FOULING OF HEATED STAINLESS STEEL TUBES WITH FERRIC OXIDE FROM FLOWING WATER SUSPENSIONS

by

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ABSTRACT

The fouling behaviour of ferric oxide (hematite) particles suspended in water flowing through 0.343 inch i.d. type 304 stainless steel tubes was experimentally investigated. Independent variables studied, using micron and submicron size particles, were ferric oxide concentration (15 - 3750 ppm), tube Reynolds No. (10090 - 37590) and heat flux (0 - 92460 BTU/ft^2-hr). For selected runs, fouled tubes were sectioned and the fouling deposit subjected to "in situ" chemical analysis by means of an electron microprobe.

During the fouling process, measurements were made of local and average thermal resistance as a function of time. The resulting fouling curves fell into three distinct categories, depending on the particle concentration and the mode of operation:

(I) At ferric oxide concentrations below 100 ppm, no thermal fouling could be detected over experimental periods of up to 14 days. Microprobe examination of such tubes showed spotty deposits.

(2) At ferric oxide concentrations of 750 ppm and higher, using mixed size particles, measurable thermal fouling occurred at a steadily decreasing rate, similar to the asymptotic type behaviour reported previously in other fouling systems. In the present study, the asymptotic condition was achieved after about four hours of operation. Prolonged operation resulted in a sudden decrease in fouling resistance at localized positions on the test section, followed by refouling of the whole test section.

(3) If the suspension was circulated through the test section at zero heat flux for approximately eight hours and then heating started, the tube commenced fouling thermally at a constant rate considerably greater than the previous decreasing rates.

Microprobe results showed the deposits to contain, in addition to iron and oxygen, significant amounts of nickel and chromium. Chemical composition profiles typically showed nickel and chromium concentration gradients from the wall inwards, concentrations varying from the highest values at the wall to zero at the deposit-fluid interface. A test section used for a series of fouling trials, when

examined under an electron microscope, was found to contain small but distinct pits.

A hypothesis is presented according to which the fouling behaviour of water suspended ferric oxide on stainless steel is controlled by the rate at which crevice corrosion of the stainless steel occurs. The corrosion products precipitate within the initially loose deposit structure and thus serve to stabilize this structure. The corrosion rate is in turn controlled by the oxygen reduction rate at unfouled areas on the tube wall.

Experiments specifically designed to test this hypothesis, such as increasing the unfouled area in an attempt to accelerate the corrosion rate, and removing oxygen with a scavenger in order to decrease the rate, gave results entirely consistent with the hypothesis. Mathematical models based on the hypothesis are explored.

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Chapter 1

INTRODUCTION

1.1 The Fouling Problem

Fouling, the accumulation of undesired deposits on heat transfer surfaces, is a major industrial problem. For example, in oil refineries coke-type deposits form on heat exchanger surfaces and impede the flow of heat. This results in higher capital costs, and can also result in costly plant shut-downs for cleaning. In nuclear reactors, fouling deposits can become radioactive, causing difficult and potentially hazardous maintenance problems. In pulp mills, chemical digester heat exchangers are prone to fouling, which results in increased steam costs. Processes with large cooling requirements, such as sulphuric acid production, also experience fouling problems, which generally manifest themselves by increasing process water requirements.

Although fouling problems are of economic importance in a large number of industries, no systematic treatment of the subject is available in the literature. As pointed out by Taborek *et al.* (1) in their review paper, "Fouling: The Major Unresolved Problem in Heat Transfer," there is not, at the present time, a single reference book covering the subject of fouling, and heat transfer texts do little more than acknowledge the existence of fouling problems. As a consequence, designers of heat transfer equipment must resort to empirical methods in computing heat exchange surface areas for processes where fouling is experienced. These methods usually involve the assumption of a fouling resistance, which is added to the other heat transfer resistances to arrive at the total thermal resistance used as the basis for design. Such an approach frequently causes inaccurate design, not only because of the unreliability of the fouling resistance estimation, but also because it fails to take into account the unsteady state nature of the fouling process.

In summary, fouling is a major problem in many process industries resulting in increased capital costs and process maintenance difficulties. At the same time, there is little information available which enables the engineer to design adequately for heat exchange where fouling is a problem. Because of current public concern regarding energy resources, process industries will face growing pressures to conserve and reclaim process heat. To meet such an objective will require an increased understanding of fouling and how to control or eliminate it.

1.2 Pertinent Prior Work

One of the earliest studies of fouling was made in 1924 by McCabe and Robinson (2). This study concerned the scaling of evaporators, and resulted in one of the first predictive equations for fouling resistance as a function of operating time. McCabe and Robinson considered the rate of change of fouling resistance with time to be proportional to the amount of liquid evaporated; that is,

$$\frac{dR_f}{dt} \propto Q \qquad (1.1)$$

where R_f = fouling resistance

t = time

Q = rate of evaporation

Since Q varies as the heat transfer rate q, equation (1.1) can be written as

$$\frac{dR_f}{dt} \propto q \qquad (1.2)$$

For q the basic heat transfer rate equation is invoked:

$$q' = q/A = U\Delta T = \frac{\Delta T}{R_0 + R_f} \tag{1.3}$$

where R_0 = clean wall resistance

ΔT = appropriate temperature difference across the total heat transfer resistance

U = overall heat transfer coefficient

A = heat transfer area

Substitution of equation (1.3) into equation (1.2) yields

$$\frac{dR_f}{dt} \propto \frac{\Delta T}{R_0 + R_f} \tag{1.4}$$

For a constant heat flow, equation (1.2) predicts a linear increase of fouling resistance with time. In the more common evaporator situations, the overall temperature difference ΔT is constant and equation (1.4) predicts an increase in R_f with time at an ever decreasing rate. R_f does not, however, reach a finite limit.

Hasson (3,4) has studied scale deposition on sensible heat exchanger surfaces using both calcium carbonate and calcium sulphate from water solutions as foulants. He found that during the initial stages, little change in thermal resistance occurred. This Hasson referred to as a nucleation period, during which it was considered that scaling nuclei form on the heat transfer surfaces. Following this period, scaling and thermal fouling were found to proceed at a non-uniform rate, being highest at the downstream end of a heated test section, due presumably to the inverse solubility effect. The existence of a nucleation (or induction) period is not included in the McCabe-Robinson approach.

Kern (5) and Kern and Seaton (6) have studied the increase in fouling resistance as a function of time for oil refinery heat exchangers. In their approach, fouling is considered to be a dynamic process involving both deposition on, and release from, the heat transfer surface. When the release rate equals the deposition rate, a finite asymptotic fouling resistance is achieved. The basic differential equation of Kern and Seaton was

$$\frac{dx}{dt} = K_1 C W - K_2 \tau x \tag{1.5}$$

where x = foulant deposit thickness

K_1 = proportionality constant

K_2 = proportionality constant

W = mass flow rate

τ = shear stress at the tube wall

t = time

C = concentration of foulant in the fluid

If it is assumed that all variables on the right-hand side of equation (1.5) are constant with the exception of x, integration from the initial condition, $x = 0$, at $t = 0$, yields

$$x = \frac{K_1 C W}{K_2 \tau}\left[1 - e^{-K_2 \tau t}\right] \qquad (1.6)$$

Assuming that, per unit area of heat transfer surface, $R_f = x/k_d$, where k_d is the thermal conductivity of the deposit, then

$$R_f = \frac{K_1 C W}{K_2 k_d \tau}\left[1 - e^{-K_2 \tau t}\right] \qquad (1.7)$$

Kern found that the dependence of R_f on t given by equation (1.7) not only described oil refinery fouling data, but also that of several unspecified aqueous fouling systems.

Watkinson (7) studied particulate fouling in a laboratory heat transfer loop using an industrial sour gas-oil distillate and a sand-water mixture. In his attempt to fit his data to a Kern-Seaton type equation (such as equation (1.7), he obtained a good fit for the sand-water mixture, but a seemingly poor fit for the gas-oil distillate except under conditions of low heat flux. Further, the initial fouling rate $\left(\left.\frac{dR_f}{dt}\right|_{t=0}\right)$ was found to vary directly with the flow rate for the lower velocity sand-water runs, in line with equation (1.7), but to vary inversely with the flow rate for the gas-oil runs. Through a study of the effect of mass flow rate on asymptotic fouling resistance $\left(\left.R_f\right|_{t=\infty} = \frac{K_1 CW}{K_2 \tau k_d}\right.$ of equation (1.7)$\Big)$, Watkinson found this resistance for the gas-oil runs to be inversely proportional to the <u>square</u> of the flow rate. Equation (1.7) predicts that the asymptotic fouling resistance should be inversely proportional to the flow rate raised to the <u>first</u> power. The latter result was found for the sand-water runs.

Other investigators, notably Parkins (8), Nijsing (9), Hatcher (10) and Charlesworth (11,12) have studied fouling associated with heat transfer surfaces in nuclear reactors. Parkins introduced the concept of fouling as an interplay of the mass flux of particles to the heat transfer surface and the probability that a particle will stick to the surface. His basic equation is

$$\frac{dR_f}{dt} = \sum_i C_i N_i \overline{U}_i S_i \qquad (1.8)$$

where $\frac{dR_f}{dt}$ = fouling film formation rate

N_i = concentration of type i particles

$\overline{U}_i$ = velocity of a particle toward the surface in close proximity to the surface

S_i = sticking probability

C_i = proportionality constant

If subsequent removal is a factor, a removal term presumably should be included. Nijsing discusses the role of Brownian movement and the effect of such factors as velocity profiles on the deposition process. Charlesworth has derived an equation for fouling in nuclear reactors under boiling conditions by corrosion products of iron. His equation resembles that of Kern and Seaton.

In order to reconcile their data for gas-oil and sand-water fouling with both the Kern-Seaton equation and the concepts of Parkins and Nijsing, Watkinson and Epstein (13) developed an equation incorporating:

(1) the deposition-release concept of Kern and Seaton,

(2) the sticking probability approach of Parkins, and

(3) implicitly, the influence of Brownian movement, as suggested by Nijsing.

The basic differential equation in this model is

$$\frac{dx}{dt} = a_1 JS - a_2 \tau x \qquad (1.9)$$

where a_1 and a_2 are constants

J = the mass flux of particles normal to the heated surface

S = the sticking probability

x = the deposit thickness

In turn J is represented by a mass transfer rate equation

$$J = k_c \, (C_b - C_w) \qquad (1.10)$$

where k_c = the mass transfer coefficient for radial transport of the particles

$(C_b - C_w)$ = the particle concentration difference between the bulk of the fluid and the tube wall.

The mass transfer coefficient k_c is related to fluid velocity by a momentum-mass transfer analogy after Metzner and Friend (14).

$$k_c = \frac{U_b\sqrt{f/2}}{11.8\ S_c^{2/3}} \qquad (1.11)$$

which applies for high S_c (low diffusivity).

The sticking probability S is assumed to be related to the surface temperature T_s by an Arrhenius-type relationship, and inversely proportional to the hydrodynamic forces on a particle at the instant the particle contacts the wall. Consequently

$$S = \frac{Ce^{-E/R_gT_s}}{U_b^{\,2}\ f} \qquad (1.12)$$

Since f, the Fanning friction factor, is related to the shear stress by the equation

$$\tau = f\rho U_b^{\,2}/2 \qquad (1.13)$$

combination of equations (1.9, 1.10, 1.11, 1.12 and 1.13) leads to

$$\frac{dx}{dt} = \frac{A_1(C_b - C_w)\ e^{-E/R_gT_s}}{U_b\sqrt{f}} - A_2 f U_b^{\,2} x \qquad (1.14)$$

If it is assumed that k_f (fouling film thermal conductivity) does not vary with x, and that f is not a function of U_b (fully rough flow), then the initial fouling rate is

$$\left.\frac{dR_f}{dt}\right|_{t=0} = \frac{A_1'(C_b - C_w)\ e^{-E/R_g T_s}}{W} \tag{1.15}$$

in keeping with the gas-oil data.

The asymptotic fouling resistance R_f^* (defined as $R_f\big|_{t=\infty}$) is found from equation (1.14) to be proportional to $\left(U_b\sqrt{f}\right)^{-3}$. Experimentally the results for the sour gas-oil fouling showed R_f^* to be proportional to $\left(U_b\right)^{-2}$.

For the particular case where S = 1 and therefore $C_w = 0$, the combination of equations (1.9, 1.10 and 1.11) leads to the equivalent of the Kern-Seaton equation, which fitted the results for the lower velocity sand-water runs.

Taborek and Associates (1,15) have approached fouling through an industrial experimental program supplemented with laboratory testing. For cooling water systems, they have found that city water deposits usually consist mainly of calcium carbonate, and that the fouling behaviour of such systems is described by the predictive equation

$$\frac{dR_f}{dt} = C_0(C_r)^r \exp\left(- \frac{E}{R_g T_s}\right) - C_2\left(\frac{\tau}{R_b}\right) \tag{1.16}$$

where C_0 = a coefficient inversely proportional to velocity

C_r = function of fouling concentration

r = exponent

E = activation energy

R_g = gas constant

T_s = heat transfer surface temperature

$\frac{dR_f}{dt}$ = fouling rate

τ = shear stress at the heat transfer surface

R_b = bonding resistance of the fouling deposit to shear

Taborek *et al.*, using equation (1.16) as a starting point, were able to predict the fouling behaviour of cooling water systems with an accuracy of ±40% for the asymptotic fouling resistance and ±35% for the initial fouling rate. Both of these figures are based upon one standard deviation.

Some investigators have studied fouling from a fluid dynamic-particle transport point of view. Beal (16,17), for example, has derived a mathematical model designed to predict fouling rates as a function of particle size and fluid dynamic parameters. (Section 6.28 contains a review of this work.) Others, notably Gasparini *et al.* (18), have concerned themselves with the effect of surface forces on the adherence of foulants to various heat transfer surface materials. Yet another approach has been taken by Kabele and Bartlett (19), who consider contaminant coagulation to be a major factor in fouling.

It is clear from the literature on fouling that the subject is indeed a broad and expanding one. A consequence of this is that researchers in the area must be content to work toward narrow and well defined objectives if progress is to be made toward finding better means of dealing with fouling problems.

1.3 Problem Area Selected and Objectives of the Research

Upon completion of his investigation of the two fouling systems, gas-oil and sand-water, Watkinson (7) stated that further work was required to test the validity of the various fouling models he had developed. In particular, the type and magnitude of forces involved in adhesion had not been identified and the particle concentration had not been varied, although it had been incorporated in the models as a parameter. Also, the removal mechanism used as a hypothesis to explain asymptotic fouling behaviour had not been directly demonstrated to exist.

Charlesworth (24), who is studying how iron corrosion products foul heat transfer surfaces in nuclear reactors (11,12), considers the following questions to be open:

(1) What are the relative importance of dissolved and particulate matter?

(2) What are the driving forces for contaminant deposition and release?

(3) Does all the oxide layer on the fouling surface participate in the fouling process?

(4) What type of bonding is involved?

(5) What effect does heat transfer surface material and finish have?

(6) Are there synergistic effects between fouling species?

Nijsing (9) concludes his paper on the particle dynamics of fouling by stating that ". . . basic experimental research on fouling requires the use of methods which enable the coolant impurity to be characterized."

Taborek (1) believes that progress in fouling research requires the systematic collection of data on a wide variety of fouling systems and the subjection of such data to the various predictive fouling models in the literature.

From the above, it appears that the main problem area in the field of fouling is that of determining what causes the frequently observed induction period, what type of deposit bonding occurs and what factors influence deposit removal. Solutions to such problems require finding or, if necessary, developing means of characterizing fouling impurities and examining the manner in which they are deposited.

In an attempt to answer some of these questions, the decision was made to investigate the fouling behaviour of a system consisting of a ferric oxide suspension in water circulating through a 304 stainless steel tube. The reasons for making this decision were as follows:

(1) Ferric oxide has frequently been identified in fouling deposits in many systems such as boilers and coolers (20,21,22). Consequently the results of such a study could have practical application.

(2) Fe_2O_3 was apparently available in pure form in a range of particle sizes, thus opening the possibility of studying the effect of particle size on fouling.

