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Zelver, N., F.L. Roe, and W.G. Characklis, "Potential for Monitoring Fouling in the Food Industry," in D. Lund, E. Plett, and C. Sander (eds.), Fouling and Cleaning in Food Processing, Univ. of Wisconsin, Dept. of Food Science, Madison, WI, 1985, pp. 255-262.

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POTENTIAL FOR MONITORING FOULING IN THE FOOD INDUSTRY

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ABSTRACT

An instrument is described which monitors accumulation of deposits on the inside of tubes by measuring changes in heat transfer and fluid frictional resistance. The microcomputer controlled system simulates process conditions (fluid velocity and heat flux) in a tube of any chosen alloy. The combined thermohydrodynamic measurements provide a very sensitive, relevant measurement of deposition in terms of process equipment performance parameters. Other features of the instrument include: (a) availability of instantaneous measurements, (b) diskette storage of data, (c) measurements are non-destructive and non-intrusive, (d) the microprocessor input/output permits flexibility in operation and control. Industrial and laboratory studies using this instrument are presented. These studies describe the use of the fouling monitor in evaluating treatments for fouling control, the effect of operating conditions on fouling, using the fouling monitor for fundamental laboratory research, and the potential for using the fouling monitor in the food industry.

INTRODUCTION

The term fouling refers to the undesirable formation of inorganic and/or organic deposits on surfaces. These deposits can: (a) thermally insulate a surface, thus reducing heat transfer through a wall, (b) increase roughness of a surface, thus increasing frictional resistance to flow, and (c) create a localized environment where corrosion is promoted. This paper discusses case studies of monitoring fouling deposition on surfaces of heat exchangers.

Fouling deposits

Several types of fouling may occur in heat exchanger systems: (a) crystalline or precipitation fouling, (b) corrosion fouling, (c) particulate or sedimentation fouling, and (d) biological fouling or biofouling. Typically, fouling deposits result from two or more of the above.

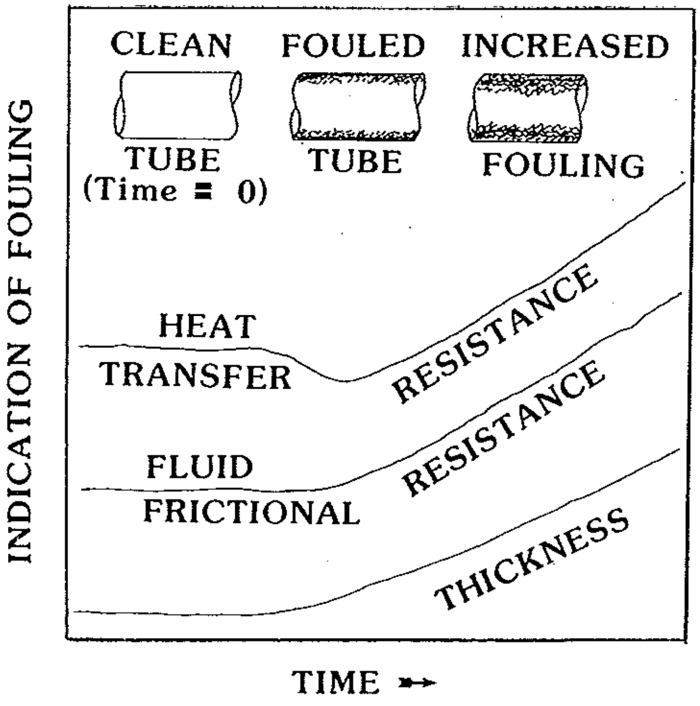

Fig. 1. Progression of fouling.

The problem

Fouling of heat exchanger systems results in energy losses. Figure 1 indicates, qualitatively, how energy losses in the form of increased fluid frictional resistance or increased heat transfer resistance occur as tubes become fouled.

