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The fouling of heat exchanger and other piping or vessel surfaces can be monitored by measuring pressure, flow, temperature, and heat flux, then using the reults to calculate fluid frictional resistance and heat transfer resistance. Results can be employed to evaluate treatments for fouling control and study the effect of equipment configurations and operating conditions on contaminant buildup.

KEYWORDS: *fouling monitors, heat exchanger performance, surface contamination, thermal conductivity, heat transfer resistance, fluid frictional resistance.*

Monitoring of Fouling Deposits: A Key to Heat Exchanger Management

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Heat exchanger and other piping or vessel surfaces may become fouled by surface accumulation of contaminants. The fouling can decrease heat transfer capacity, impede fluid flow, and create local surface conditions that promote corrosion or erosion. The associated costs can be significant. For instance, fuel expenditures to overcome biofouling-related fluid friction and heat transfer resistance at a representative 600-MW coal-fired electric power plant have been estimated at $500,000 per year (Ref 1). The economics of unscheduled downtime can be even more devastating — on the order of $1 million per day at a nuclear generating station. Costs of fouling are also reflected by factors such as increased frequency of maintenance and component replacement (Ref 2).

FOULING DETECTION

Fouling is most often monitored manually, by examining sections of a pipe or vessel wall removed from operating equipment. This generally requires that a unit be shut down or placed in a bypass mode; it is also not continuous, so conditions may become unacceptable between inspections. A further disadvantage is that analysis of the deposit does not necessarily indicate how fouling affects flow, heat transfer, or other key system performance criteria.

For pipelines and other applications in which heat loss or flow capacity is the dominant performance variable, fouling can be monitored in terms of fluid frictional resistance. This value can be calculated directly from measurements of flow rate and pressure drop.

For heat exchanger applications, energy transfer capacity is usually of greatest concern. Heat transfer resistance is therefore an appropriate fouling indicator (Ref 3). Overall heat transfer resistance can be calculated from measurements of heat flux through a surface. Heat transfer, however, is affected by factors such as the inherent thermal conductivity of a material and the turbulence of the flow at its surface. It is therefore sometimes desirable to know the convective and conductive components of heat transfer resistance as well as the overall value. Information of this type can be derived from measurements of pressure drop and flow as well as heat flux (Ref 4).

Figure 1 shows why convective and conductive components of the heat transfer resistance may be important. The indicated values were obtained

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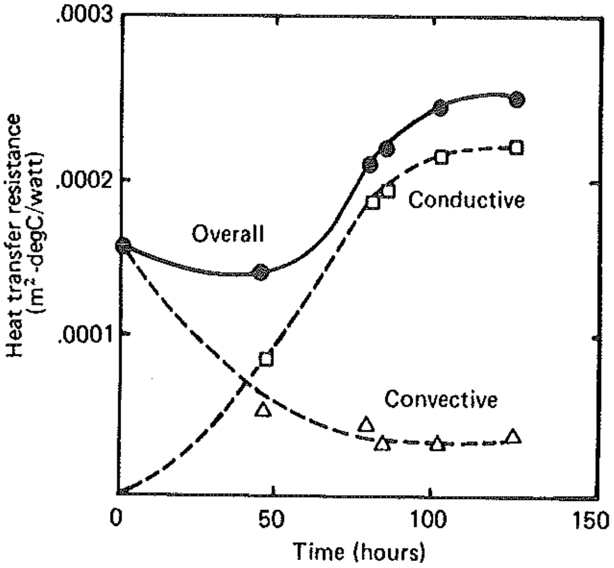

FIGURE 1. Fouling due to a biofilm, showing how convective and conductive components of heat transfer resistance can respond differently to increasing biofilm accumulation.

from measurements of biological fouling on an aluminum surface. Conductive heat transfer resistance increased with biofilm thickness because the contaminant had relatively low thermal conductivity. Convective heat transfer resistance decreased with film thickness, however, because the surface was rough and induced turbulence. Because of differences in relative magnitudes of these components, the overall heat transfer resistance first fell slightly with biofilm thickness, then increased.