(3) Ferric oxide is practically insoluble in water and therefore the study was limited to particulate fouling uninfluenced by fouling from solution.

The decision was also made to use the heat transfer loop constructed by Watkinson (7) and modified by Mayo (23) for his study, since this would give a degree of data continuity useful in the assessment of results.

Specifically, the objectives of the proposed research were as follows:

(1) To determine the effects of ferric oxide concentration, particle size, heat flux and fluid velocity on the fouling characteristics of a ferric oxide-water-304 stainless steel system.

(2) To determine how well the fouling results from such a system fit fouling models such as those proposed by Kern and Seaton (6) and by Beal (16,17).

(3) To study, through use of the electron microprobe, the manner in which deposits are laid down in order to gain some insight into possible mechanisms for deposition and release.

Chapter 2

APPARATUS AND MATERIALS

2.1 Heat Transfer Loop

All fouling runs were made in a heat transfer loop originally constructed by Watkinson (7) and modified by Mayo (23) and the present author to include automatic logging of data. Mayo (23) has given a detailed description of the experimental set-up, a summary of which follows.

Figure 1 shows a schematic of the test loop and Table I lists the components along with details concerning size, specifications and materials of construction. The essential features of the heat transfer loop are given below.

A steam coil jacketted storage tank insulated with fibre glass wool held the 200 kg of fluid used for each run. The storage tank was equipped with a fluid recirculation pipe and a compressed air line which extended to the bottom of the tank. Both of these features helped to minimize settling of the ferric oxide suspension and

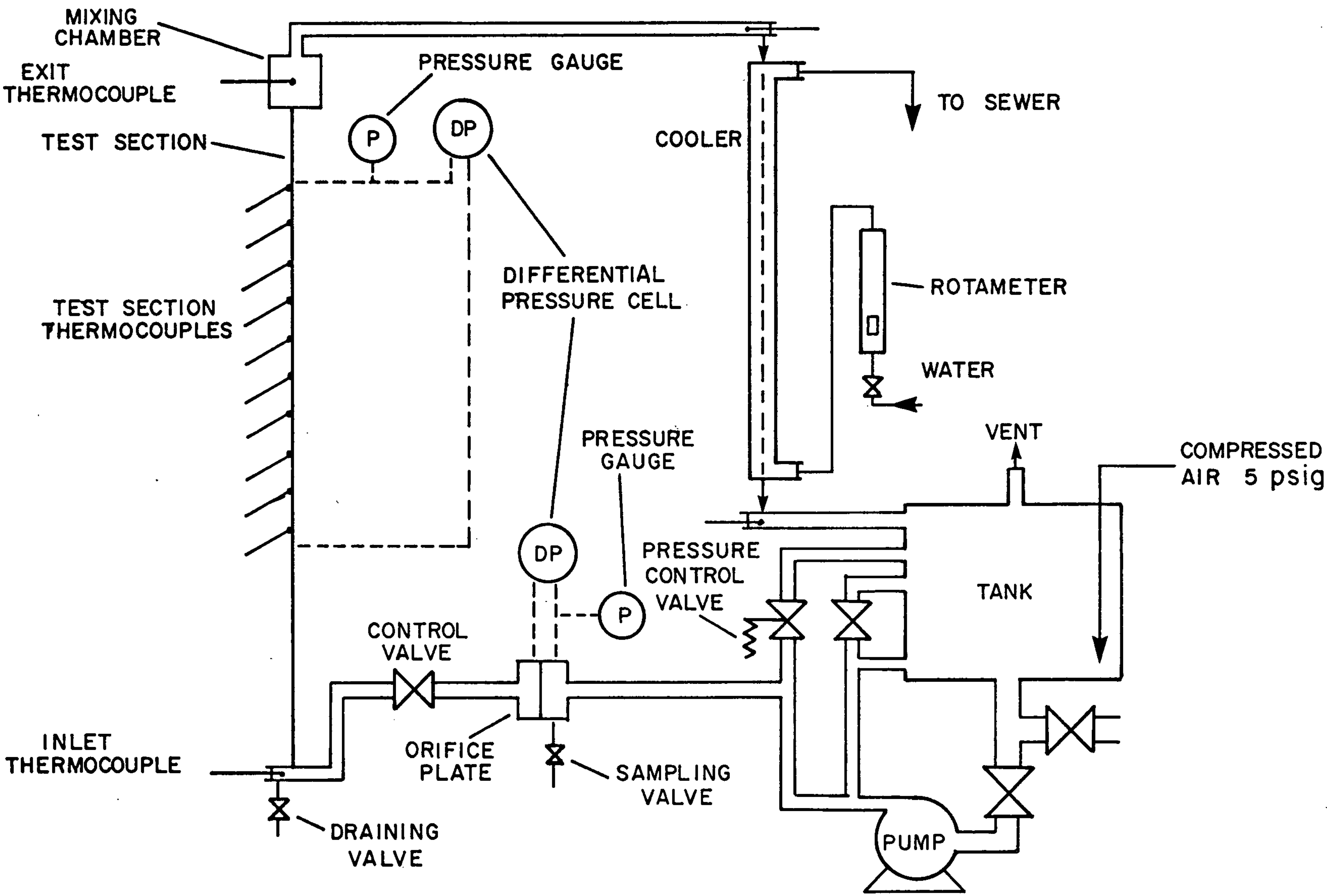


Figure 1. Heat Transfer Loop Schematic.

Table I

Equipment Component List

Component	Description
Storage Tank	45 gallon-316 stainless steel drum
Pump	Sieman and Hinsch Type CAD Model 3102 two-stage self-priming centrifugal pump, stainless steel
Motor	3 HP
Flow Meter	Stainless steel sharp-edged orifice (β = 0.301, β = 0.602)
Differential Pressure Cells	Honeywell DP meter Y227X2-L2
Pump Pressure Gauge	Marsh Bourdon tube, 0-200 psi
Test Section	3/8 inch O.D. x 0.016 inch wall thickness type 304 stainless steel seamless tubing
Pressure Taps	Stainless steel, spaced 19-1/4 inches and 45-7/16 inches from lower end of tube (see Appendix I for drawings)
Electrical Terminals	Brass, soldered 20-3/4 inches and 44-1/32 inches from lower end of tube (see Appendix I for drawings)
Electrical Cable	Insulated copper cable size 000

(Continued)

Table I (Continued)

Component	Description
Test Section Thermocouples	30 gauge copper-constantan heat fused thermocouples shielded with 11/64 inch diameter tinned copper braiding
Fluid Thermocouples	Copper-constantan 'Ceramocouples,' Thermoelectric Part No. Ce 50418-T with 304 stainless steel sheaths and shielded leads
Globe Valves	Power 1/2 inch stainless steel
By-Pass Valve	Farris No. 1870 spring loaded valve (100 psig rating)
Pressure Transducer	Viatran, model 209, 0-15 psi pressure transducer
Pressure Switch	Honeywell Pressure troll Model L404C
Variacs	Superior Electrical type 1156D mounted on a common shaft
Primary Transformer	General Electric Cat. No. 10M36 rated at 10KUA 220/110 volts
Secondary Transformer	Bartholomew and Montgomery 17 KVA 220/40 volts
Ammeter	Weston model 155, 0-2-1/2, 0-5 amp AC dual range meter
Ammeter Transformer	Instrument Service Laboratories 500/5 amps

(Continued)

Table I (Continued)

Component	Description
Voltmeter	Fuji Denki 0-15, 0-30 volt AC dual range meter
Cooler	Double pipe cooler. Overall length 6 feet. Inside pipe 3/8 inch O.D. x 0.035 inch wall thickness stainless steel tubing. Outside pipe 1/2 inch galvanized iron
Cooler Rotameter	Brooks Type 12-1110
Test Section Insulation	Inside - Asbestos powder Outside - 1 inch thick Caposite
Pipe and Tank Insulation	1 inch fibreglass
Gasket and Seal Material	Teflon

insured that the test fluid remained saturated with oxygen during the course of a run.

A typical heat transfer fouling surface test section used for the trials is shown in Figure 2. It consisted of a $51\frac{15}{16}$ inch long 304 stainless steel seamless tube having an outside diameter of 3/8 inch and a wall thickness of 0.016 inch. Attached to the test section were two stainless steel pressure taps and two brass electrical contacts. Size and spacings for these components are given in Table I. The test section can be subdivided into three parts, an entrance length of $19\frac{1}{4}$ inches (51 diameters I.D.) to establish the velocity profile, a $6\frac{1}{2}$ inch exit section, and a $23\frac{9}{32}$ inch middle section used as the heated portion of the tube. Twelve copper-constantan thermocouples constructed from 30 gauge wire were attached to the heated section at two-inch intervals. Precise locations are given in Table II. Thermocouples were bonded to the tube wall using "Eccocoat" epoxy resin according to a procedure given in Section 3.1. Insulation for the test section consisted of a 0.3 inch layer of asbestos powder adjacent to the tube held in place by a one-inch thick layer of "Caposite" pipe insulation. Caposite is a mineral wool-Amosite fibre bound with asbestos cement.

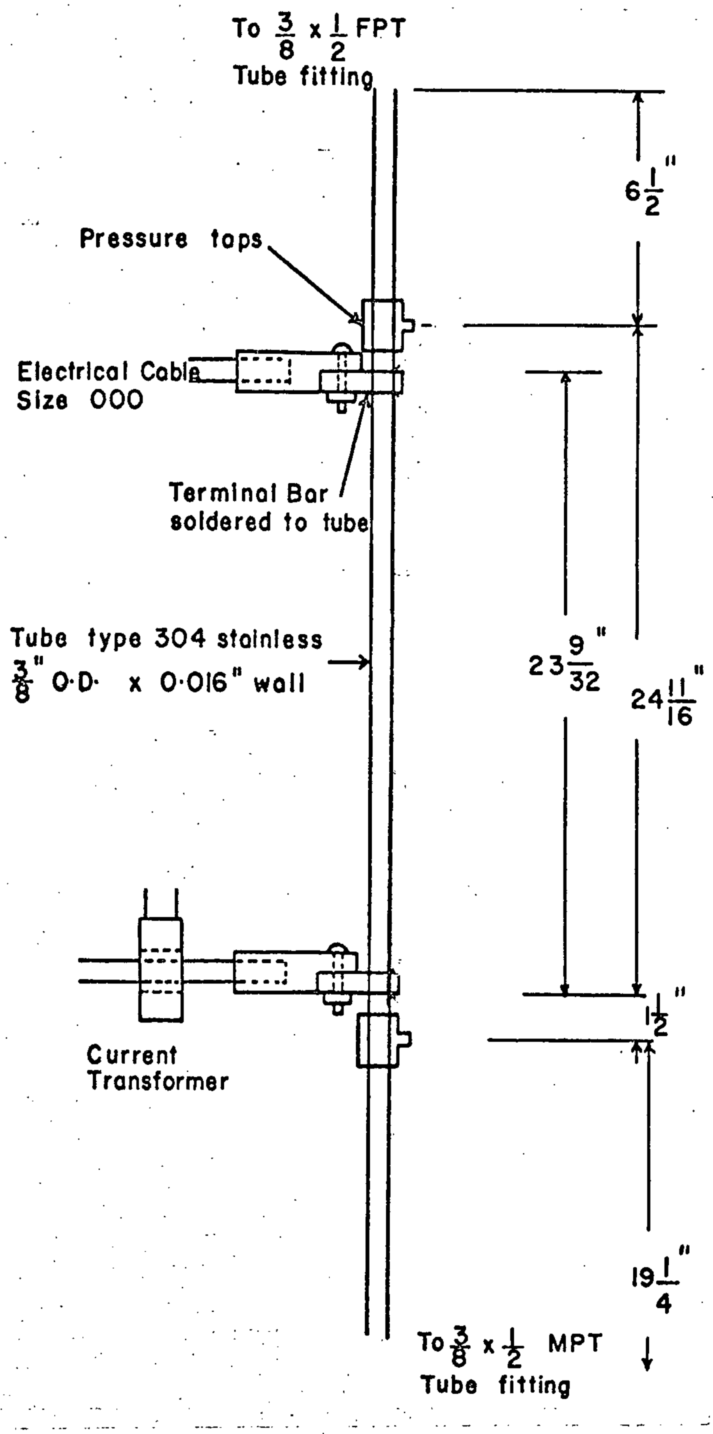


Figure 2. Test Section. (Test Section design by Watkinson (7) and used by Watkinson (7), Mayo (23) and the present investigator for all fouling runs. Drawing from Watkinson (7).)

Table II

Thermocouple Locations on Test Section

Thermocouple Number	Test Section Position Designation	Location: Distance From Lower, Tube End, Inches
1	T215	21.5
2	T235	23.5
3	T255	25.5
4	T275	27.5
5	T295	29.5
6	T315	31.5
7	T335	33.5
8	T355	35.5
9	T375	37.5
10	T395	39.5
11	T415	41.5
12	T428	42.8

The middle portion of the test section was heated electrically using a power circuit shown in Figure 3. The electrical system consisted of a 220 volt single phase power source wired to two variacs mounted in parallel on a common shaft. The output from the variacs was stepped down to a maximum of 20 volts using two transformers in series. The first reduced voltage from 220 volts to 110 volts and the second reduced the voltage to 20 volts. Details concerning the electrical equipment, the wiring and the current and voltage measuring instruments are given in Table I.

All thermal and pressure drop data were recorded automatically using a Solartron data logging system model LY1471. Mayo (23) gives a detailed description of this system. Specifications of its main components are given in Table III. Briefly, it consists of a digital voltmeter, a digital clock, a scanner, a system program pinboard, a thermocouple compensating unit and a solenoid-operated typewriter. The output from the heat transfer loop thermocouples and the pressure transducer were fed into the digital voltmeter through the pinboard assembly, according to a program established by the scanner. At a predetermined interval, usually one minute, each input channel was monitored and the data transmitted through the system

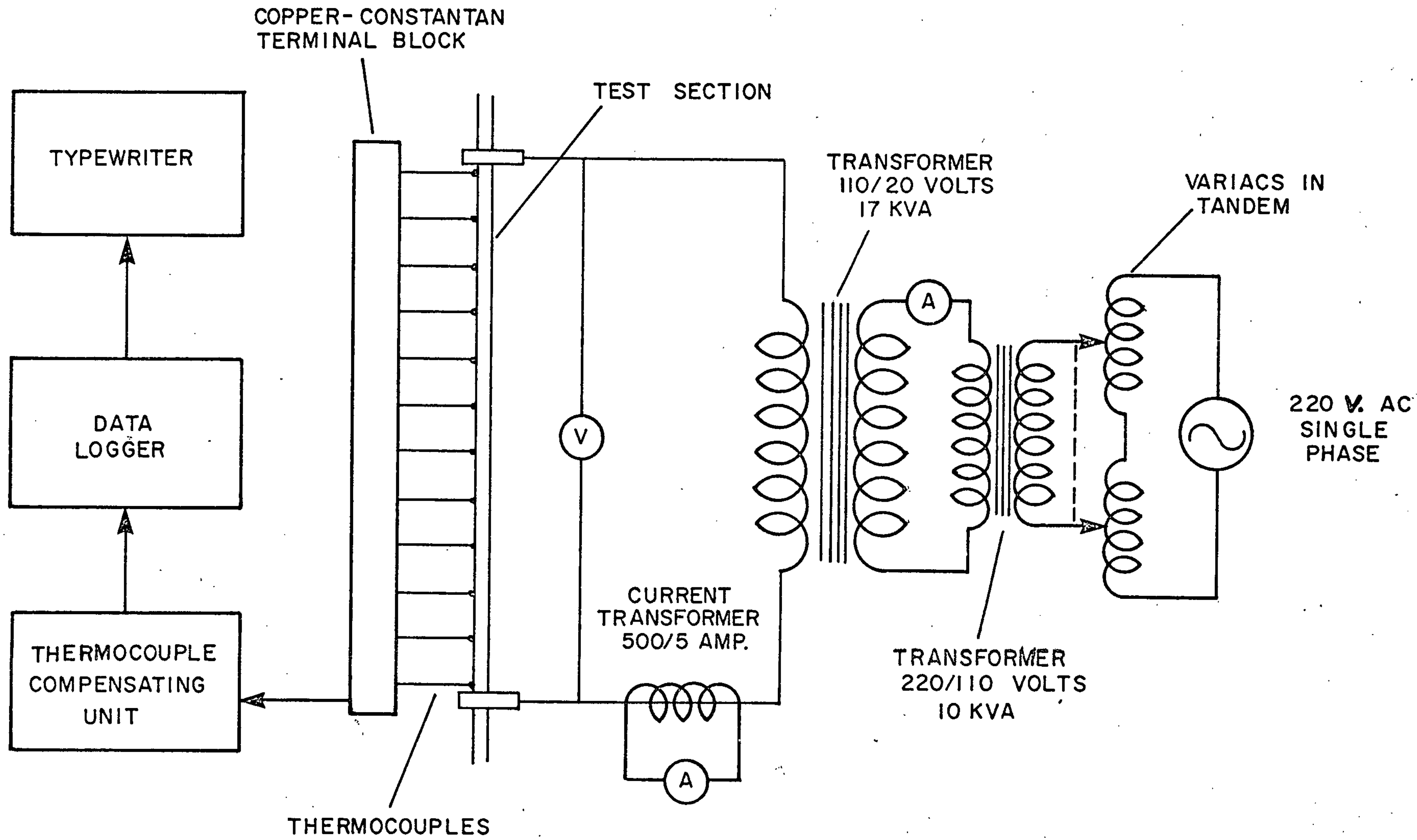


Figure 3. Heat Transfer Loop Electrical and Data Logging System Schematic. (Arrangement designed by Watkinson (7) and modified by Mayo (23) and Hopkins to include data logging. Drawing from Mayo (23).)

