures in discrete locations of tubes that are otherwise intact; for example, if a tube has a circular crack just beyond the inner face of the tubesheet

Before applying sleeving to similar problems at CPI plants, it is useful to: be aware of the sleeving methods and equipment available, be able to determine how sleeves affect the heat transfer performance of heat exchangers, and be able to calculate the changes in pressure drop through the tubes.

Utility-plant roots

It is understandable that sleeving first made its name at power plants, where planned feedwater-heater and steam surface-condenser life may be as long as 40 years [*1*]. Power stations defer replacing feedwater heaters as long as they can because it is costly and time-consuming, and they seldom replace steam surface condensers at all. Full-length sleeving in those condensers is an alternative for power-plant management, as are the options of continuous cleaning of the tubes, cleaning during outages, replacement of individual tubes, full retubing, and ferruling the inlet ends of the tubes.

Admittedly, planned heat-exchanger life in the process industries is seldom as long as ten years. So, many heat exchanger installations are designed with ease of replacement and/or onsite retubing in mind. Whereas it would not be economical for a power station to keep spare feedwater-heater bundles on hand, many petroleum refineries and other CPI plants keep spares in inventory; they replace bundles in which the tubes have deteriorated with those spares, and then retube and store the original bundles. Furthermore, the life of the tubes in a CPI heat exchanger might be so short that the user considers it to be expendable if the cost of retubing approaches the exchanger's replacement cost.

Despite these facts, the engineers charged with minimizing maintenance and replacement costs at CPI plants are increasingly viewing sleeving as an option for extending the lives of exchangers with high rates of tube deterioration. Sleeving is also making its appearance in CPI heat transfer equipment to protect tube inlets from erosion and, as with power plants, to restore deteriorated and plugged tubes to service.

Three methods of sleeving

Ball expanding: The earliest method of expanding sleeves into place was to force through the sleeve a lubricated steel ball slightly larger than the sleeve's inside diameter. However, this method had two disadvantages: contact between the outside of the sleeve and inside of the tube was seldom uniformly tight; and lack of control of the sleeving process could bulge the tube between the baffles and supports, which made retubing difficult. This method gave way to roller expanding.

Roller expanding: For many years, the principal method of fastening sleeves into tubes was roller expanding, and it is still widely used. This method, also used for joining tubes to tubesheets, employs a rotating, power-driven, expanding mandrel device that operates via torque control.

In roller expanding, the sleeving contractor must establish the adequacy of sleeve expansion by experimentally correlating rolling torque with sleeve-to-tube tightness. It is not practical to instead use sleeve-wall percent reduction as the criterion for successful sleeving, as is common in tube rolling, because the sleeves are typically only about 0.010 to 0.030 in. thick, so the measurements needed for the sleeve-wall percent-reduction option would be unreliable [*2*].

Torque control of rolling equipment is less precise than the control of hydraulic sleeving equipment, discussed below, and it varies over a wider range. The torque-control setting may drift, requiring periodic verification of torque output. Furthermore, not all of the torque output applies to expanding a sleeve — the control device functions by sensing the resistance to rotation, and that resistance varies with the roller condition, the lubrication, and chance intrusion of foreign matter. Consequently, rolling sleeves into tubes is being replaced by hydraulic methods that produce more-reproducible and more-uniform results.

Hydraulic expanding: In this option, hydraulically transmitted pressure forces the sleeve into its tight fit. The hydraulic expanding pressure can be controlled precisely: hydraulic equipment used in sleeving maintains the set expanding pressure within tolerances of ±1.25 to ±2.5% depending upon the yield strength of the sleeve. Therefore, there is very little risk of over-expanding causing the tube to bulge between supports and baffles. Although there are theoretical methods for optimizing expansion pressure, it is best determined experimentally using mock-ups.

The figure on p. 66 shows a cross-sectional view of an expanding mandrel, plus a photo of a sleeve and mandrel before the sleeve is inserted in the tube end.