MEASUREMENT APPLICATIONS

Details of the instrumentation and calculations required for an application depend on the reasons for determining fouling and the equipment being monitored (Refs 5, 6). For instance, Figure 2 shows a laboratory instrument used to evaluate proposed water treatment processes and equipment operating conditions for heat exchangers. An electrical heater is clamped to a tube of the alloy matching the heat exchanger being modeled. Fluid frictional resistance is calculated from flow rate and pressure drop.

Overall heat transfer resistance is calculated from the temperature of fluid passing through the tube, the temperature of the outside tube wall, and the heat input. The convective component of the heat transfer resistance can be computed from fluid frictional resistance; the conductive component can be found by subtracting the convective term from the overall heat transfer resistance.

Biocide cleaning

A zero-discharge recirculating cooling tower was installed at a processing plant. Biofouling was expected to occur and an oxidizing agent was to be evaluated as a means of controlling the accumulation (Ref 7). Overall heat transfer resistance was monitored to determine the effectiveness of the biocide.

As indicated in Figure 3, heat transfer resistance increased from the time the unit was started until the biocide was introduced; the heat transfer resistance then returned to normal. Independent measurements of total viable bacterial counts in the cooling water are also indicated; these values do not correlate with heat transfer resistance, indicating the unsuitability of water quality analysis to measure fouling.

Sponge ball cleaning

Heat transfer resistance was measured at an electric power plant to determine the extent of fouling in brass heat exchanger tubes and to evaluate the effectiveness of passing sponge balls

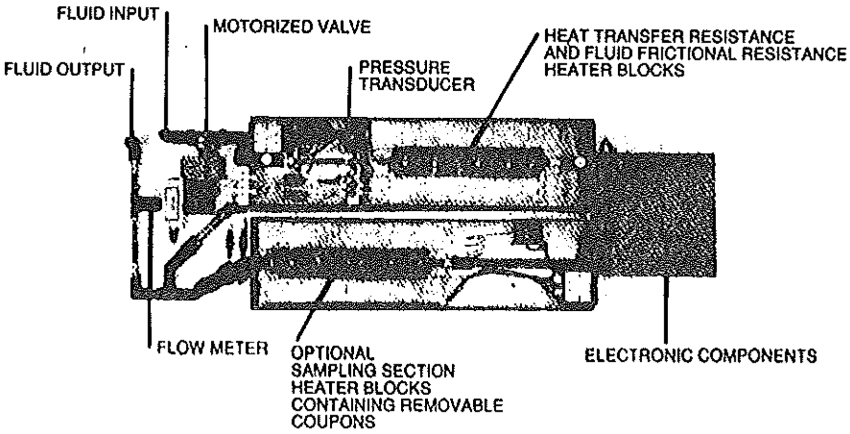

FIGURE 2. Instrumentation employed for laboratory monitoring of fouling in heat exchangers.

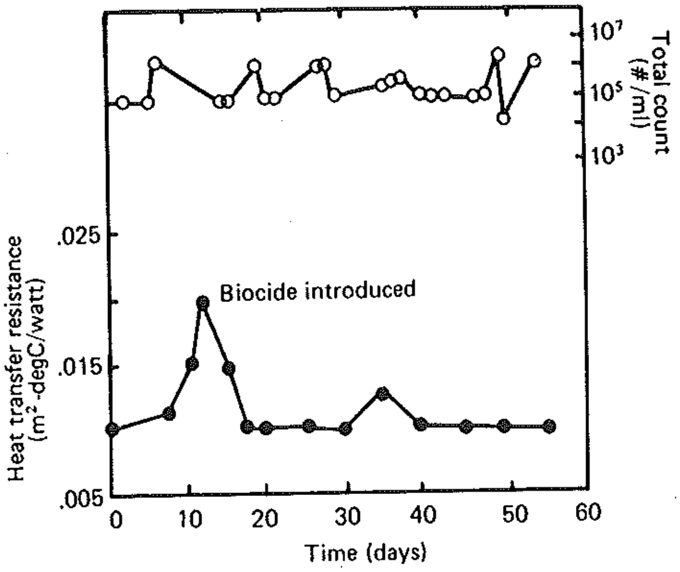

FIGURE 3. Use of heat transfer resistance to indicate fouling in evaluating a biocide in a zero-discharge cooling tower loop.