Fouling monitors: State of the art

Recently, instruments have been developed to monitor conditions on a tube surface to indicate accumulation of fouling deposits and, in some cases, to indicate the effect on heat exchanger performance. Various types of fouling monitors are described in detail elsewhere [1, 4]. These monitors are used to model fouling in a heat transfer system and are typically installed on a side-stream of the heat exchanger cooling water. The following is a summary of the different types of fouling monitors:

Removable sections of the fouled surface. These provide samples which may be used for microscopic examination, mass measurements, or for chemical and biological analyses of the deposit. Disadvantages of this technique include: (a) the sampling procedure is intrusive, often requiring shutdown of the system, which may upset an ongoing test, (b) the sample is usually not heated; thus temperatures may not be representative of the heat transfer system being modeled, (c) sample area may be too small for chemical and physical assays, and (d) there is no indication of how the deposit affects performance of the heat exchanger system.

Pressure drop. Some systems monitor flow velocity and pressure drop across a length of heat exchanger tubing. This provides a measure of fluid frictional resistance which usually increases with build-up of fouling deposits. This device is relatively inexpensive and is easy to operate. However, there are several serious limitations: (a) the measurement is insensitive until a critical thickness or roughness of deposit develops, (b) the tube is usually not heated, and (c) pressure drop is usually an important performance criterion only in pipelines and channels.

Heat transfer resistance monitors. Knudsen [4] reviewed a number of devices which monitor fouling by determining the effect of the deposit on overall heat transfer resistance. Advantages to using heat transfer resistance include: (a) the technique indicates the effect of fouling on the parameter of concern to heat exchanger operators, (b) heat transfer resistance is a more sensitive indicator of deposit accumulation compared to fluid frictional resistance, and (c) the fouling monitor surface can be heated to match the temperature of the system being modeled.

Monitoring only overall heat transfer resistance can give a misleading indication of fouling since overall heat transfer resistance is the sum of two types of heat transfer resistance (overall = convective + conductive). The two types of heat transfer resistance can be affected differently depending on the type of deposit. Convective heat transfer resistance depends on fluid motion and is affected by surface roughness or fluid frictional resistance (increased roughness results in increased turbulence resulting in *less* heat transfer resistance). Conductive heat transfer resistance depends on the thermal conductivity of a deposit (a low thermal conductivity insulates the surface and results in a *higher* heat transfer resistance). Thus, a deposit with a large surface roughness and a high thermal conductivity gives an unrealistically low estimate of fouling even though considerable deposit has accumulated.

Our approach has been to develop an instrument which combines the best features of the above techniques and provides a method of separating the convective and conductive components of overall heat transfer resistance. Our goal has been to develop a fouling monitor system to accomplish the following:

(a) Simulate the process environment (e.g., wall temperature, heat flux, flow rate, pressure drop, and fluid shear stress).

(b) Determine the rate and extent of fouling in a non-intrusive, non-destructive manner.

(c) Determine the influence of fouling deposition on energy losses (heat transfer resistance and fluid frictional resistance) in the process environment.

(d) Distinguish between different deposit compositions *in situ* [3].

(e) Permit accessible sampling of the fouling deposit and tube alloy.

THE INSTRUMENT

. The instrument consists of a heat exchanger tube fitted with sensors used to monitor heat transfer and frictional resistances and equipment to control the necessary physical parameters for modelling a heat exchanger system. Figure 2 shows the following components in detail:

(1) Motorized flow control valve for controlling fluid velocity or fluid shear stress.

(2) Heated test section for determining heat transfer resistance and controlling inner tube wall surface temperature or heat flux.

(3) Differential pressure cell for measuring pressure drop and fluid frictional resistance.

(4) Thermistors for measuring fluid and heat exchanger temperatures.

(5) Flow meter for measuring fluid velocity.