The impact of plugging

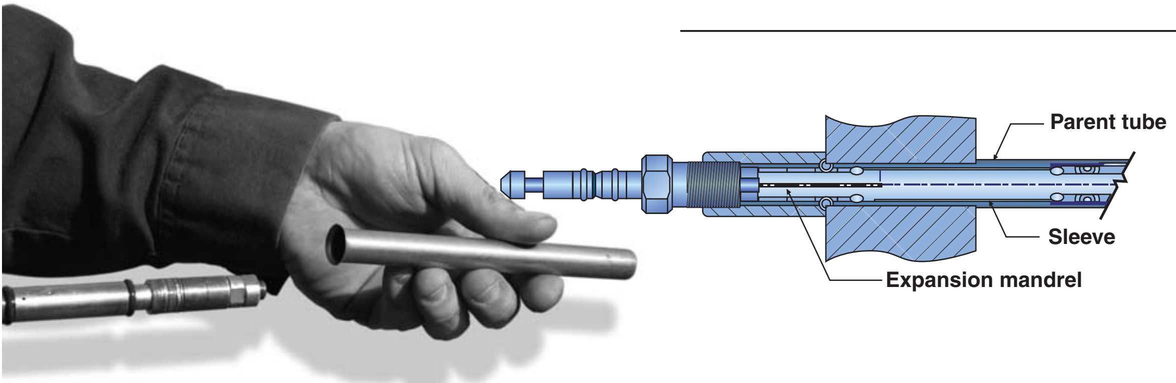
As noted above, sleeving is in many cases done in order to bring previously plugged tubes back into service. Therefore, as a preliminary to understanding the effects of sleeving upon heat exchanger performance, it is helpful to recognize the effects upon heat exchanger performance that the plugging step itself created when that earlier operation was carried out.

Plugging some of the tubes in an exchanger reduces the cross-sectional tube flow area, and removes part of the exchanger's heat transfer surface. The reduced flow area raises the fluid velocity, u, in all of the tubes that are not plugged, by the ratio of original total cross-sectional tube area to the tube cross-sectional area that remains in the tubes that were not plugged.

The Reynolds number, N_{Re}, for the tube-side flow increases linearly with the flow velocity, because N_{Re} equals *Du*r/m, where D is tube diameter and r and m are fluid density and viscosity, respectively. With a rising Reynolds number, both the frictional resistance and the film coefficient of heat transfer for the inside of the tube increase. So, the greater flow velocity that results when plant personnel plug some tubes in an exchanger causes a higher pressure loss and an elevated inside film coefficient. However, there is a net reduction in duty (the heat-exchange capability of the exchanger) because the effect of removing surface outweighs the effect of increasing the inside film coefficient.

Calculating plugging's effects

Using commercial or privately developed software programs for heat transfer and pressure drop, one can predict the effect of plugging on heat transfer and pressure drop. This requires adjusting the program inputs so that the programs will calculate the shell side resistance to heat transfer and pres-



The diagram at left is a cross-section of an expanding mandrel, whereas the photo shows the sleeve and mandrel before the sleeve is inserted into the end of a tube

sure drop for the no-plugs condition at the same time that it calculates the tube side resistance and pressure drop for the plugged condition. Some familiarity with how the programs work, and with how they can be manipulated to get the correct results, is necessary.

When a computer program is not available, the engineer can make a reasonably good prediction of the effect of plugging for simple single-phase tube side flow if he or she knows the various resistances (in units of, for instance, $[ft^2][°F][h]/Btu$) to heat transfer that were employed to estimate the overall coefficient of the exchanger U, when it was new. This prediction is simply a matter of first subtracting the "as-new" tube-side resistances in the straight lengths of tubing from the sum of the resistances for the exchanger, then adding in the calculated post-plugging resistances, as detailed in the next few paragraphs. The same procedure can be used for the pressure drops.

To simplify the calculations, assume the following: that the shell-side film resistance and tube-side and shell-side fouling resistances remain unchanged; that there will be no changes in the properties of the fluids in the exchanger; and that the changed conditions will not affect the log mean temperature difference (LMTD, or ΔT_m). The results using these assumptions will not significantly differ from those from more-rigorous calculations.