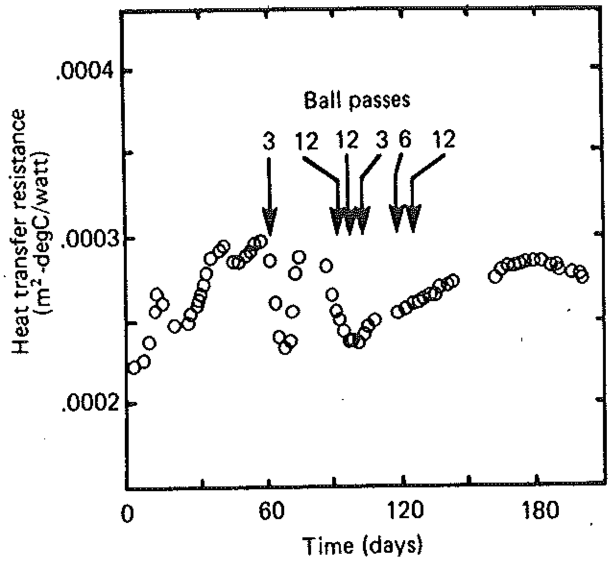

FIGURE 4. Use of heat transfer resistance to indicate the effectiveness of sponge balls for removal of fouling deposits from heat exchanger tubes.

through the unit to remove deposits. Figure 4 shows that fouling increased steadily for the first 60 days, during which no treatment was applied. At this point, three sponge balls were passed through the tube; the treatment was successful, as indicated by a drop in heat transfer resistance. The data show that repeated use of the sponge balls was less effective — and that a hard deposit ultimately formed which could not be removed in this manner (Ref 8).

Flow excursion cleaning

Measurements of heat transfer resistance were used at a nuclear power plant to determine if wall shear stresses accompanying short-term increases in flow rate could remove fouling deposits (Ref 9). Figure 5 shows that the heat transfer resistance gradually increased during the operation of a heat exchanger tube at a constant 0.5 m/s; after 80 days, the flow was raised to 1.7 m/s for 0.5 hr then returned to 0.5 m/s. The heat transfer resistance dropped considerably after the flow excursion.

Flow velocity effect

Heat transfer resistance determinations at a power plant also showed that steady-state fluid velocity affected rate of fouling in continuously-operated stainless steel heat exchangers. Heat transfer resistance increased more rapidly with operation at 0.3 than 0.5 m/s. The greater fouling at the lower velocity was attributed to sedimentation (Ref 9).

Tube alloy differences

Differences in fouling of two heat exchanger tube materials were evaluated in an electric power plant by measuring heat transfer resistance. Figure 6 compares values determined for a pair of Al-6X stainless steel tubes to that for a copper-nickel tube under the same operating conditions. Heat transfer resistance was initially lower in the copper-nickel tube because of its higher thermal conductivity through the uncontaminated material (Ref 9); the data show that the rate at which heat transfer resistance increased was also lower in the copper-nickel than the Al-6X alloy.

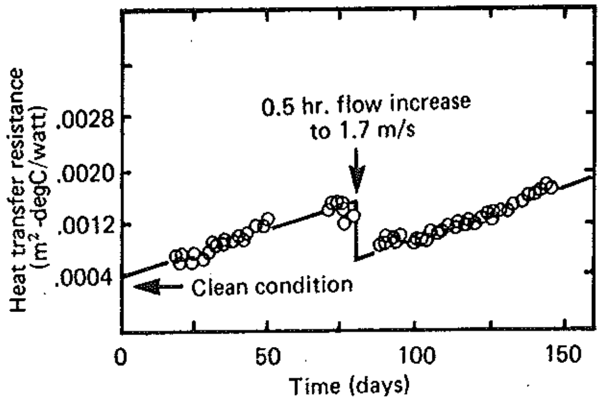

FIGURE 5. Use of heat transfer resistance to indicate the effectiveness of flow excursions for cleaning the tubes of a power plant heat exchanger.