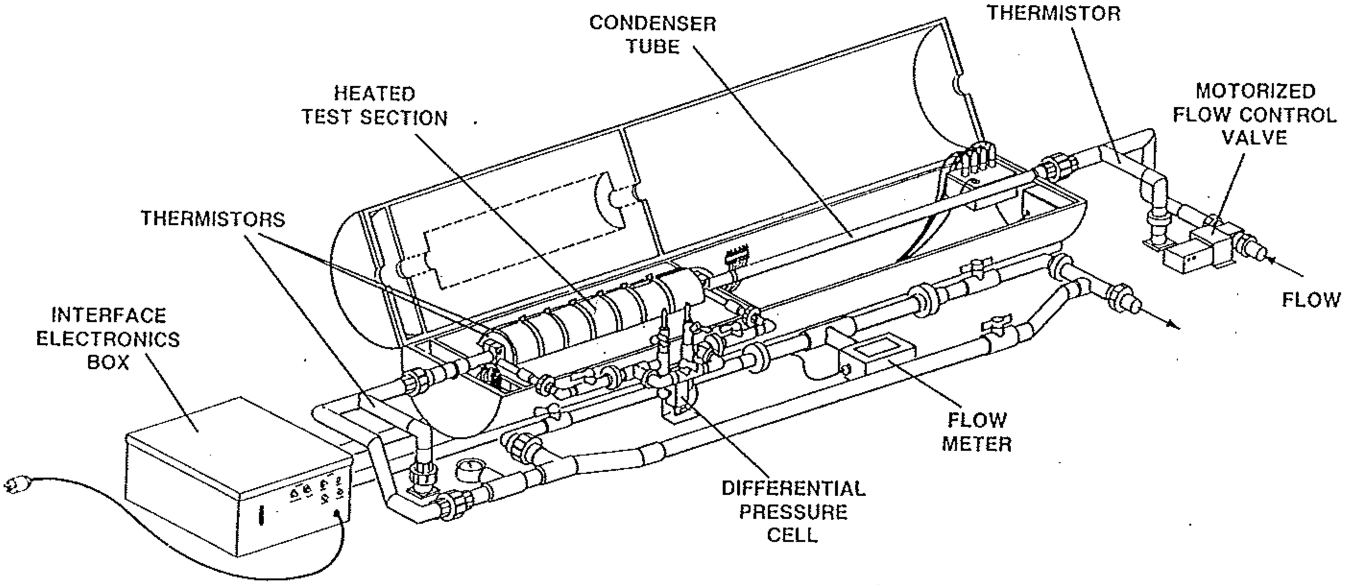

Fig. 2. Fouling monitor.

Test coupons

In some cases, a second tube for sampling is included. This tube is operated under identical flow and heat conditions as the first tube but has pre-scored sections or coupons of heat exchanger tubing which are removed periodically for analyses.

Computer interface

The instrument includes electronics which condition the signals and allow communication with a microcomputer. The microcomputer controls flow and heat to match selected conditions of the heat exchanger system being modeled. The microcomputer also continuously records data on a diskette and provides output to a video screen. In some cases, peripheral equipment such as pH/ISE meters have been interfaced to the same microcomputer.

Methodology

Figure 3 shows a detailed schematic of the heat exchanger and pressure drop sections. An electrically heated aluminum block is clamped to a tube of an alloy matching the heat exchanger system being modeled. Thermistors allow calculation of the outside tube wall temperature. Overall

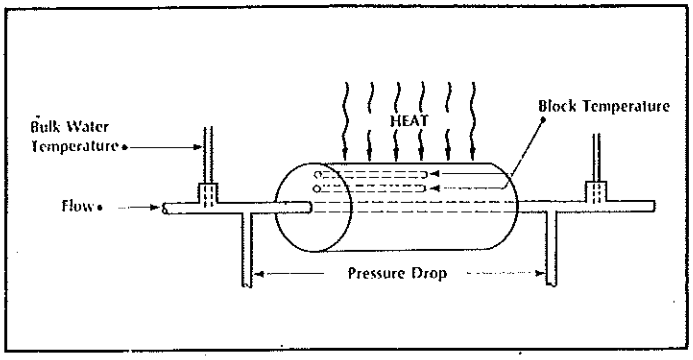

Fig. 3. Fouling monitor heater section.

heat transfer resistance is calculated from the temperature of fluid passing through the tube, the temperature of the outside tube wall, and the input heat. Fluid frictional resistance is calculated from fluid velocity and pressure drop. Convective heat transfer resistance can be determined from fluid frictional resistance, and thus the convective and conductive components of overall heat transfer resistance can be determined. Details of these calculations and theoretical background are presented elsewhere [5, 6].