Table III

Data Logging System Components

Component	Model Number
Thermocouple Compensating Unit	Solartron LU 1468
Scanner	Solartron LU 1461
System Program Pinboard	Solartron LX 1689
Digital Clock	Solartron LU 1463
Digital Volt-meter	Solartron LM 1426
Typewriter Drive	Solartron LU 1469
Typewriter	IBM LX 1653

and printed. Recorded with each series of data was the time at which the monitoring sequence commenced. Recorded with the heated section thermocouple data were also the outputs of thermocouples located at the entrance to and exit from the test section, as well as a thermocouple indicating room temperature.

Another feature of the heat transfer loop was a 6 foot double pipe heat exchanger installed after the test section on the return line to the tank. Table I gives details pertaining to this unit.

System piping for the heat transfer loop consisted of ½ inch 316 stainless steel schedule 40 pipe, with the exception of the inlet pipe to the pump, which was 1 inch 316 stainless steel pipe. All seals, gaskets, packing and the like were made of Teflon.

2.2 Electron Microprobe

Deposits from selected ferric oxide fouling trials, and from a variety of other sources, were analyzed in a Japanese Electron Optical Limited (JEOL) electron microprobe located in the Metallurgy Department of the University of British Columbia. Figure 4 shows a schematic diagram of the probe and Figure 5 illustrates its principle of operation.

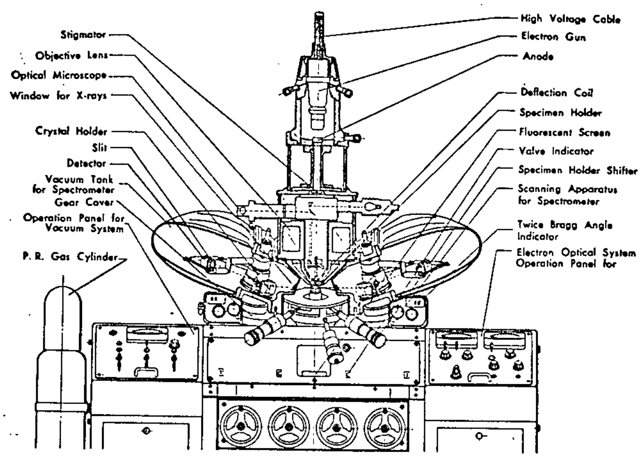


Figure 4. The JEOL Electron Microprobe.

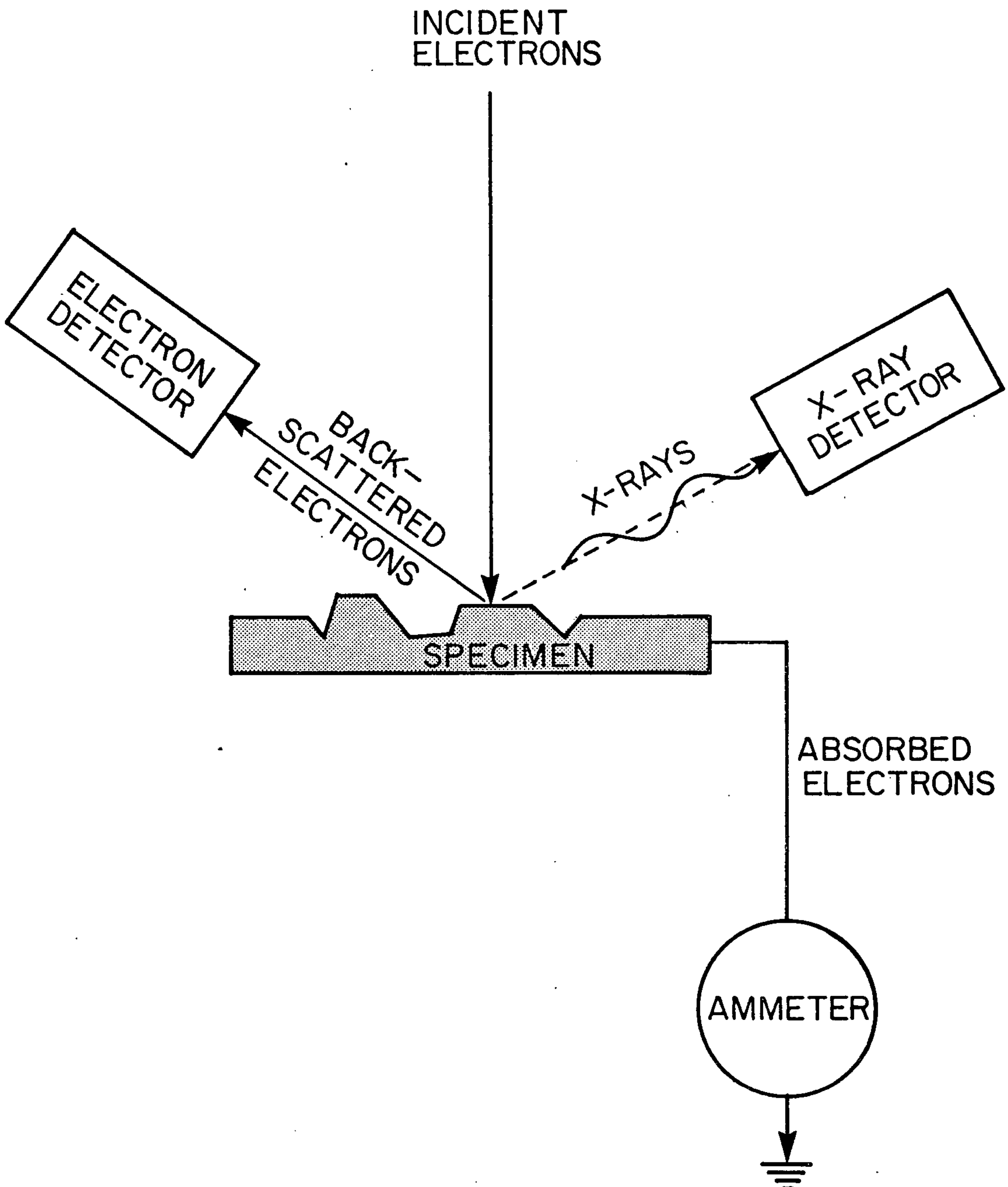


Figure 5. Illustration Demonstrating Fundamental Principles of Electron Microprobe Analysis.

Briefly, the principle upon which the microprobe operates is as follows. Electrons, from an electron gun, are focused through a condensor lens into a ½ micron beam, accelerated through a potential, typically 25 KV, and directed upon the sample being analyzed. There, the bombarding electrons can: (1) collide with the nucleus of an atom and rebound, or (2) collide with and displace a planetary electron of an atom in the sample.

If the electron rebounds, it can be picked up in a detector and used to form an optical image of the surface of the material being examined. If the bombarding electron displaces a planetary electron of an atom, that atom becomes excited and emits X-rays having a frequency characteristic of the element. Determination of this frequency, using a crystal system, gives positive identification of the element. Measurement of the intensity of these X-rays gives a quantitative estimate of the amount of that element present in the sample.

For a detailed description of the microprobe, its principle of operation and fundamental theory, reference should be made to the work of Brown (25), Birks (26), van Olphen and Parrish (27) and Castaing (28).

2.3 Properties of Ferric Oxide Fouling Materials

The ferric oxide used in this study was obtained from two sources:

(1) Bulk, mixed-size analytical grade ferric oxide supplied by Allied Chemical Co. Ltd. Table IV gives the physical and chemical properties of this material.

(2) Presized, analytical grade ferric oxide obtained in two 10 gram batches from Particle Information Service. Batch No. 1 had a particle size range of 0.3-0.8 micron, and Batch No. 2 a range of 0.3 to 3.7 microns. The size of these particles was determined by the supplier using electron microscope examination techniques.

The particle size of the bulk ferric oxide was determined by two methods. In method I, a water slurry of particles was prepared and sized by straining through a series of millipore filters. Results, which are shown in Table IV, are not considered a reliable measure of particle size because of the tendency of ferric oxide to coagulate. In method II, an ethanol dispersion of particles was placed on a glass slide, the ethanol evaporated and the particles examined in a scanning electron microscope. Figure 6 shows photomicrographs at magnifications of 14,400 and 60,000. The individual particle size of this ferric oxide

Table IV

Properties of Ferric Oxide Powder

Allied Chemical Batch D344

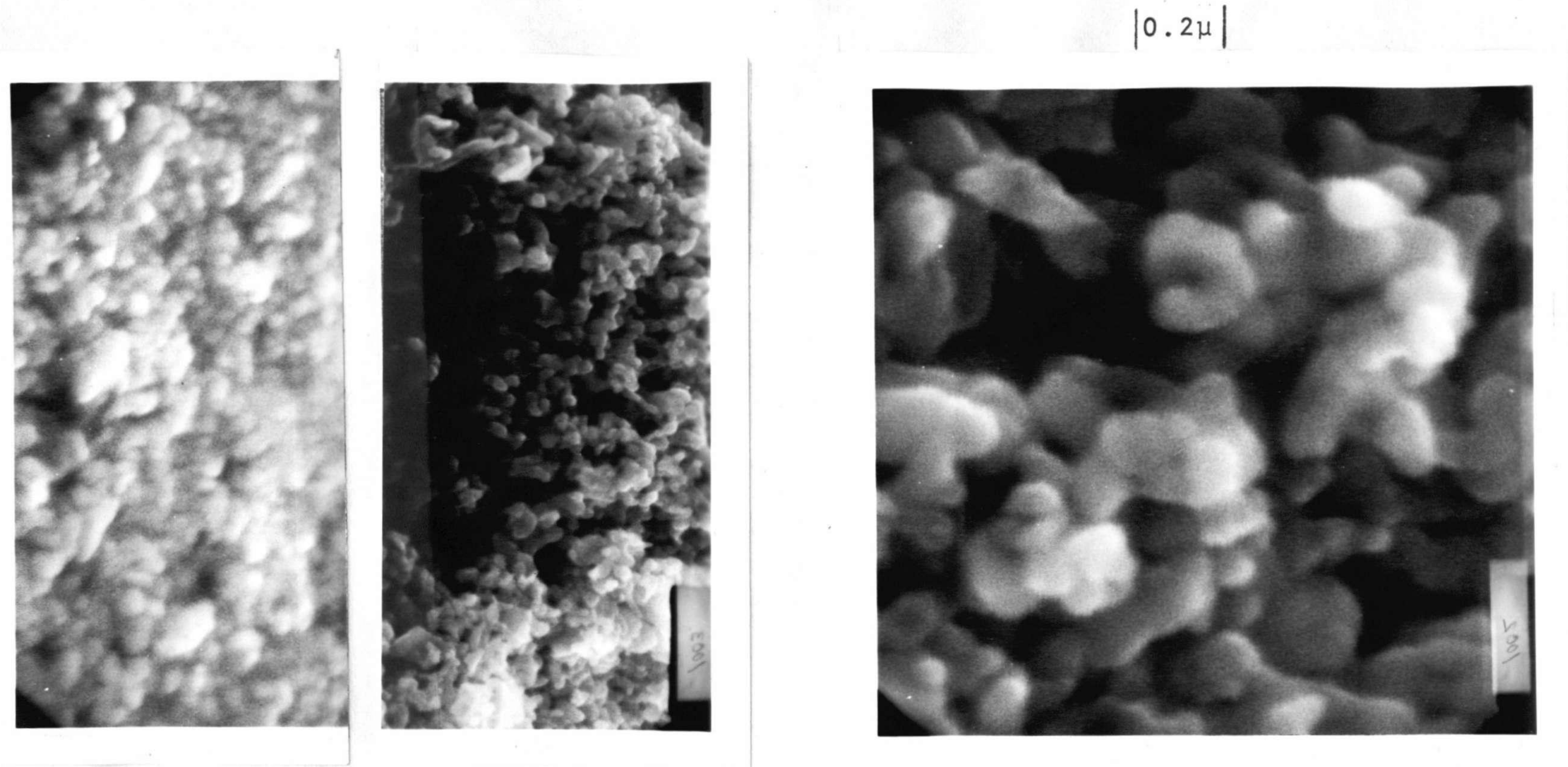
Fe_2O_3 Molecular Weight	159.69
Assay (Fe_2O_3) min.	99%
Specific Gravity	5.12
Solubility Product $Fe(OH)_3 \rightleftharpoons Fe^{+++} + 3OH^-$	1.1×10^{-36}

Maximum Limit of Impurities

Insoluble in $\underline{\underline{H}}Cl$	0.2%
Sulphate ($SO_4^=$)	0.2%
Copper (Cu)	0.005%
Zinc (Zn)	0.005%
Substances not precipitated by NH_4OH (as Sulphates)	0.1%
Manganese (Mn)	0.05%
Phosphates	0.02%

Particle Size Determination

Retained on 10-15 micron millipore filter	99.0%
Passed 10-15 micron millipore filter retained on 4-5 micron millipore filter	1.0%
Passed 4-5 micron millipore filter	0%



6A 14400X 6B 14400X 6C 60000X

Figure 6. Particle Size of Mixed-Size Ferric Oxide in Feedstock and in Fouling Deposit.

(Ferric oxide particles added to the system have a minimum size of approximately 0.2 microns. Such particles however do not appear to deposit as single entities but rather as agglomerates. Figure 6a shows the particle size in the deposit while Figures 6b and 6c show that of feed ferric oxide.)

is estimated by this method to be in the range of 0.2μ. However, the 0.2 micron particles were almost never found to exist as distinct entities but rather as larger agglomerates. Consequently 0.2 micron represents a lower limit size estimate only, the effective upper limit being in the range of several microns.

Chapter 3

EXPERIMENTAL PROCEDURES

3.1 Test Section Preparation Procedure

As stated in Section 2.1, all test sections were fabricated from 304 stainless steel seamless tubing by soldering pressure taps and electrical connections to the tubes as shown in Figure 2, and attaching copper-constantan thermocouples. In order to eliminate AC leakage from the electrically heated test section to the Solartron data logging system, a fault which causes the data logging system to give erroneous results, thermocouples were attached to the tube wall using a high electrical resistivity epoxy resin. This resin, which has the trade name "Eccocoat," also has a comparatively high thermal conductivity. Properties are shown in Table V.