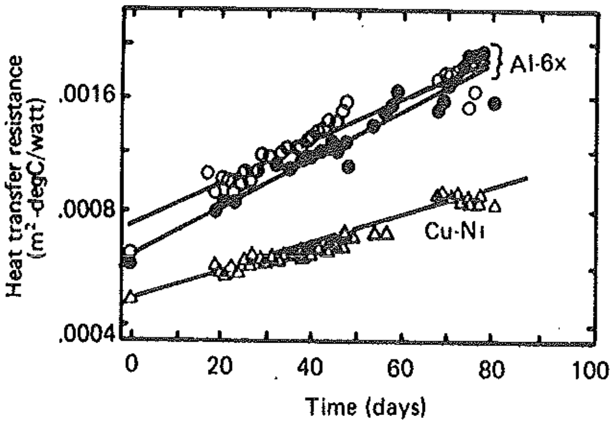

FIGURE 6. Use of heat transfer resistance to indicate differences in the susceptibility of stainless steel and copper-nickel alloys to fouling.

Surface temperature effects

Heat transfer resistance has also been useful in studying the influence of surface temperature on fouling. In one instance, measurements were made on separate sections of a tube — one at stream temperatures varying between 3 and 17 C, the other heated to 50 C. Heat transfer resistance was greater in the heated section, most likely because the elevated temperature was more conducive to biological growth (Ref 9).

Deposit characteristics

Convective and conductive heat transfer resistance terms were used to determine the effects of fouling by calcium carbonate — alone and in combination with silicate. Figure 7a shows the progression of heat transfer resistance due to deposition of calcium carbonate only. The deposit remained relatively smooth so the convective term was essentially constant. Overall heat transfer resistance increased in almost direct proportion to the conductive component. Figure 7b shows that fouling due to calcium carbonate and silicate causes convective heat transfer resistance to decrease — because the deposit is rough and induces turbulence. The conductive heat transfer resistance increases faster when silicate is added to the calcium carbonate, most likely because the deposit is thicker and has a lower inherent thermal conductivity.

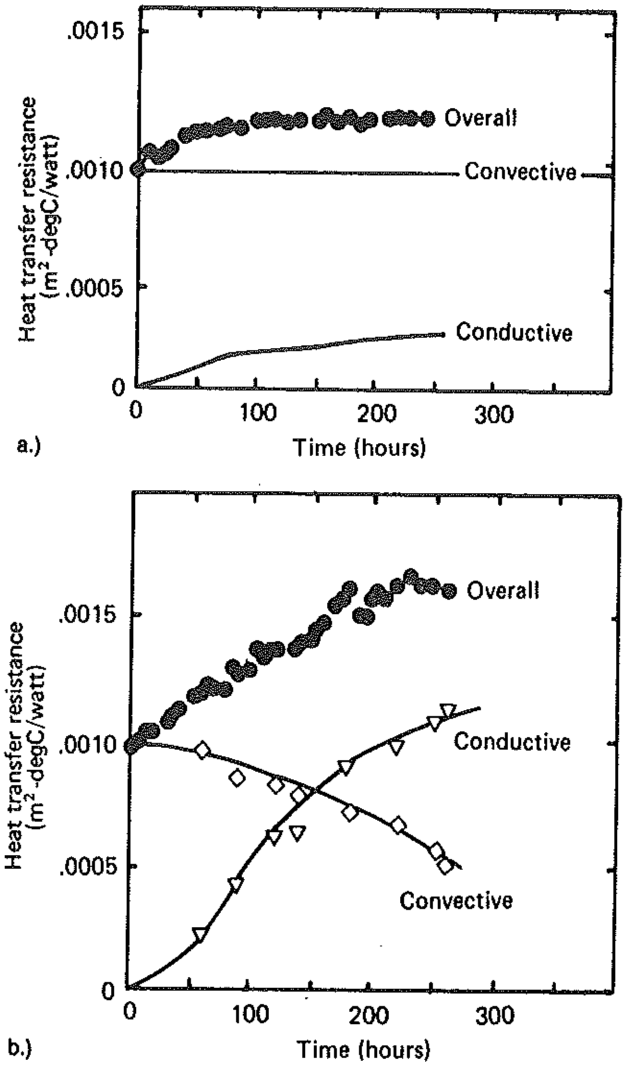

FIGURE 7. Use of convective and conductive components of heat transfer resistance in studying the fouling tendencies of a) calcium carbonate, and b) calcium carbonate plus silicate.

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