CASE STUDIES

We have used the fouling monitor in a number of studies to determine the effect of operating conditions on fouling and to determine optimum treatment programs to minimize fouling. The studies presented here are from electric power plant condenser systems and laboratory experiments. However, the techniques are useful in studying any heat exchanger system and may be applied to investigating fouling in heat exchanger systems in the food industry.

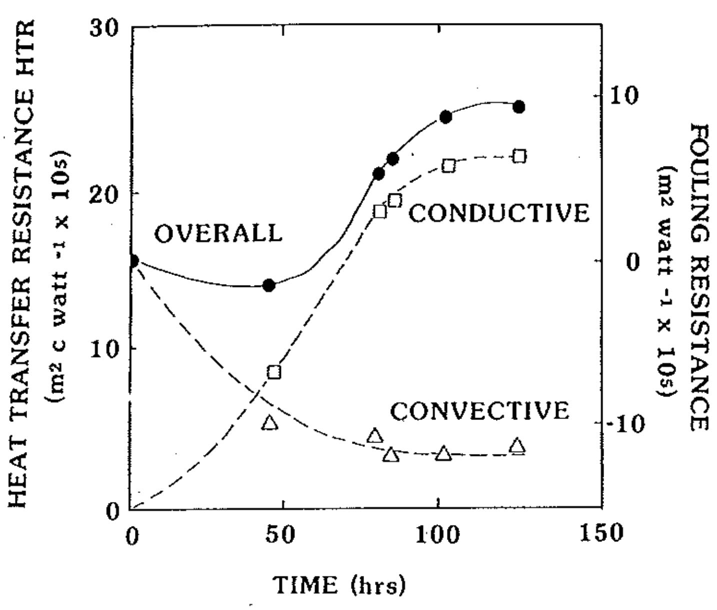

Fig. 4. Fouling due to a biofilm.

Figure 4 presents an example of data obtained using our fouling monitor. In this case, the data was collected during a laboratory experiment with a biological deposit build-up (biofilm) on an aluminum surface. This figure shows conductive heat thickness as the biofilm insulates the inside tube wall surface. Convective heat transfer resistance decreases with increasing biofilm thickness as the "rough" biofilm surface results in more turbulence. The increase in conductive heat transfer resistance is greater than the drop in convective heat transfer resistance; thus overall heat transfer resistance increases.

Treatment evaluations

The fouling monitor has been used in the laboratory for fundamental studies as described above and in the field to evaluate treatments and operating conditions for managing fouling.

Biocide. Tests at a chemical process plant were conducted to evaluate effectiveness of a new oxidizing biocide in controlling biofilm accumulation. Prior to the test, the plant was fitted with a new "zero discharge" recirculating cooling tower system and biofouling was expected to increase significantly. The results, shown in Figure 5, indicate an increase in heat transfer resistance during

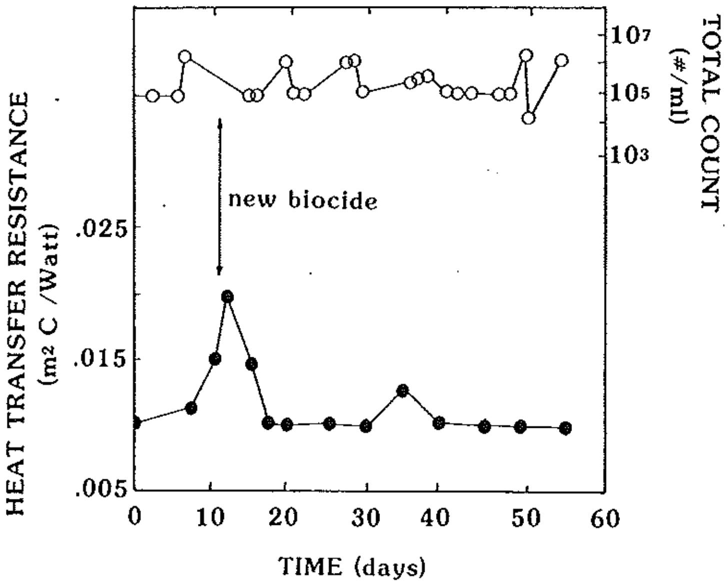

Fig. 5. Fouling at a chemical process plant.