It was found that resin preparation and attachment of thermocouples were the most critical operations in test section preparation. After several failures involving poor bonds or thermocouples in electrical contact

Table V

Properties and Preparation Instructions for Eccocoat 582 Epoxy Resin

PROPERTIES

Thermal Conductivity (BTU/ft-hr-°F)	0.9
Dielectric Strength (volts/mil)	420
Thermal Expansion Coefficient (ft/ft-°F)	19.0×10^{-6}
Volume Resistivity (ohm-cm)	10^{15}
Dielectric Constant at 1 kHz	6.5
Dissipation Factor at 1 kHz	0.02
Service Temperature, max °F	325

PREPARATION INSTRUCTIONS

1. Clean surface to be bonded with trichloroethylene or toluene.

2. Mix contents of Eccocoat 582 Part A and use 100 parts by weight of Part A with 7 parts by weight of the catalyst (Part B)

3. Coat thermocouples and tube with resin and allow to harden overnight at room temperature.

with the tube wall, the following procedure was adopted:

(1) All dirt and grease were removed from the outside of the tube by lightly sanding with fine emergy paper followed by scrubbing with an acetone-soaked cloth. Dirt and grease cause a poor bond between thermocouple and tube wall.

(2) Epoxy resin was prepared exactly according to specifications given in Table V.

(3) At each thermocouple location, a small amount of resin was dabbed on the tube and the thermocouple coated with sufficient resin to completely cover all bare metal. The thermocouples were then laid on the tube at the appropriate locations.

(4) After 15 minutes, each thermocouple was lifted and allowed to settle back on the test section. This precaution reduced the risk of having electrical contact between tube wall and thermocouple tip.

(5) The test section was then allowed to sit overnight at room temperature. This was sufficient time for the epoxy resin to harden.

(6) Following hardening of the resin, the test section was fitted with electrical and piping connections, and insulated.

(7) Prior to installation in the heat transfer loop, the test section was honed using a 38 calibre bronze pistol brush attached to a one-quarter inch drill, and then degreased using an acetone-soaked 'pull through' rifle kit.

In order to insure that use of epoxy resin did not cause temperature drops of sufficient magnitude to cause inaccurate results, a special test section was prepared which contained 12 silver-soldered thermocouples and 12 epoxy-coated thermocouples. Wall temperature values were found to be the same by both methods. The epoxy-coated thermocouples did tend to lag behind the silver-soldered ones when step changes were made in wall temperature. This lag was however small, in the range of four minutes.

3.2 Fouling Run Procedure

In total, 70 experimental trial runs were made during the course of this study. Although there were some variations in procedure to accommodate trials with unique objectives, most trials were performed using the procedure outlined below.

3.2.1 Cleaning of system.

To clean the system, the test section was replaced by a plastic tube, the tank was filled with tap water and the circulation pump was started. Following one-half hour of circulation, the system contents were dumped. This operation was repeated until no trace of residual ferric oxide could be detected visually. It should be noted that 20 ppm ferric oxide is a brilliant red suspension, and that approximately 1 ppm gave water a red tint. The above refers to the procedure followed when the preceding run had been made with ferric oxide. Prior to the initial run, the system was cleaned with a 50% hydrochloric acid solution followed by a water rinse, a 10% sodium hydroxide cleaning followed by a water rinse, and by another 50% hydrochloric acid cleaning with a water rinse. The last water rinse was repeated until the pH of the discharged water equalled that of the input water, namely pH $\sim$ 6.4. According to the Greater Vancouver Regional District analysis, this water contained only 18 ppm total residue, including 0.5 ppm chloride and 4.0 ppm total hardness as $CaCO_3$.

3.2.2 Tank filling.

Twenty-four hours prior to start-up, the cleaned tank was filled with 200 kg of tap water and the steam heating jacket turned on. At this point, the test section was installed in the heat transfer loop.

3.2.3 Start-up.

At start-up, the mixing air to the tank was turned on, the circulation pump started, the variacs turned up to give the desired test section heating, and the cooling water turned on. At this point, the Solartron data logging system was also switched on. Adjustments were then made to the flow rate and cooling water valves to bring the fluid to target inlet and outlet temperatures over the test section.

3.2.4 Elimination of thermal transients.

In order to warm up the data logging system electronics, and to eliminate thermal transients associated with bringing the test section insulation to steady state, the heat transfer loop was operated for a minimum of three hours on tap water. During most of the runs, particularly those in which the influence of heat flux, Reynolds number and ferric oxide concentration was studied, this time was increased to 24 hours.

Following this step, the system was adjusted so that flow rate, inlet temperature, outlet temperature and test section power consumption were precisely at target levels. Table VI shows the variance from target conditions

Table VI

Variance From Target Conditions Tolerated for Run 39

Variable	Target Value	Maximum Value	Minimum Value
Inlet Fluid MV x 200	420 (127.0°F)	421 (127.2°F)	419 (126.8°F)
Outlet Fluid MV x 200	470 (138.3°F)	471 (138.5°F)	470 (138.3°F)
Test Section Volts	9.35	9.37	9.34
Test Section Amps	253	256	253

tolerated for a typical run. After one-half hour, the series of test section wall temperature readings obtained were considered to correspond to the clean wall condition and to be free from errors caused by thermal transients.

3.2.5 Addition of ferric oxide.

Following determination of clean wall temperatures, the desired weighed amount of ferric oxide was slurried in a 5 litre sample of system tap water and added to the heat loop tank as a slug dose. The time of addition was considered to be time zero for the fouling run.

3.2.6 Operating procedure during trials.

During the run, the cooling water rate was varied to hold the inlet temperature to the test section at the target value. With power input and inlet temperature at their respective target values, flow rate variations manifested themselves as variations in outlet temperature. Consequently, the flow could be precisely controlled by adjusting the flow control value to hold the outlet temperature constant. Usually, runs required very few adjustments to hold the system at the target conditions.

3.2.7 Shut-down procedure.

At the end of the trial, the circulating pump and the test section heating were stopped simultaneously, and a series of wall temperatures taken to insure that there were no defective thermocouples. (At zero heat flux, all thermocouples should read approximately the same.) The test section was then removed from the heat transfer loop and rinsed with tap water from a squeeze bottle to remove residual ferric oxide suspension from the fouling deposit on the tube wall. The rinsed test section was set on an incline and allowed to dry.

3.2.8 Fouling deposit sample preparation.

For tubes destined for electron microprobe analysis, the insulation and thermocouples were removed and the tube filled with 'Clear-Cast' liquid polyester resin. Following 24 hours for curing, the tube was cut with tube cutters at locations corresponding to the positions of the thermocouples. These sections were then recut into one-half inch samples, placed in moulds and more polyester resin added. The resulting specimen, which was three-quarter inch in diameter and one-half inch thick, was then ground and polished by standard metallurgical techniques, thereby exposing the fouling deposit and the tube wall to which it adhered. Such samples showed the structure of the deposit perpendicular to the direction of flow of the fluid.

An alternate method of specimen preparation was to turn the polyester-filled tubes in a lathe to remove the burred edges caused by the tube cutters, and to press the polyester core out of the tube. The fouling deposit, which always adhered to the polyester core, then needed no polishing or grinding prior to examination. These samples were analyzed for chemical composition in the Electron Microprobe of the UBC Metallurgy Department.

Chapter 4

DATA COLLECTION AND COMPUTATIONAL PROCEDURES

The data-logging system made possible the collection of a large number of thermal measurements. Typically, in a three hour trial, over 3000 thermocouple readings would be logged. In addition, flow and electrical measurements were recorded manually. To illustrate the procedures followed in gathering and processing data, Run 63 has been selected as a typical run. The steps followed and main computational procedures adopted are outlined below.

4.1 Establishing Objectives of Trial and Setting Trial Conditions

The first step in making a run was to record the objective of the trial and set the conditions under which it was to be run. Table VII is a reproduction of this for Run 63 which had as its objective the determination of a fouling curve at a mixed-size ferric oxide concentration

Table VII

Typical Log Sheet Showing Run Objective and Target Conditions

Run No. 63 Date: 13 Sept. 1972

OBJECTIVE

To determine the fouling curve for a ferric oxide concentration of 2130 ppm at a heat flux of 93,000 BTU/ft^2-hr and a Reynolds number of 26000.

TARGET CONDITIONS

Flow Rate	86.0	(gauge units)
Inlet Fluid MV x 200	420	
Outlet Fluid MV x 200	526	
Variac Setting	70	(gauge units)
Test Section Volts	13.50	
Test Section Amps	355	
Steam Jacket Pressure	22	(lbs/in^2)
Fluid pH	6.2	
Cooling Water Setting	30	(gauge units)
NaCl added	0	(gms)
Ferric Oxide added	426	(gms)
Air	On	
Inlet Fluid Pressure	62	(lbs/in^2)

of 2130 ppm, a heat flux of 93,000 BTU/ft^2-hr and a Reynolds number of 26,000. Following the selection of trial conditions, computer program PAR (see Appendix II) was run to establish that the parameters selected did indeed correspond to the desired trial conditions. For Run 63, the basic input data to PAR was

063 x 13.50 x 355

02130

2.10 x 2.63 x 86.0

where the numbers shown have the following significance:

Run No. = 063

Test Section Volts = 13.50

Test Section Amperes = 355

Ferric Oxide Concentration = 2130 ppm

Thermocouple Reading Inlet Fluid (MV) = 2.10

Thermocouple Reading Exit Fluid (MV) = 2.63

Orifice Meter DP Cell Reading (gauge units) = 86.0

Blank spaces = x

Stored in PAR are data covering orifice meter and thermocouple calibrations, test loop dimensions and thermal conductivity, and the properties of the test fluid. The output from PAR (see Table VIII), in addition to showing

Table VIII

Output from Program PAR

```
*******RUN NO63.*******

FERRIC OXIDE CONC (PPM)   2130.

VOLTS:13.50        AMPS: 355.

HEAT FLOW SUPPLIED 16356.8    BTU/HR
HEAT FLUX SUPPLIED   93897.   BTU/SQFT-HR

BETA0.301          TCR=TINLET127.0   DEG F
DENSITY:0.986 GRAM/CC
                   T OUTLET150.3     DEG F

FLOW RATE 0.1888  LBS.M/SEC

AVG TEMP:138.6    DEG F
KINEMATIC
VISCOSITY:0.479   SQ.CM/SEC

FLUID VELOCITY 4.790   FT/SEC
REYNOLDS NO  26534.0
PRANDTL NO   3.02

HEAT SUPP     16356.8   BTU/HR
HEAT TRANS    15921.4   BTU/HR
HEAT LOST       435.4   BTU/HR
PERCENT HEAT LOST    2.66
HEAT FLUX TRANS. BTU/SQFT-HR   91397.
NUSSELT NO    121.5
RFILM     0.623
RWALL     0.143
RTOTAL     0.765     SQFT-HR-DEG F/BTU
```

<u>Table IX</u>

Output From Datalogger

System Started up at 9:30 on Tap Water
Following Honing of Tube

1140	0475	0476	0461	0452	0466	0462	0461	0447	0133	0198	0203	0444	0402	0456	0465	0360	0198	00.00	000.

Heat Flux Turned Back on Following Thermocouple Check

1310	0447	0551	0684	0682	0724	0724	0732	0707	0125	0210	0207	0708	0611	0749	0779	0287	0210	13.50	355.
1410	0421	0528	0672	0672	0709	0711	0719	0696	0130	0218	0206	0696	0603	0736	0765	0297	0218	13.50	355.
1420	0421	0526	0668	0668	0707	0707	0716	0693	0131	0219	0207	0695	0601	0735	0763	0246	0219		
1430	0416	0525	0667	0667	0706	0706	0712	0691	0130	0220	0209	0692	0600	0733	0760	0248	0219		
1432	0421	0522	0658	0656	0697	0699	0703	0677	0130	0220	0207	0680	0573	0719	0753	0253	0220		
1433	0421	0522	0661	0660	0699	0698	0705	0680	0131	0001	0206	0683	0580	0721	0753	0252	0220		
1434	0421	0525	0665	0663	0705	0704	0709	0684	0132	0001	0206	0685	0584	0725	0757	0294	0220		
1435	0421	0524	0664	0661	0702	0702	0708	0685	0132	0001	0207	0687	0586	0726	0756	0295	0220		
1436	0421	0524	0665	0664	0702	0704	0708	0685	0133	0001	0207	0687	0588	0724	0755	0296	0220		
1437	0421	0523	0662	0661	0698	0699	0706	0682	0134	0001	0206	0685	0587	0724	0753	0294	0220		
1438	0421	0523	0663	0661	0701	0700	0706	0683	0132	0001	0207	0685	0588	0723	0754	0293	0220		
1439	0420	0523	0662	0661	0700	0699	0707	0683	0132	0220	0208	0685	0588	0724	0753	0294	0220	13.50	355.
1440 0	0420	0523	0665	0661	0698	0697	0705	0683	0132	0001	0209	0685	0589	0724	0751	0289	0221		
1441	0420	0522	0661	0662	0699	0698	0706	0683	0130	0221	0210	0685	0589	0724	0751	0298	0221		
1442	0420	0523	0664	0661	0699	0699	0705	0683	0131	0001	0210	0686	0589	0725	0753	0295	0221		

426 Grams of Ferric Oxide Added to System

1443	0421	0525	0665	0663	0705	0704	0709	0684	0132	0001	0206	0685	0584	0725	0757	0294	0221	13.50	355.
1444	0420	0522	0662	0661	0702	0701	0708	0685	0132	0001	0210	0688	0591	0728	0755	0293	0221		
1445	0421	0525	0667	0667	0704	0701	0708	0687	0131	0001	0210	0688	0592	0727	0758	0294	0221		
1446	0421	0526	0668	0666	0703	0705	0711	0689	0131	0001	0210	0699	0595	0737	0758	0291	0221		
1447	0421	0530	0673	0673	0705	0703	0712	0691	0131	0001	0210	0691	0596	0731	0761	0294	0221		
1448	0421	0525	0667	0666	0703	0703	0712	0689	0131	0221	0212	0692	0596	0733	0763	0293	0221	13.50	355.
1449	0422	0525	0668	0666	0702	0704	0712	0689	0130	0221	0212	0697	0597	0738	0768	0255	0221		
1450	0421	0525	0667	0667	0705	0706	0715	0692	0131	0221	0212	0695	0597	0734	0763	0295	0221	13.50	355.
1455	0421	0525	0670	0668	0705	0707	0714	0692	0129	0222	0211	0695	0598	0735	0763	0300	0221	13.50	355.
1457	0421	0525	0670	0670	0708	0709	0716	0693	0131	0222	0209	0695	0598	0735	0765	0294	0222	13.50	355.
1500	0420	0527	0675	0679	0715	0716	0723	0700	0131	0222	0209	0703	0602	0741	0769	0295	0222		
1505	0420	0528	0679	0676	0715	0717	0724	0701	0130	0222	0211	0703	0605	0740	0771	0295	0222		
1508	0420	0525	0671	0670	0712	0709	0717	0695	0132	0001	0209	0697	0601	0735	0766	0295	0222	13.50	355.
1510	0420	0524	0674	0673	0711	0711	0718	0695	0133	0001	0209	0696	0601	0735	0763	0297	0223		
1515	0420	0524	0673	0670	0711	0708	0717	0693	0133	0001	0209	0696	0600	0732	0762	0295	0223		
1520	0420	0525	0675	0673	0709	0711	0716	0694	0131	0001	0211	0696	0601	0734	0762	0296	0223		
1525	0421	0525	0675	0674	0711	0712	0718	0695	0131	0001	0212	0697	0601	0735	0763	0296	0223	13.50	355.
1530	0420	0529	0684	0684	0720	0720	0727	0704	0127	0001	0210	0705	0607	0744	0773	0296	0223		
1534	0421	0525	0675	0674	0710	0710	0716	0693	0125	0224	0211	0695	0600	0732	0762	0296	0224	13.50	355.
1540	0421	0525	0674	0672	0709	0707	0713	0692	0125	0224	0212	0694	0600	0731	0758	0296	0224		
1544	0421	0525	0674	0673	0712	0711	0718	0694	0121	0224	0210	0696	0600	0733	0762	0296	0224	13.50	355.
1550	0422	0525	0675	0674	0712	[illegible]	0717	0694	0121	0224	0211	0696	0601	0734	0761	0296	0224		
1600	0422	0527	0678	0677	0715	0713	0720	0697	0113	0224	0212	0699	0603	0737	0765	0298	0224		
1611	0421	0525	0676	0676	0712	0712	0718	0695	0103	0225	0213	0697	0602	0735	0762	0298	0225	13.50	355.
1620	0420	0523	0674	0671	0708	0708	0714	0691	0101	0225	0212	0693	0599	0731	0758	0297	0225		
1629	0420	0525	0679	0676	0714	0713	0719	0696	0096	0225	0212	0697	0601	0734	0761	0299	0226	13.50	355.