Calculate the new tube-side flow velocity by multiplying the original design velocity by xa_n/xa_{up}, where xa_n is the total cross-sectional flow area of the tubes before plugging and xa_{up} is the area for the tubes that remain unplugged. Using this calculated post-plugging velocity, compute the new Reynolds number. Use the frictional-resistance curves in standard reference works, such as References [*3*] and [*4*], to estimate the resistance with which to calculate the pressure loss and film coefficient for the changed conditions.

Calculate the heat transfer by adding the reciprocal of the post-plugging tube-side film coefficient (referred to the tube outside diameter) to the fouling, metal-wall and shell-side resistances. Invert the sum to get its reciprocal, which is the new overall coefficient for the plugged condition, U_p. Then, calculate the surface area, A_p, for the tubes that were not plugged. Then the post-plugging heat transfer equals U_pA_pLMTD.

Finally, calculate the post-plugging pressure drop from the tube-side friction factors, for straight tubes and their return bends.

The impact of sleeving

As noted near the beginning of this articles, sleeving may be employed not only to restore previously plugged tubes but also to protect against erosion at the inlet end of the heat exchanger tubes. Sleeving all of the tubes in the inlet pass with short sleeves or ferrules to protect against erosion increases the overall pressure drop, because of the increased frictional loss in the short lengths as well as the greater entrance head loss into the sleeves (which have a smaller diameter than the tubes) and enlargement head loss at the sleeve exits.

As for the sleeving of only some, previously plugged, tubes with full-length sleeves, this activity causes the flow velocity in all of the tubes to be higher than it is in a new exchanger, but less than that of a unit with the same number of plugged tubes.

The cross-sectional area of an array of sleeved tubes is smaller than that of the tubes before sleeving. This reduces the total cross sectional area for flow in all the tubes. That reduced area causes the flow velocity to increase by the ratio xa_n/xa_s, where xa_s is the total cross-sectional flow area of the sleeved and the not sleeved tubes.

Turbulence where fluid exits the sleeves into the tubes adds somewhat to the pressure loss despite the sleeves having tapered exits. The pressure drop calculations, discussed below, depend upon the number of tube-side passes, and on whether all of the inlet-pass tubes were sleeved with short sleeves to protect against inlet flow erosion or, instead, various randomly located, previously plugged tubes were sleeved with full-length sleeves to recover heat transfer surface.

The rate of corrosion of tubes in process exchangers is usually temperature-dependent; it is greater at the tube end that has the higher tube-metal temperature. If corrosion throughout the tube field at the inlet end of the hot pass is uniformly distributed, sleeves installed to recover tube surface from plugged tubes need be only as long as the unacceptably deteriorated tube lengths.

Calculating sleeving's effects

Tube flow velocity: For a single-pass exchanger, estimate the flow velocity after sleeving, u_s, by multiplying the design flow velocity, u_{new}, (that is, the new-exchanger tube-side velocity) by the aforementioned xa_n/xa_s ratio. For multipass exchangers, this u_s will be the velocity only in the sleeved pass; the velocity in the other passes will be unchanged.

Pressure drop: The procedure for calculation of pressure drop due to sleeving varies with the type of situation. Following are suggestions for several of them:

Single-pass exchangers with all tubes sleeved with short sleeves: To estimate pressure drop when all of the tubes are sleeved, treat the exchanger as two exchangers in series with identical tube counts and tube-side fluid flows.

The tubes in the "first exchanger" are of the inside diameter and length of the sleeves. Using the calculated

ESTIMATED CONTACT RESISTANCES AND RECOVERY OF SURFACE		
Tube and Sleeve Material Combination	**Resistance, (h)(ft^2)(°F)/Btu**	**Effective Recovery of Surface, %**
S.S. Type 304 tubes, S.S. Type 304 sleeves	0.011	89
Admiralty brass tubes, 90-10 Ni-Cu sleeves	0.0013	89
Admiralty brass tubes, SS 304 sleeves	0.0046	70
Monel tubes, Monel sleeves	0.0026	80

S.S. = stainless steel — Readers should be aware that the listed contact resistances have not been established by extensive testing

new flow velocity, calculate the pressure drop in the sleeved tubes, including the inlet and exit losses.