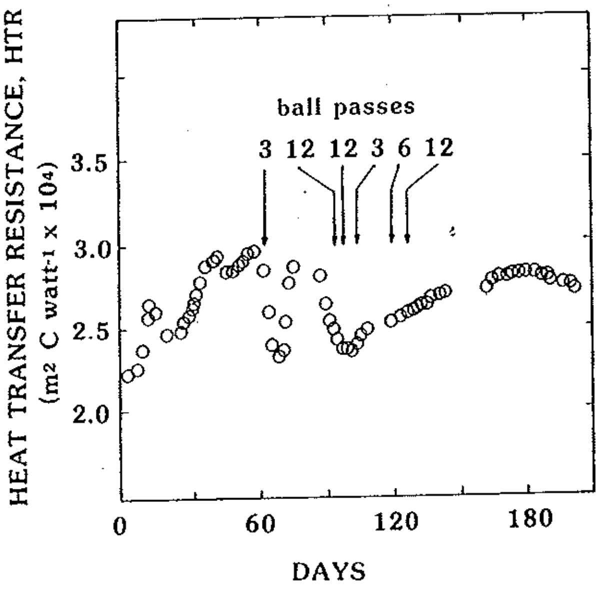

Fig. 6. Effect of sponge ball cleaning at a power plant.

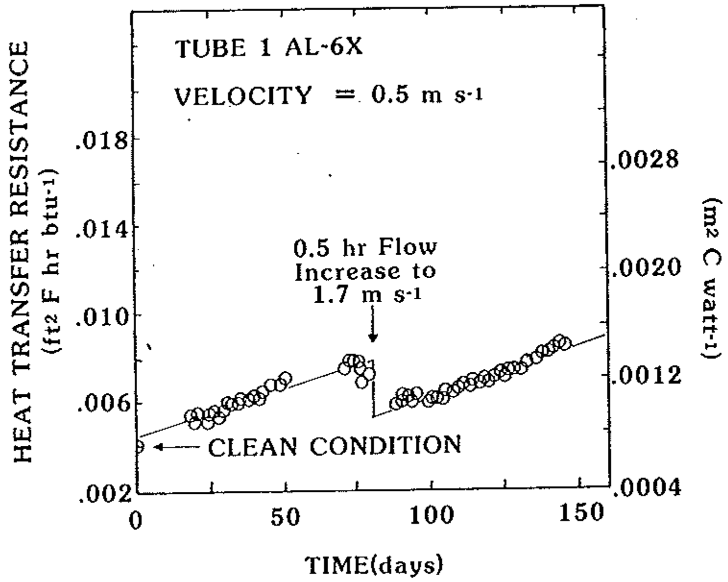

Fig. 7. Effect of flow excursion cleaning at a power plant.

several weeks before the new biocide was introduced. After the new biocide was added, conditions returned to near normal. Note, concurrent total viable bacterial counts in the water did not correlate with heat transfer resistance, indicating a limitation in using water analyses as a measure of fouling. As a result of this study, a new, more effective biofouling control program was implemented and plant operation was not disturbed [7].

Sponge balls. The fouling monitor was used 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 through the tube to remove fouling deposits. Figure 6 shows fouling, as indicated by increase in heat transfer resistance, progressed steadily for the first 60 days when no treatment was applied. At approximately 60 days, three balls were passed through the tube and material was removed as indicated by a drop in heat transfer resistance. Subsequent treatments, however, were less effective. Ultimately, a rather hard deposit accumulated which could not be removed [8].

Flow excursions. Tests were conducted at a nuclear power plant to determine if an instantaneous increase in flow could remove fouling deposits. The fouling monitor heat exchanger tube was operated at a velocity of 0.5 meters sec^{-1} for 80 days at which time flow was increased to 1.7 meters sec^{-1} for 0.5 hr then returned to 0.5 meters sec^{-1}. Results (Figure 7) indicate heat transfer resistance dropped considerably after the flow excursion. This effect is attributed to increased fluid shear stress at the higher velocity [9].