1715 Hours Trial Stopped

Reynolds number and heat flux, also computes a heat balance over the test section and predicts from the Sieder-Tate equation the film resistance. Since these computations are straightforward, no sample calculations are included here.

4.2 Data Gathering and Data Processing

The method used to gather data was as follows: The equipment and data logging system were warmed up on tap water for a period of at least three hours and usually 12 hours. When the system was at steady state and at target conditions, as for example at time 1442 for Run 63 (see Table IX), the desired amount of ferric oxide was added to the system and the run commenced. As the run progressed, "lines of data" were selected at regular intervals and recorded on a separate log sheet, subject to the provision that voltage, current, flow rate, inlet thermocouple millivolt reading and outlet thermocouple millivolt reading were at or very near target conditions. The study of experimental errors summarized in Section 5 had shown that all of these variables have a bearing on the accuracy of the data. Table X shows this log sheet.

The thermal and pressure drop data shown in Table X are in units of millivolts times 200. The program

Table X

Data Used for Fouling Curve Determination

1443	0421	0525	0665	0663	0705	0704	0709	0684	0206	0685	0584	0725	0757	0294
1448	0421	0525	0667	0666	0703	0703	0712	0689	0212	0692	0596	0733	0763	0293
1450	0421	0525	0667	0667	0705	0706	0715	0692	0212	0695	0597	0734	0763	0295
1455	0421	0525	0670	0668	0705	0707	0714	0692	0211	0695	0598	0735	0763	0296
1457	0421	0525	0670	0670	0709	0709	0716	0693	0209	0695	0598	0735	0765	0294
1508	0420	0525	0671	0670	0712	0709	0717	0695	0209	0697	0601	0735	0766	0295
1524	0421	0525	0675	0674	0711	0712	0718	0695	0212	0697	0601	0735	0763	0296
1534	0421	0525	0675	0674	0710	0710	0716	0693	0211	0695	0600	0732	0762	0296
1544	0421	0525	0674	0673	0712	0711	0718	0694	0210	0696	0600	0733	0762	0296
1604	0421	0525	0677	0675	0711	0712	0719	0695	0212	0698	0603	0735	0763	0298
1611	0421	0525	0676	0676	0712	0712	0718	0695	0213	0697	0602	0735	0762	0298
1629	0420	0525	0679	0676	0714	0713	0719	0696	0212	0697	0601	0734	0761	0299
1638	0420	0524	0677	0677	0712	0714	0718	0695	0212	0697	0602	0735	0763	0299

STOMV (see Appendix II) was used to convert the time from real time to fouling run time, to transform the millivolt readings times 200 to millivolts, and to place the data in a standard format compatible with all subsequent programs. Table XI is the output from this program.

Two methods were used to compute fouling resistances from the thermal data. The first of these was the method developed by Watkinson (7) and used also by Mayo (23). It computes the fluid film resistance plus fouling resistance for the whole tube at any specified time. Since the program based on this method was available to this investigator, it was routinely run. However, since this method does not compute fouling resistances at localized positions on the tube, only limited use was made of the data thus generated.

The second method used to compute fouling resistance overcomes this difficulty and enables local fouling resistance to be found. This method is based upon the following considerations: At time zero, the total resistance to heat transfer is given by

$$R_0 = \frac{T_{wo} - T_{bo}}{q'} \tag{4.1}$$

where

Table XI

Output From Program STOMV Input to Program FOUL

REAL TIME	RUN TIME	MV IN	MV OUT	MILLIVOLT READINGS OF THERMOCOUPLES ON WALL OF TEST SECTION T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	COOL MV	INSL MV	AMB MV	DELT MV
14.43	0.0	2.10	2.62	0.0	3.32	3.31	3.52	3.52	3.54	3.42	3.42	2.92	3.62	3.78	0.0	0.0	0.0	1.03	1.47
14.48	0.08	2.10	2.62	0.0	3.33	3.33	3.51	3.51	3.56	3.44	3.46	2.98	3.66	3.81	0.0	0.0	0.0	1.06	1.46
14.50	0.12	2.10	2.62	0.0	3.33	3.33	3.52	3.53	3.57	3.46	3.47	2.98	3.67	3.81	0.0	0.0	0.0	1.06	1.47
14.55	0.20	2.10	2.62	0.0	3.35	3.34	3.52	3.53	3.57	3.46	3.47	2.99	3.67	3.81	0.0	0.0	0.0	1.05	1.48
14.57	0.23	2.10	2.62	0.0	3.35	3.35	3.54	3.54	3.58	3.46	3.47	2.99	3.67	3.82	0.0	0.0	0.0	1.04	1.47
15.08	0.42	2.10	2.62	0.0	3.35	3.35	3.56	3.54	3.58	3.47	3.48	3.00	3.67	3.83	0.0	0.0	0.0	1.04	1.47
15.24	0.68	2.10	2.62	0.0	3.37	3.37	3.55	3.56	3.59	3.47	3.48	3.00	3.67	3.81	0.0	0.0	0.0	1.06	1.48
15.34	0.85	2.10	2.62	0.0	3.37	3.37	3.55	3.55	3.58	3.46	3.47	3.00	3.66	3.81	0.0	0.0	0.0	1.05	1.48
15.44	1.02	2.10	2.62	0.0	3.37	3.36	3.56	3.55	3.59	3.47	3.48	3.00	3.66	3.81	0.0	0.0	0.0	1.05	1.48
16.04	1.35	2.10	2.62	0.0	3.38	3.37	3.55	3.56	3.59	3.47	3.49	3.01	3.67	3.81	0.0	0.0	0.0	1.06	1.49
16.11	1.47	2.10	2.62	0.0	3.38	3.38	3.56	3.56	3.59	3.47	3.48	3.01	3.67	3.81	0.0	0.0	0.0	1.06	1.49
16.29	1.77	2.10	2.62	0.0	3.39	3.38	3.57	3.56	3.59	3.48	3.48	3.00	3.67	3.80	0.0	0.0	0.0	1.06	1.49
16.38	1.92	2.10	2.62	0.0	3.38	3.38	3.56	3.57	3.59	3.47	3.48	3.01	3.67	3.81	0.0	0.0	0.0	1.06	1.49

R_0 = total resistance at time zero

T_{wo} = outer wall temperature at time zero

T_{bo} = fluid temperature at time zero

q' = heat flux transferred to the fluid
= heat flux supplied minus heat losses

As the tube fouls, a fouling resistance R_f is formed on the inside of the tube. If the heat flux is maintained constant, and the bulk temperature remains constant, the wall temperature must rise in response to the increase in thermal resistance to a new value, say T_{wt}. Equation (4.1) then becomes

$$R_0 + R_f = \frac{T_{wt} - T_{bo}}{q'} \qquad (4.2)$$

Eliminating R_0 between equations (4.1) and (4.2) gives

$$R_f = \frac{T_{wt} - T_{wo}}{q'} \qquad (4.3)$$

that is, the fouling resistance is simply the outer wall temperature rise divided by the heat flux. An assumption implicit in this method of calculation is that the heat losses are negligible and/or do not increase significantly as the wall temperature increases, an assumption validated by the fact that the difference between inlet and outlet temperatures remained constant throughout the course of a run. Another implicit assumption is that R_0 is representative of the wall plus fluid film resistance throughout the course of a run. Since wall temperatures typically increased by about 2 F°, this latter assumption is believed to be valid. However, where large increases in wall temperatures were obtained, a correction might be required to account for possible blockage effects and for the effect of changing surface roughness on deposit-to-fluid heat transfer.

For Run 63, time 1.92 hours, station T235, the fouling resistance is therefore

$$R_f = \frac{T_{wt} - T_{wo}}{q'}$$

$$= \frac{177.0 - 174.6}{91397} = 2.6 \times 10^{-5} \text{ft}^2\text{-hr-°F/BTU}$$

Table XII shows the output from program <u>FOUL</u> which computes these fouling resistances. The stations showing a resistance of 0.0 after time zero are blanked stations not included in the calculations. Blanked stations are those containing defective thermocouples.

Included in Table XII, for the sake of completeness, are the following data:

Wall Temperatures

Inlet Fluid Temperature (TIN)

Outlet Fluid Temperature (TOUT)

Mean Wall Temperature (TM)

Fluid Temperature Rise (DELTA)

Film plus Fouling Heat Transfer Coefficient (H)

Film plus Fouling Thermal Resistance (R)

Time

Units used throughout are BTU, DEGREE F, HOUR, FOOT.

Table XII also includes a print-out of the local fouling resistance at each thermocouple station and the mean of these resistances (RFM).

The mean fouling resistance is fitted by the least squares method to the equation

$$R_f = R_f^* \left[1 - e^{-b\bar{t}} \right] \qquad (4.4)$$

The print-out from this subroutine, as shown in Table XII, contains the calculated value of mean fouling resistance and the fitted value as predicted from equation (4.4).

Table XII

Output from Program FOUL

```
*******RUN NO63.*******

FERRIC OXIDE CONC (PPM)    2130.

VOLTS:13.50         AMPS: 355.

HEAT FLOW SUPPLIED 16356.8      BTU/HR
HEAT FLUX SUPPLIED    93897.    BTU/SQFT-HR

BETA0.301           TOR=TINLET127.0     DEG F
DENSITY:0.986 GRAM/CC
                    T OUTLET150.3       DEG F

FLOW RATE 0.1888  LBS.M/SEC

AVG TEMP:138.6     DEG F
KINEMATIC
VISCOSITY:0.479    SQ.CM/SEC

FLUID VELOCITY 4.790     FT/SEC
REYNOLDS NO  26534.0
PRANDTL NO    3.02

HEAT SUPP     16356.8    BTU/HR
HEAT TRANS    15921.4    BTU/HR
HEAT LOST       435.4    BTU/HR
PERCENT HEAT LOST     2.66
HEAT FLUX TRANS. BTU/SQFT-HR    91397.
NUSSELT NO     121.5
RFILM     0.623
RWALL     0.143
RTOTAL     0.765       SQFT-HR-DEG F/BTU
```

```
ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.18680               .78614
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.25054E-01           .10544
ESTIMATE OF RO,RINF,AND B IN RF=RINF*(1.-EXP(-B*TIME))
.0                   2.0669                5.7124
```

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.08	0.77	0.76
0.12	1.15	1.03
0.20	1.29	1.41
0.23	1.58	1.51
0.42	1.82	1.88
0.68	2.01	2.02
0.85	1.77	2.05
1.02	1.92	2.06
1.35	2.11	2.07
1.47	2.16	2.07
1.77	2.25	2.07
1.92	2.20	2.07

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	174.6	174.2	182.5	182.5	183.3	178.6	178.6	0.0	186.5	192.7	0.0	127.0	149.9	181.5	23.0	1676.2	0.5966	0.0
0.0	175.0	175.0	182.1	182.1	184.1	179.4	180.2	0.0	188.0	193.9	0.0	127.0	149.9	182.2	23.0	1648.0	0.6068	0.08
0.0	175.0	175.0	182.5	182.9	184.5	180.2	180.6	0.0	188.4	193.9	0.0	127.0	149.9	182.6	23.0	1632.5	0.6125	0.12
0.0	175.8	175.4	182.5	182.9	184.5	180.2	180.6	0.0	188.4	193.9	0.0	127.0	149.9	182.7	23.0	1630.0	0.6135	0.20
0.0	175.8	175.8	183.3	183.3	184.9	180.2	180.6	0.0	188.4	194.3	0.0	127.0	149.9	183.0	23.0	1620.6	0.6170	0.23
0.0	175.8	175.8	184.1	183.3	184.9	180.6	180.9	0.0	188.4	194.7	0.0	127.0	149.9	183.2	23.0	1612.1	0.6203	0.42
0.0	176.6	176.6	183.7	184.1	185.3	190.6	180.9	0.0	188.4	193.9	0.0	127.0	149.9	183.3	23.0	1607.3	0.6222	0.68
0.0	176.6	176.6	183.7	183.7	184.9	180.2	180.6	0.0	188.0	193.9	0.0	127.0	149.9	183.1	23.0	1616.9	0.6185	0.85
0.0	176.6	176.2	184.1	183.7	185.3	180.6	180.9	0.0	188.0	193.9	0.0	127.0	149.9	183.3	23.0	16[illegible]0.4	0.6210	1.02
0.0	177.0	176.6	183.7	184.1	185.3	180.6	181.3	0.0	188.4	193.9	0.0	127.0	149.9	183.4	23.0	1604.7	0.6232	1.35
0.0	177.0	177.0	184.1	184.1	185.3	180.6	180.9	0.0	188.4	193.9	0.0	127.0	149.9	183.5	23.0	1604.1	0.6234	1.47
0.0	177.4	177.0	184.5	184.1	185.3	180.9	180.9	0.0	188.4	193.5	0.0	127.0	149.9	183.6	23.0	1601.4	0.6244	1.77
0.0	177.0	177.0	184.1	184.5	185.3	180.6	180.9	0.0	188.4	193.9	0.0	127.0	149.9	183.5	23.0	1602.4	0.6241	1.92

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1676.2	0.5966	0.0
0.0	0.43	0.87	0.0	0.0	0.86	0.86	1.73	0.0	1.72	1.28	0.0	127.0	149.9	0.77	23.0	1648.0	0.6068	0.08
0.0	0.43	0.87	0.0	0.43	1.29	1.73	2.16	0.0	2.15	1.28	0.0	127.0	149.9	1.15	23.0	1632.5	0.6125	0.12
0.0	1.30	1.30	0.0	0.43	1.29	1.73	2.16	0.0	2.15	1.28	0.0	127.0	149.9	1.29	23.0	1630.0	0.6135	0.20
0.0	1.30	1.73	0.86	0.86	1.72	1.73	2.16	0.0	2.15	1.71	0.0	127.0	149.9	1.58	23.0	1620.6	0.6170	0.23
0.0	1.30	1.73	1.72	0.86	1.72	2.16	2.59	0.0	2.15	2.14	0.0	127.0	149.9	1.82	23.0	1612.1	0.6203	0.42
0.0	2.17	2.60	1.29	1.72	2.15	2.16	2.59	0.0	2.15	1.28	0.0	127.0	149.9	2.01	23.0	1607.3	0.6222	0.68
0.0	2.17	2.60	1.29	1.29	1.72	1.73	2.16	0.0	1.72	1.28	0.0	127.0	149.9	1.77	23.0	1616.9	0.6185	0.85
0.0	2.17	2.17	1.72	1.29	2.15	2.16	2.59	0.0	1.72	1.28	0.0	127.0	149.9	1.92	23.0	1610.4	0.6210	1.02
0.0	2.60	2.60	1.29	1.72	2.15	2.16	3.02	0.0	2.15	1.28	0.0	127.0	149.9	2.11	23.0	1604.7	0.6232	1.35
0.0	2.60	3.03	1.72	1.72	2.15	2.16	2.59	0.0	2.15	1.28	0.0	127.0	149.9	2.16	23.0	1604.1	0.6234	1.47
0.0	3.03	3.03	2.15	1.72	2.15	2.59	2.59	0.0	2.15	0.85	0.0	127.0	149.9	2.25	23.0	1601.4	0.6244	1.77
0.0	2.60	3.03	1.72	2.15	2.15	2.16	2.59	0.0	2.15	1.28	0.0	127.0	149.9	2.20	23.0	1602.4	0.6241	1.92

Chapter 5

EXPERIMENTAL ERROR STUDY

In order to establish the precision with which thermal resistances could be determined, a series of water trials were made with the following objectives in view:

(1) To isolate variables which, if inadequately controlled, would bear upon the accuracy of results.