Then, calculate the pressure drop in the tubes of the "second exchanger" (consisting of the portions of the tubes that are not sleeved), omitting the first pass, and add to it the inlet, exit and turnaround losses.

To determine the total pressure drop, add the calculated pressure drops in both assumed exchanger configurations

Single-pass exchangers with a randomly distributed number of long sleeves: When some of the tubes are sleeved with full-length sleeves, recalculate the Reynolds number and the tube-side frictional resistance with the higher velocity to determine the pressure drop Manual calculation of the increased pressure drop is straightforward. However, if a computer program is being used, it may require some tinkering.

Multipass tube-side exchangers with inlet-pass tubes sleeved with short ferrules: Assume that the tube count is the total number of tubes divided by the number of passes. Calculate the pressure drop in the inlet pass as two single-pass exchangers in series, one with tubes of the sleeved length and sleeve inside diameter and the other with tubes of the remaining length and diameter, as summarized above. Add the pressure drops calculated for the not sleeved passes and for the inlet pass.

Multipass tube-side exchangers with inlet pass tubes sleeved with full length sleeves: Assume that the tube count is the total number of tubes divided by the number of passes. Calculate the pressure drop in the sleeved inlet pass and add it to the pressure drop calculated for the not sleeved passes.

Heat transfer: Oxide films on the sleeve exteriors and tube interiors increase the overall resistance to heat transfer. So do any regions of possibly incomplete contact between sleeves and tubes. The resistance of these "barriers" between tube and sleeve is called contact resistance. The thickness of the sleeve metal also increases resistance to heat transfer.

In short, the tubes restored by sleeving have less capacity to transfer heat because the additional resistances reduce the overall coefficient of heat transfer, U. Consequently, whether the purpose of sleeving is to restore plugged tubes to service or to prolong life of tubes with walls so thin that they would otherwise be removed from service by plugging, there is a reduction in the overall capability (duty) of the exchanger.

Based on examination of unpublished data from a sleeving contractor, contact resistances appear to be about as shown in the table, above. *However, be aware that the resistance values shown in the table have not been established by extensive testing.*

As for the added metal resistance due to the increased wall thickness, the magnitude of this effect depends on whether or not the tube metal and sleeve metal have the same thermal conductivity. If they do, the combined metal resistance in the restored tubes equals $r_m[(t_t + t_s)/t_t]$, where r_m is the metal resistance of the tube alone, t_t is the tube thickness and t_s is the sleeve metal thickness. If, instead, the sleeve-metal thermal conductivity is different from that of the tube, the combined metal resistance equals ($r_m + t_s/k_s$), where k_s is the thermal conductivity of the sleeve.

To get the inside film coefficient of heat transfer for sleeved tubes, calculate it starting with a Reynolds number based on the post-sleeving velocity in the tubes. Note that this calculated inside coefficient will be the same for the sleeved and not sleeved tubes. Its reciprocal is the resistance through the inside film.

To obtain the overall heat transfer coefficient for the sleeved tubes, U_s, add up that inside-film resistance, the contact and metal resistance through the wall, the resistance through the outside (shell-side) film and the fouling resistance, and take the reciprocal of that sum. (In this summary, we assume that the effects of sleeving upon shell-side pressure drop and heat-transfer film coefficient are modest, an assumption that is valid unless precise results are needed.)

Finally, to calculate the actual heat transfer for a partially sleeved heat exchanger, start by calculating the areas of the sleeved and not sleeved tubes, A_s and A_u respectively. Then, assuming no change in the log mean temperature difference due to sleeving, the total heat transferred, Q, will be the sum of the heat transferred in the sleeved and in the not sleeved tubes as shown in the following equation:

$$Q = (U_u A_u + U_s A_s)\Delta T_m$$

where U_u is the overall coefficient for the not sleeved tubes. ■

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