OPERATING CONDITIONS

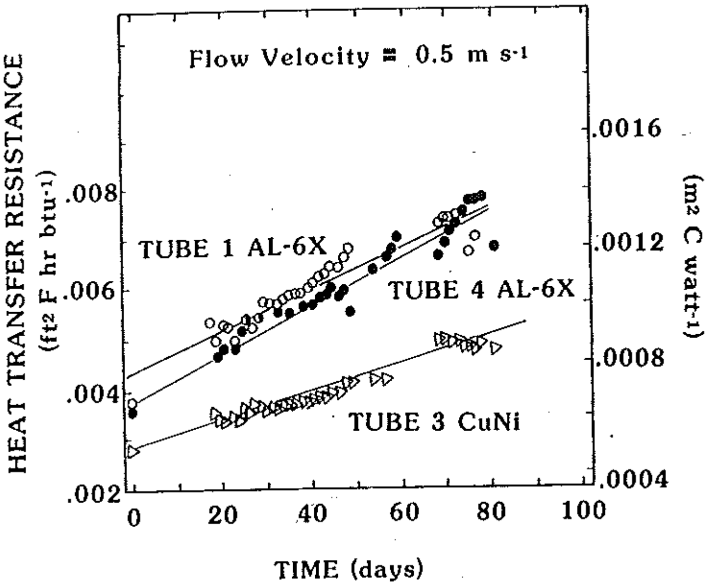

Fig. 8. Effect of tube alloy on fouling in a power plant.

Tube alloy

Tests were conducted to determine how different heat exchanger tube alloys affected fouling at an electric power plant. Figure 8 compares progression of heat transfer resistance in Al-6X stainless steel tubes to fouling in a copper-nickel tube. Both the rate and extent of fouling, as indicated by increase in heat transfer resistance, appeared lower in the copper-nickel tube. Microbial cell counts on the surface were the same for both tubes indicating toxicity of the copper was not affecting biofouling. The copper-nickel, however, had evidence of corrosion which did not appear on the stainless steel. The reduction of fouling on the copper-nickel may have been due to fouling deposits sloughing from the surface along with corrosion material. Clean or starting condition heat transfer resistance was lower in the copper-nickel tube because of the higher thermal conductivity of copper-nickel [9].

Flow velocity

Tests have been conducted at an electric power plant comparing continuous operation of stainless steel heat exchangers at different velocities. In this study, more fouling was indicated in a tube operated at 0.3 meters sec^{-1} compared to a tube operated at 0.5 meters sec^{-1}. The greater fouling at the lower velocity was attributed to a large amount of sediment in the deposit. The sediment settled at a greater rate at the lower velocity [9].

Surface temperature

Tests were conducted comparing fouling deposit mass on a heated (35°C) section of heat transfer tubing to an unheated section of the same tube (3-17°C). These results showed greater mass accumulated on the heated section of tubing. This was attributed to the 35°C temperature being more conducive to biological growth [9].

LABORATORY STUDIES

Effect of deposit composition on energy losses. Tests have been conducted in the laboratory to determine how different types of deposits affect heat transfer resistance and fluid frictional resistance. Figure 9 shows the progression of heat transfer resistance due to deposition of calcium

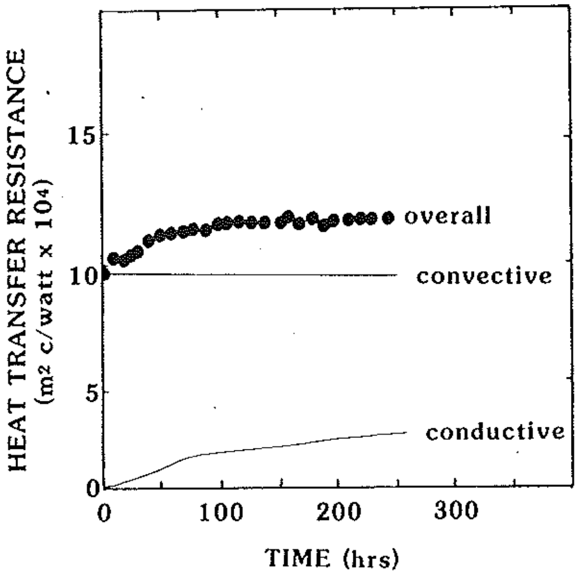

Fig. 9. Fouling due to calcium carbonate.