(2) To determine the extent to which changes in wall temperature and therefore changes in operating variables produce apparent or real changes in measured thermal resistance.

Variables considered to be of prime importance were flow rate, heat flux, and inlet temperature to the test section. From experience in operating the heat transfer loop, it became evident that the values of the above variables were affected by fluctuations of the following type:

(1) Variations in line voltage to the test section due to variations in input power supplied to the

building. This effect manifests itself as a variation in heat flux.

(2) Variations in flow rate caused by the tendency of the flow control valve to close during the first few hours of a run.

(3) Variations in cooling water temperature which cause cyclic fluctuations in the inlet temperature to the test section.

In addition, a transient type behaviour was noted in which the apparent thermal resistance was found to rise at a decreasing rate from start-up to an elapsed time approaching three hours. Since this transient type behaviour was found to be the largest source of error in determining fouling resistances, it will be discussed first.

5.1 Influence of Thermal Transients in Determining Thermal Resistance

From trials made in co-operation with Mayo (23) using a solution of aluminium oxide in aqueous caustic soda, it was noted that, if for any reason the equipment was stopped, then upon restarting, the test section wall temperatures did not return to their pre-shutdown values. Rather, the wall temperatures remained depressed for periods ranging from a few minutes to an hour or more, depending upon the length of the shutdown. Such behaviour indicated either a defouling process, or a thermal transient situation which caused the wall temperatures to be depressed.

In order to determine the cause of this behaviour, a "fouling" run was made using tap water. The procedure followed was to by-pass the test section and heat the fluid to target inlet conditions. The fluid was then directed into the test section and a trial made in which, at time zero minus, the test section was at room temperature, and at time zero plus, the flow rate and heat flux were at their target values.

Figure 7 shows the results of this trial plotted as apparent thermal resistance versus time. The die-away behaviour typical of electrical and thermal transients is clearly evident. Note that over a period of two hours, apparent thermal resistances range from 0.684×10^{-3} to 0.808×10^{-3} ft^2-hr-°F/BTU — a difference of 0.124×10^{-3}. This latter figure is of the same order of magnitude as the fouling resistances found for most ferric oxide trials studied here.

Trials using tap water were made in which the test section was brought to thermal steady state, shut down and then honed to remove any possible fouling deposit.

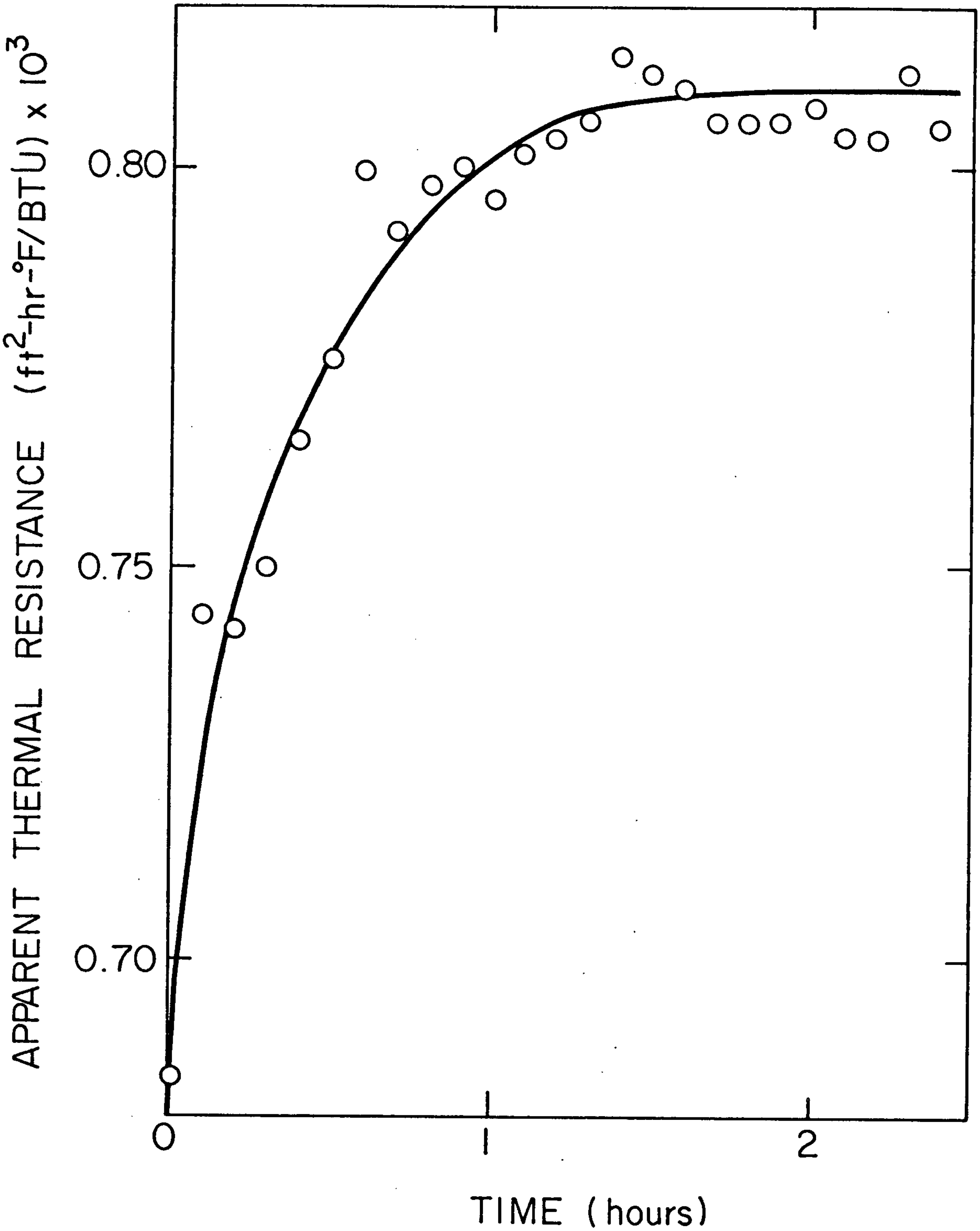


Figure 7. Apparent Thermal Resistance Versus Time for Run 1 on Tap Water.

Results clearly showed that no fouling deposit was present, and that the transient behaviour discussed above is associated with heat absorption by the insulation until thermal equilibrium is achieved.

Although thermal transients were found to result in the largest source of inaccuracy in determining fouling resistance versus time curves, their elimination was easily effected. All fouling trials were made by either: (1) bringing the system to steady state by operating on tap water for over three hours and then adding the ferric oxide contaminant, or (2) if ferric oxide was already in the system, operating for a minimum of three hours and then removing any deposit by honing the hot tube. Either method gives the same fouling curve (see Section 6).

5.2 Errors Due to Variation in Line Voltage

The next largest source of potential error in determining thermal resistance was caused by uncontrolled variations in input supply voltage to the test section. Table XIII shows values for test section voltage recorded for Run 13 at random intervals. Note that the range of power drawn, expressed as a heat flow, is from 15,687 BTU/hr to 16,283 BTU/hr. This difference of approximately 600

Table XIII

Variation in Electrical Power Supplied to the Test Section - Run 13

Date	Time Hrs:Min	Volts	Amps	Power BTU/hr
24 March '71	16:00	13.52	344	15873
	19:52	13.68	347	16201
	20:43	13.70	348	16271
	22:30	13.60	346	16060
25 March '71	10:17	13.44	342	15687
	13:31	13.68	347	16201
	14:33	13.71	348	16283
	15:00	13.60	346	16060
	18:00	13.44	342	15687
26 March '71	12:00	13.69	348	16259
	15:00	13.52	344	15873
27 March '71	15:10	13.62	346	16083

BTU/hr, if not taken into account, will cause an error in measured thermal resistance of approximately 2×10^{-5} ft^2-hr-°F/BTU. Since 2×10^{-5} ft^2-hr-°F/BTU is the total fouling resistance found in some runs, line voltage variation errors had to be eliminated.

To prevent errors due to line voltage variations, the following procedure was adopted:

> When the objective of a trial required precise data, the equipment was never left unattended. If the voltage varied by more than ±0.15 volts over the test section, the variacs were adjusted to return the power input to target conditions. As an added precauticn, no data were used for thermal resistance computation if the test section voltage deviated by more than 0.02 volts from the target value. This procedure reduced the error from this source to approximately $\pm 0.1 \times 10^{-5}$ ft^2-hr-°F/BTU, which is less than 5% of the lowest fouling resistance measured in the ferric oxide trials.

Although line voltage errors could be thus substantially reduced by manual control, this procedure was tedious. It is recommended that a voltage regulator be added to the heat transfer loop prior to beginning any new investigation of the type presented here.

5.3 Errors Due to Flow Rate Variations

Variations in flow rate cause variations in thermal resistance, which in turn cause errors in the measurement of fouling resistances. In the study made here, flow rate variations were usually the result of ferric oxide deposition on the flow control valve. Since electrical power to the test section was held more or less constant, flow rate changes tended to produce variations in outlet temperature from the test section. In fact, the outlet temperature minus the inlet temperature was a more precise means of measuring flow rate than the orifice meter on the heat transfer loop.

Figure 8 shows the relationship between thermal resistance and temperature rise for a tap water run (Run 4), with no attempt made to control flow rate. The variation in observed thermal resistance associated with the total change in flow rate was 5×10^{-5} ft^2-hr-°F/BTU. This variation could be explained by the known relationship between film coefficient of heat transfer and fluid velocity. By making flow adjustments, and only using for computation data in which the temperature rise was at its target value, this source of error was effectively eliminated.

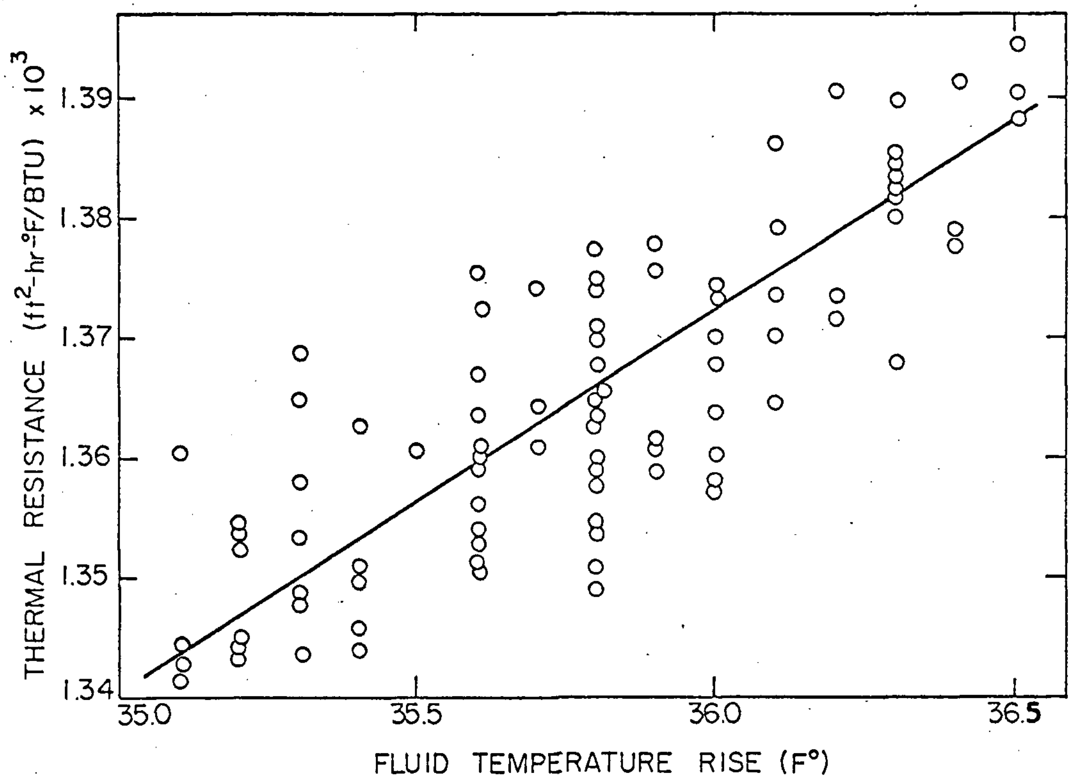


Figure 8. Thermal Resistance Versus Fluid Temperature Rise, Run 4 (Tap Water).

5.4 Errors Due to Inlet Temperature Variations

The inlet temperature to the test section could vary in response to cooling water temperature changes. Usually, such variations were small. Figure 9 shows the relationship between thermal resistance and inlet temperature. The drop in thermal resistance with temperature level can be explained by the corresponding changes in fluid properties, especially viscosity. Total variation during an uncontrolled run was 2×10^{-5} ft^2-hr-°F/BTU. By holding inlet temperature at target values, this source of error too was effectively eliminated.

5.5 Errors Caused by Wet Insulation

In one run, Run 16, a large amount of A.C. current was detected on some thermocouples. Thermocouple readings were obviously incorrect, even for those in which no A.C. leakage was detected. When the test section was dismantled, it was found that the insulation was wet due to a leak in the top fitting of the tube. Consequently, current leaked from the test section to the thermocouple leads except for those liberally coated with Eccocoat epoxy resin. These tended to give steady but low values.

To avoid errors of this type, all fittings were carefully inspected prior to test section installation.

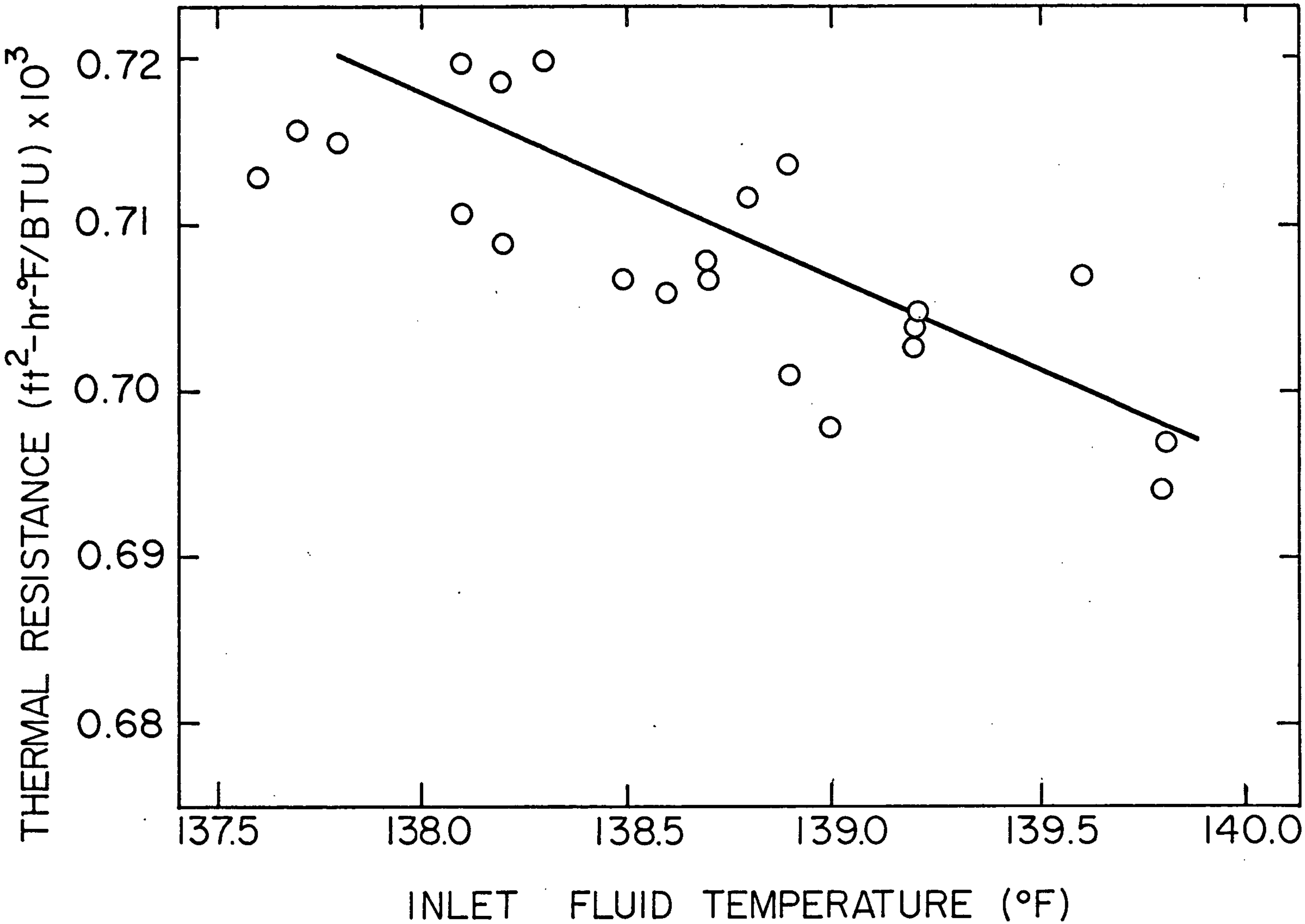


Figure 9. Thermal Resistance Versus Inlet Temperature for Run 5 on Tap Water.