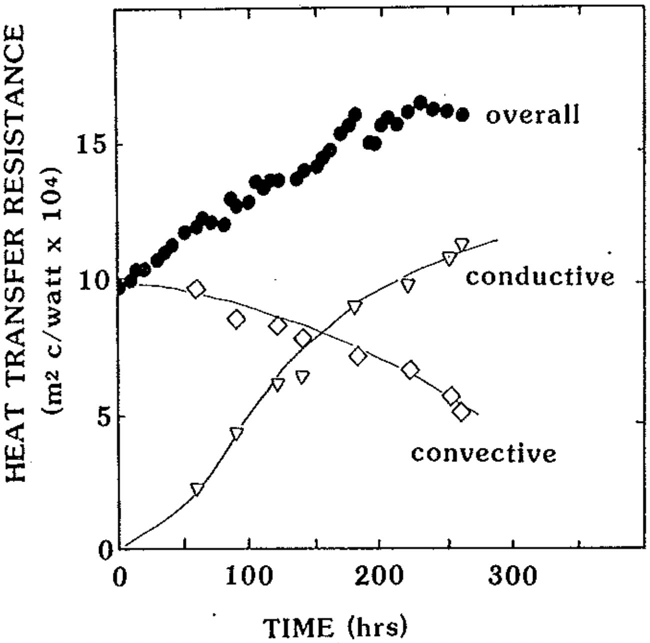

Fig. 10. Fouling due to calcium carbonate plus sodium silicate.

carbonate. In this case, the deposit remained relatively "smooth" and the convective heat transfer resistance changed very little. Overall heat transfer resistance, therefore, increased almost in direct proportion to conductive heat transfer resistance.

Figure 10 shows results of an identical test as above except fouling is due to a calcium carbonate *plus* silicate scale. The added silicate results in a "rougher" deposit; thus convective heat transfer resistance drops considerably. At 300 hours, the calcium carbonate *plus* silicate test has a conductive heat transfer resistance approximately 4 times greater than the test with calcium carbonate alone.

Possible reasons for the greater conductive heat transfer resistance when silicate is added include: (a) the calcium carbonate *plus* silicate deposit is thicker, (b) the calcium carbonate *plus* silicate deposit has a lower thermal conductivity, or (c) the calcium carbonate *plus* silicate deposit has a lower density.

Other tests with biofouling and with combined biofilm/scale deposits show still different patterns in the progression of heat transfer resistance. These laboratory tests are designed to provide information which will allow us to fingerprint or identify different deposit compositions using the fouling monitor [3].

CONCLUSION

A state of the art fouling monitor has been described along with results from field and laboratory studies using the monitor. Although these results are from studies conducted at electric power plants and chemical process plants, the technology is a promising development in investigating fouling of many other heat exchanger systems including those found in the food industry. The fouling monitor combines most features of other fouling monitors (fluid frictional resistance and heat transfer resistance) to provide industry with a method for managing fouling problems and minimizing costly plant shutdowns. Results using this instrument indicate the following:

– The ability to separate convective and conductive heat transfer resistances provide a much clearer view of the fouling process. With further research, we may be able to identify fouling deposit composition from this information.

– If a fouling deposit imparts a "rough" surface, overall heat transfer resistance can actually drop despite accumulation of substantial fouling deposit.

– Water analysis is not a good method of determining rate or extent of fouling deposit build-up on a surface. Surface measurementss are required for a comprehensive view of the fouling process.

– The benefits of using this instrument in evaluating treatments for fouling have been demonstrated in the field. Use of the fouling monitor has provided information on how to effectively treat fouling problems at selected sites.

– The fouling monitor has also been successfully used in evaluating operating conditions which affect fouling (surface temperature, flow velocity, and tube alloy).

– As field and laboratory work with the fouling monitor continue, its benefits in managing fouling problems will become even more evident. We are developing a library of data from these studies which further enhances our ability to interpret the results.

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