As a further precaution, thermocouple leads near the tube wall were coated with Eccocoat as outlined in Section 3.

5.6 Miscellaneous Errors

In order to insure that the use of tap water and the test section honing procedure had no hidden pitfalls, a trial was made on tap water for a period of 24 hours. The system was then stopped, the test section honed, and the trial restarted. Table XIV shows a series of thermal resistances before and after honing. There is no evidence from these data that tap water produces fouling deposits or that honing changes the tube. The possibility that deposits were formed which were not removed by honing is discounted, since even very hard scales were shown to be removable by this method.

5.7 Reproducibility and Validity of Thermal Fouling Data

The reproducibility of ferric oxide fouling resistance versus time curves obtained in this study was established by analysis of four trials made over the course of the investigation. These trials, numbered 34, 35, 38 and 59, were replicates made using 2130 ppm of ferric oxide at a Reynolds number of 19550 and a heat flux of 44,360

Table XIV

Data From Run 15 to Determine Effect of Honing Tube Wall on Thermal Resistance

	Inlet Temp °F	Outlet Temp °F	Mean Temp °F	Fluid Temp. Rise °F	Thermal Resist. x 10^{+3} ft^2-hr-°F/BTU	Time hrs:min
Steady State Prior to Honing Wall	157.7	188.5	225.1	30.9	0.7313	11:11
	157.3	188.5	224.7	31.3	0.7294	11:13
	157.7	188.5	224.9	30.9	0.7298	11:15
	157.7	188.5	224.6	30.9	0.7252	11:17
	157.3	188.5	224.6	31.3	0.7274	11:19
	157.7	188.2	224.1	30.5	0.7201	11:21
	157.7	187.8	222.9	30.1	0.7059	11:23
	157.7	188.5	224.8	30.9	0.7283	11:25
	157.3	189.3	224.4	32.1	0.7200	11:27
	157.7	188.2	224.2	30.5	0.7220	11:27
	157.6	188.5	224.4	30.9	0.7239	-
Steady State After Honing Wall	156.8	188.5	224.3	31.7	0.7256	13:42
	156.8	188.2	223.5	31.3	0.7172	13:50
	157.3	189.3	225.5	32.1	0.7329	14:00
	157.3	188.2	223.7	30.9	0.7167	14:10
	157.3	187.8	222.3	30.5	0.7004	14:20
	157.3	188.2	223.4	30.9	0.7131	14:30
	157.3	188.2	222.9	30.9	0.7064	14:40
	156.8	187.8	222.7	30.9	0.7074	14:50
	156.8	187.4	222.3	30.6	0.7059	15:00
	156.8	187.8	223.0	30.9	0.7133	15:10
	157.1	188.1	223.4	31.1	0.7140	-

BTU/ft^2-hr. Figure 10 shows a composite plot of data from all four trials, and Table XV gives the parameters R_f^* and b for the least squares fit of the data to the equation

$$R_f = R_f^* \left[1 - e^{-bt}\right] \tag{4.4}$$

As can be seen, the curves are fairly reproducible, with the parameter R_f^* having a coefficient of variation of 11% and b a coefficient of variation of 29%.

As will be discussed in Section 6, early ferric oxide fouling trials resulted in no detectable thermal fouling. These trials were made at ferric oxide concentrations of approximately 15 ppm. When wall temperature increases were detected in Run No. 31 at a concentration of 2130 ppm, the question arose as to whether these increases reflected a fouling process or were caused by fluid property changes resulting from ferric oxide addition. From an analysis of the data from many trials, it is concluded that the fouling curves obtained accurately reflect the build-up of fouling deposits. The reasons for this view are as follows:

(1) Sectioning of the test section following Run 31 showed a uniform deposit measured as about 100 microns

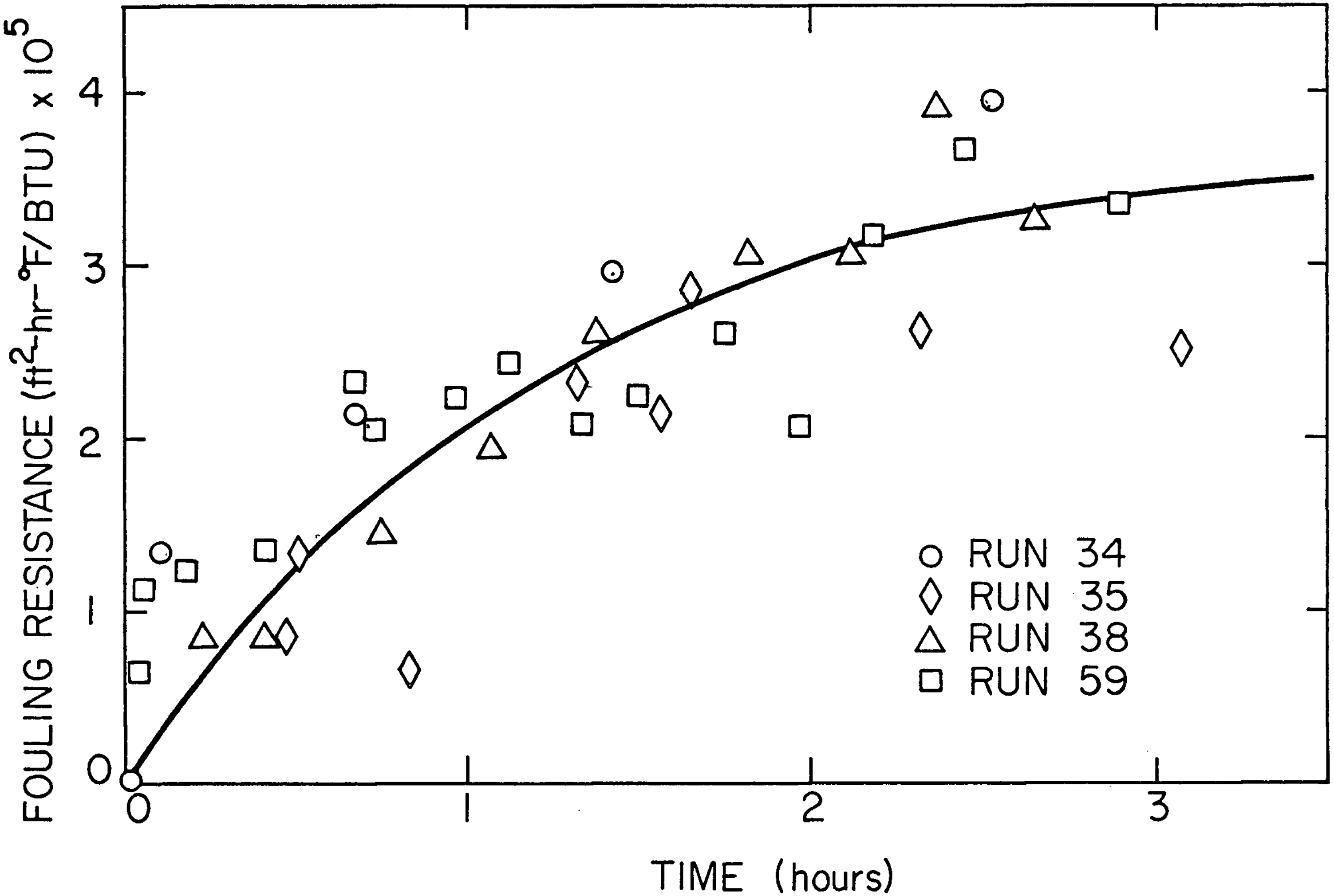


Figure 10. Fouling Curve Reproducibility as Shown by Superimposing Data for Replicate Runs 34,35,38,59. Ferric Oxide Conc. = 2130 ppm, q' = 44,360 BTU/ft^2-hr, Re = 19,550.

Table XV

Reproducibility of Fouling Curve Parameters Obtained by Fitting Data to the Equation $R_f = R_f^*(1 - e^{-bt})$. Ferric Oxide Conc. = 2130 ppm, Re = 19550, Heat Flux = 44,360 BTU/ft^2-hr

Run No.	R_f^* (ft^2-hr-°F/BTU x 10^5)	b (hr^{-1})
34	3.9	1.3
35	3.1	1.8
38	3.5	0.9
59	2.9	1.6
Avg	3.3	1.4
Std. Dev.	0.4	0.4
Coeff. of Var.	11%	29%

thick over the whole tube. If 10 BTU/hr-ft-°F is taken as a reasonable thermal conductivity for the deposit, wall temperatures would have to rise by 1.3 F° to maintain the energy balance. The actual measured wall temperature rise was 1.8 F°, indicating that $k_d \sim 7.2$ BTU/hr-ft-°F.

(2) The time for the wall temperature to reach its asymptotic value following ferric oxide addition in Run 31 was nearly four hours. If the same wall temperature increase of 1.8°F is obtained by a slight increase in heat flux, a new asymptote is reached in approximately 10 minutes. This indicates that the wall temperature versus time curve obtained is not a thermal transient set up by a sudden change in fluid properties and hence fluid resistance causedby the sudden addition of ferric oxide.

(3) If a trial is stopped and the test section honed, wall temperatures return to the clean wall conditions existing prior to ferric oxide addition.

(4) If the fluid properties change because of ferric oxide addition, the property most likely to be of importance with respect to heat transfer is the viscosity. Using Einstein's equation for the viscosity of dilute suspensions,

$$\mu = \mu_0(1 + 2.5\phi) \qquad (5.1)$$

where μ_0 is the viscosity with no solids, and ϕ is the volume fraction of suspended solids, the percentage change in viscosity caused by the addition of 2130 ppm ferric oxide is computed to be 0.01% - a negligible change.

Chapter 6

RESULTS AND DISCUSSION

6.1 Summary of Fouling Trials

During the course of this investigation, 70 trial runs were made. These can be divided into five main categories:

(1) Trials on tap water in order to identify and eliminate sources of error in measuring heat transfer coefficients. (The results of these trials have been presented and discussed in Section 5.)

(2) Trials designed to determine the influence of ferric oxide concentration, heat flux and Reynolds number on the shape of fouling resistance versus time curves.

(3) Trials to determine the effect of ferric oxide particle size on fouling.

(4) Specialty trials designed to test the validity of various hypotheses concerning fouling behaviour which were formed during the course of the investigation.

(5) Miscellaneous trials using as foulants such materials as polystyrene and silicon dioxide. These are not discussed here, but the data are on file in data book No. 5 at UBC Chemical Engineering.

Tables XVI and XVII show the operating conditions for each ferric oxide trial, give a short statement as to the purpose for making the trial and where appropriate state the outcome. For each trial which exhibited thermal fouling, the fouling curve obtained has been fitted to the Kern-Seaton type equation

$$R_f = R_f^* \left[1 - e^{-bt} \right] \tag{4.4}$$

where R_f = fouling resistance

t = time

R_f^* = fitted constant ≡ asymptotic fouling resistance

b = fitted constant

Included in Table XVII is the initial fouling rate $\left(\left. \frac{dR_f}{dt} \right|_{t=0} \right)$,

Table XVI

Summary of Fouling Trials Run at Low Ferric Oxide Concentrations

Run Number	Heat Flux (BTU/ft^2-hr)	Reynolds Number	Ferric Oxide Conc. (ppm)	Ferric Oxide Particle Size (Microns)	Maximum Approximate Deposit Thickness (Microns)	Trial Duration (hrs)	Comments
1	91660	24700	15	Mixed[1]	70	48	Initial fouling run. No thermal fouling.
4	91660	25510	15	Mixed	70	24	Repeat of Run 1 with close control. No thermal fouling.
13	91250	25600	15	Mixed	70	72	Repeat of Run 1 with extended operating time. No thermal fouling.
15	92460	26470	375	Mixed	100	30	Repeat Run 1 - increased ferric oxide conc. No thermal fouling.
16	92310	25070	15	Mixed	60	168	Repeat Run 1 - operating time one week. No thermal fouling.
17	92310	25070	15	Mixed	120	25	Repeat Run 1 with 3000 ppm NaCl. No thermal fouling.
19	92310	25070	15	0.3-0.8	0	48	Repeat Run 1 with presized particles. No deposit detected. No thermal fouling.
20	0	25000 approx	15	0.3-0.8	70	72	Repeat Run 19 at 0 heat flux. Deposit detected.
21	92310	25070	15	0.3-3.7	0	24	Repeat Run 19 with larger presized particles. No deposit. No thermal fouling.
22	92310	25070	15	0.3-3.7	0	168	Repeat Run 21 with extended operating time. No deposit. No thermal fouling.
23	0	25000 approx	15	0.3-3.7	70	96	Repeat Run 22 at 0 heat flux. Deposit detected.

[1]Agglomerates of approximately 0.2μ particles.

Table XVII

Summary of Ferric Oxide Trials Using Mixed-Size Particles

Run Number	Heat Flux (BTU/ft^2-hr)	Reynolds Number	Mixed-size Ferric Oxide Conc. (ppm)	$R_f^* \times 10^5$ (ft^2-hr°F/BTU)	b (hr^{-1})	Initial Fouling Rate $bR_f^* \times 10^5$ (ft^2-°F/BTU)	Comments
33	44360	19550	2130	8.5	0.3	2.6	Effect of high conc. R_f^* and b inaccurate due to voltage fluctuations
34	44360	19550	2130	5.7	1.3	7.4	Repeat of Run 33. R_f^* and b inaccurate because of limited data
35	44360	19550	2130	3.3	0.6	2.0	Repeat of Run 33. Data not accurate. Tube not honed at time zero minus
38	44360	19550	2130	3.7	0.9	3.3	Repeat of Run 33. Tube honed at time zero. Air line in tank. First trial with accurate data
39	44870	25390	2130	4.4	2.3	10.1	Repeat Run 38 at higher Reynolds number
40	44870	25390	2130	7.0	1.6	11.2	Effect of Honing Portion of Deposit from a prefouled tube (Run 39) at time zero minus
41	44870	25390	2130	8.9	1.2	10.7	Effect of high velocity cooling on prefouled tube (Run 40)
42	89750	26490	2130	-	-	-	Effect of increasing heat flux. R_f^* and b inaccurate due to insufficient data
43	44360	19550	2130	-	-	-	Repeat of Run 33. Loss of deposit indicated in upper region of tube. R_f^* and b inaccurate

(Continued)

Table XVII (Continued)

Run Number	Heat Flux (BTU/ft²-hr)	Reynolds Number	Mixed-size Ferric Oxide Conc. (ppm)	$R_f^* \times 10^5$ (ft²-hr°F/BTU)	b (hr^{-1})	Initial Fouling Rate $bR_f^* \times 10^5$ (ft²-°F/BTU)	Comments
44	89890	37590	2130	2.2	2.9	6.4	Effect of high heat flux and high Reynolds number
45	89750	26490	250	0.5	2.2	1.1	Effect of Conc. of 250 ppm
46	89750	26490	750	0.6	0.5	0.3	Effect of Conc. of 750 ppm
47	89750	26490	1000	1.0	3.6	3.6	Effect of Conc. of 1000 ppm
48	89750	26490	1750	0.4	3.4	1.4	Effect of Conc. of 1750 ppm
49	89750	26490	2130	2.1	5.3	11.1	Effect of Conc. of 2130 ppm
50	89750	26490	2130	3.1	3.7	11.5	Repeat of Run 49
52	89750	26490	3750	3.3	0.9	3.0	Effect of Conc. of 3750 ppm
53	44360	19550	3750	5.9	2.7	15.9	Effect of reduced heat flux and Re at 3750 ppm
54	16540	10090	2130	8.8	0.9	7.9	First trial in a series at low heat flux and Re
55	25800	15740	2130	5.4	1.7	9.2	Effect of Raising heat flux
56	89860	20850	2130	2.3	4.1	9.4	Effect of raising heat flux and Reynolds number
58	88090	26440	2130	1.6	8.4	9.7	Effect of Raising Re. R_f^* and b inaccurate (limited data)
59	44360	19550	2130	3.1	1.6	5.0	Repeat of Run 38
61	41970	33700	2130	2.2	6.2	13.5	Effect of heat flux and Reynolds number
62	44360	19550	2130	-	-	-	Attempt to repeat Run 59. Tube went into linear fouling

(Continued)

Table XVII (Continued)

Run Number	Heat Flux (BTU/ft^2-hr)	Reynolds Number	Mixed-size Ferric Oxide Conc. (ppm)	$R_f^* \times 10^5$ (ft^2-hr°F/BTU)	b (hr^{-1})	Initial Fouling Rate $bR_f^* \times 10^5$ (ft^2-°F/BTU	Comments
63	91400	26500	2130	2.1	5.7	12.0	Repeat of Run 49
64	89860	20850	2130	-	-	-	Successful attempt to induce linear fouling
70A	89670	26580	2130	-	-	-	Linear fouling with oxygen in system
70B	89670	26580	2130	-	-	-	Linear fouling with no oxygen

equivalent to bR_f^* for those runs which could be fitted by Equation (4.4). For those trials which showed a linear dependence of fouling resistance on time, the constant R_f^* is meaningless since such curves do not approach an asymptote, and only the constant fouling rate is therefore reported.

Following selected trials, the test section was removed, sectioned, and the deposit analyzed both quantitatively and qualitatively in an electron microprobe. These results are presented in detail in Section 6.4. *They point strongly to the conclusion that ferric oxide fouling of 304 stainless steel is intimately associated with corrosion of the stainless steel under the ferric oxide deposit.* Consequently, many of the trial runs were made for purposes of determining how various changes in trial conditions, which should predictably alter the corrosion behaviour of stainless steel, would change the fouling resistance versus time curves. Such trials included varying the Reynolds number and the heat flux, increasing the ferric oxide concentration, using an oxygen scavenger, and initiating fouling runs using a prefouled rather than a clean tube.

6.2 Thermal Fouling Versus Time Behaviour

6.2.1 Types of thermal fouling curves obtained.

Three distinct types of fouling curves were obtained for ferric oxide-tap water suspensions on 304 stainless steel. These are illustrated in Figures 11, 12 and 13, and each type is discussed below.

The curve shown in Figure 11 was the most frequent type of fouling curve obtained. It illustrates classical fouling behaviour as described by Kern and Seaton (6). This curve is characterized by asymptotic type behaviour and can be fitted by the equation

$$R_f = R_f^* \left[1 - e^{-bt} \right] \qquad (4.4)$$

For the ferric oxide-tap water-304 stainless steel system studied here this curve could be readily reproduced and, as will be described later, its shape was a function of heat flux, Reynolds number and ferric oxide concentration.

Figure 12 shows the type of fouling curve obtained when an attempt is made to operate an asymptotically fouled tube for an indefinite period of time. Under such conditions, fouling becomes an unsteady state process characterized by a sudden decrease in fouling resistance followed

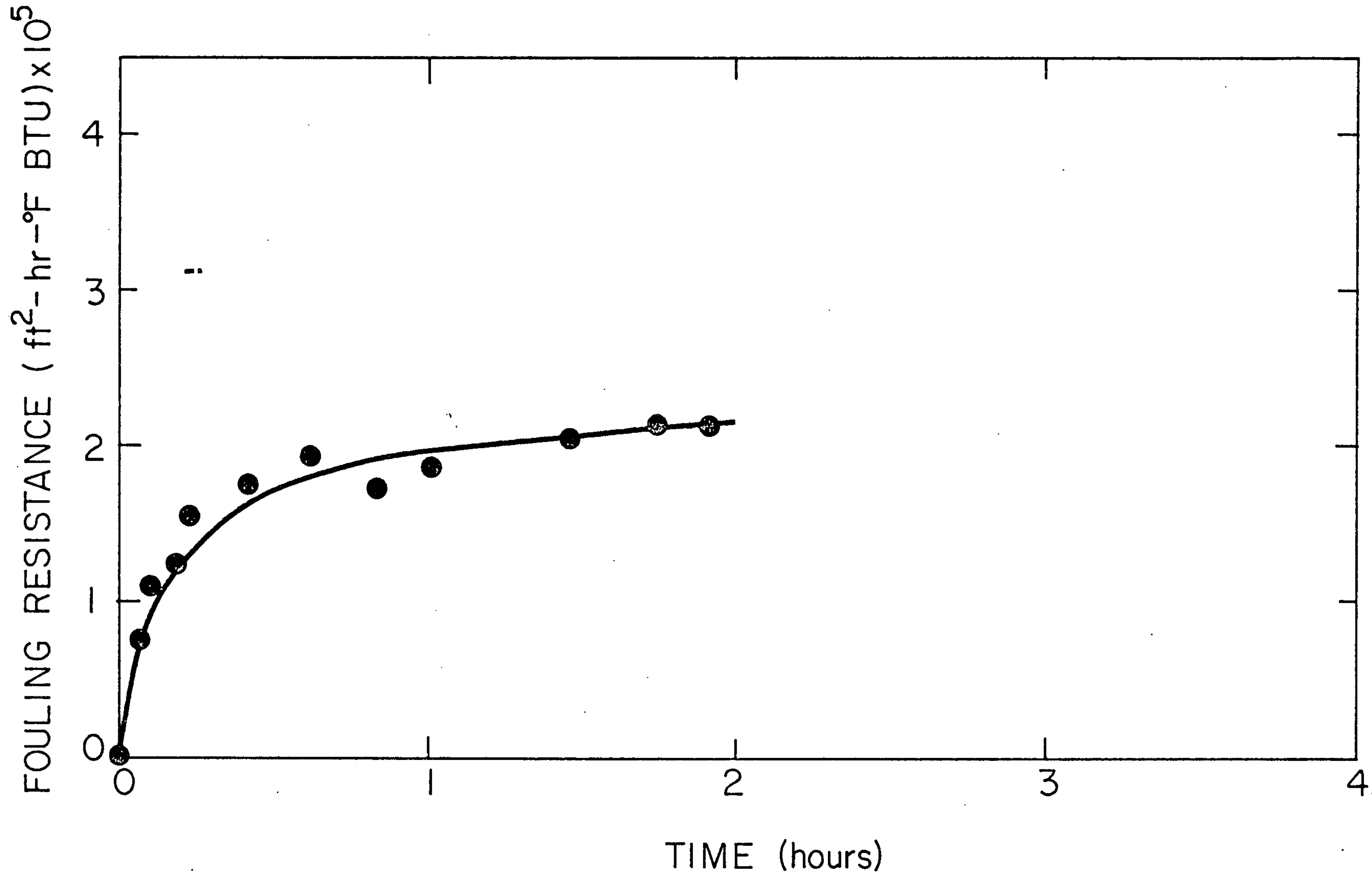


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Figure 11. Fouling Curve Illustrating Asymptotic Type Behaviour (Run 63, Heat Flux 91,400 BTU/ft^2-hr, Re 26,500, Mixed-Size Ferric Oxide Conc. 2130 ppm).

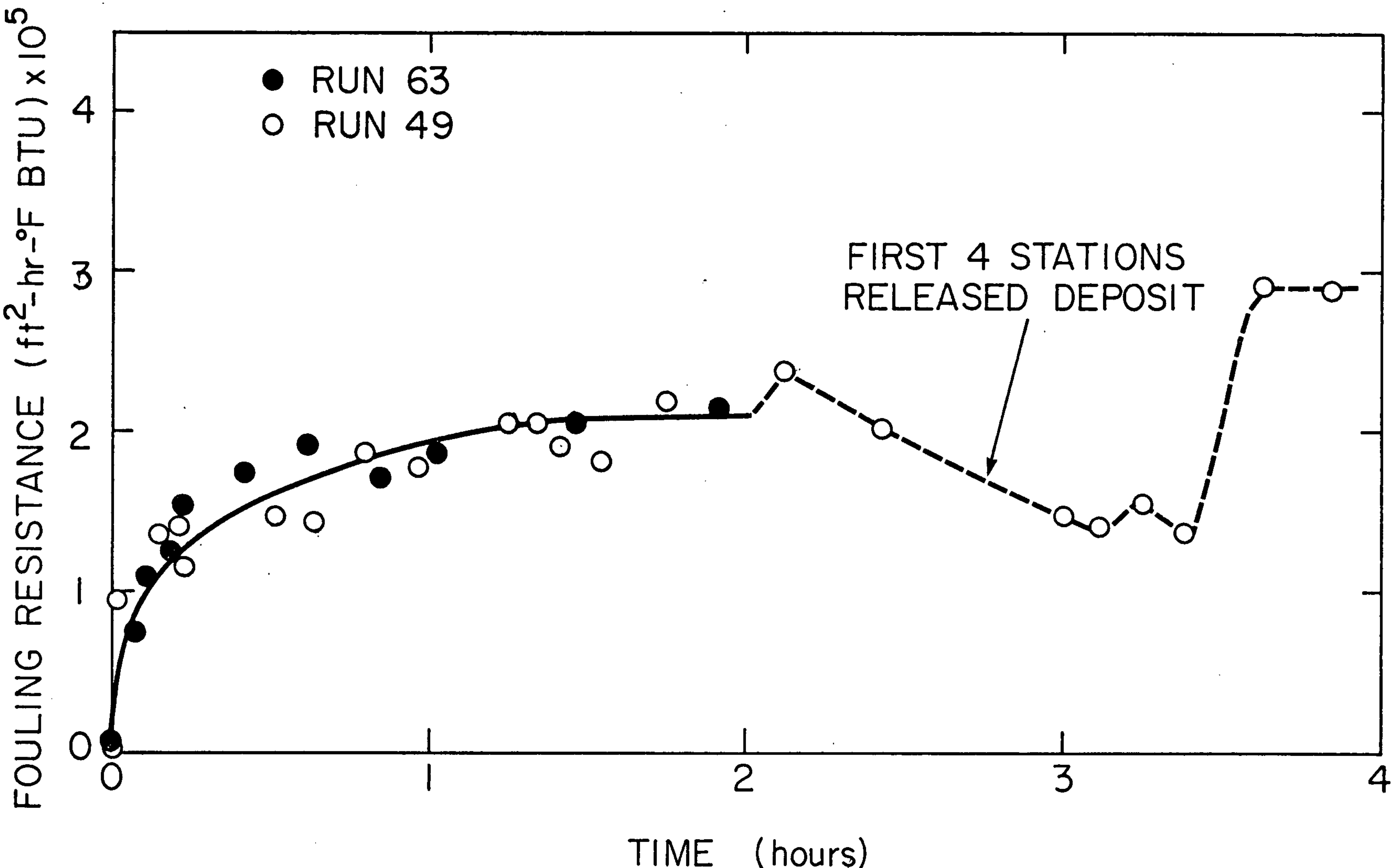


Figure 12. Effect of Prolonged Operation on Fouling Behaviour (Heat Flux 89,750 BTU/ft^2-hr, Re 26,500, Mixed-Size Ferric Oxide Conc, 2130 ppm).

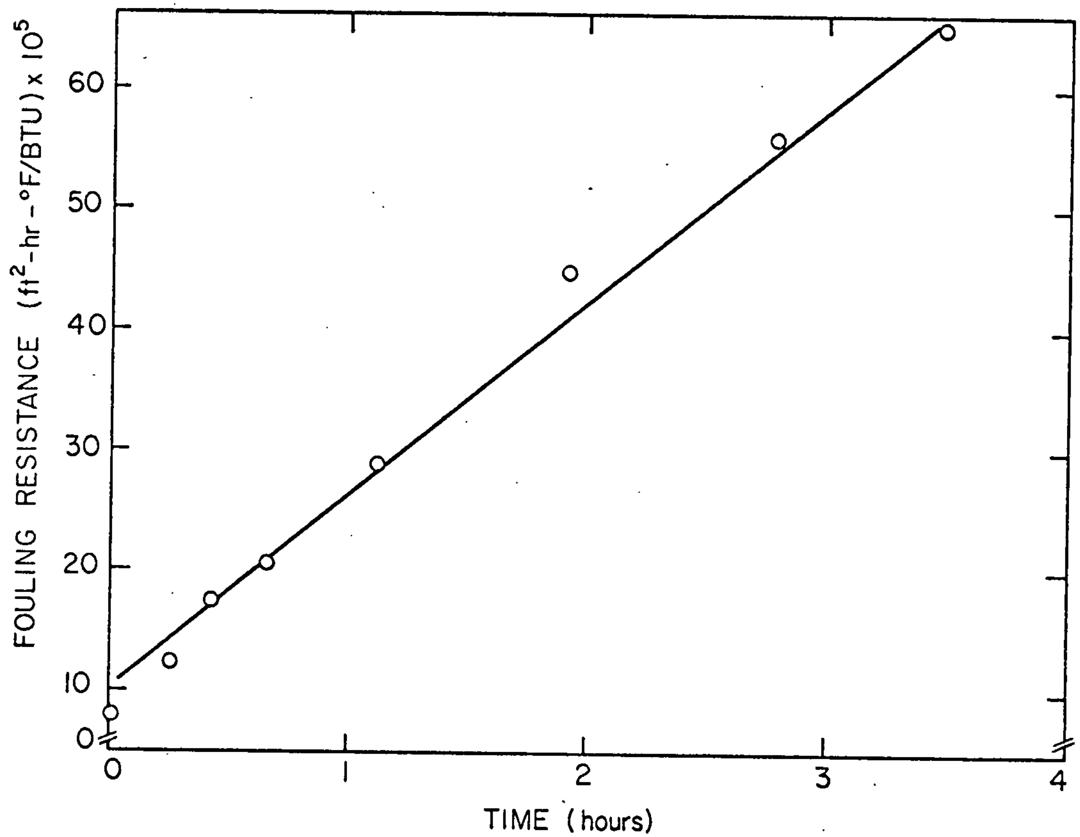


Figure 13. Linear Fouling Behaviour (Run 64, Heat Flux = 89,850 BTU/ft^2-hr, Re = 20,850, Mixed-Size Ferric Oxide Conc. = 2130 ppm).

by refouling. Taborek *et al.* (1) also show curves of this type.

Figure 13 illustrates a third type of fouling curve obtained in a ferric oxide-tap water-204 stainless steel system. This curve was obtained at low heat fluxes, or by fouling the tube at zero heat flux for periods longer than about eight hours and then heating. It is characterized by a near linear dependence of fouling resistance with time.

It should be stressed that all three types of fouling curves can be obtained whilst operating under identical conditions of heat flux, inlet temperature, flow rate and ferric oxide concentration. The curves differ because that shown in Figure 12 results from operating for extended time periods, and that shown in Figure 13 is the consequence of starting the run with a prefouled tube.

6.2.2 Effect of Reynolds number and heat flux on fouling curves.

In order to determine the effect of Reynolds number and heat flux on the shape of fouling curves, a series of trials were made using mixed-size ferric oxide at a concentration of 2130 ppm. Results are shown in

Table XVIII and plotted in Figure 14-16. An examination of these data shows the following:

At high heat flux, in the range of 90,000 BTU/ ft^2-hr, fouling curves depict asymptotic type behaviour. The curves obtained (see Figure 14) can be readily fitted to the equation

$$R_f = R_f^* \left[1 - e^{-bt}\right] \tag{4.4}$$

The asymptotic fouling resistance does not appear to be a function of Reynolds number, but the initial fouling rate may be lowered slightly by an increase in Reynolds number. As either the Reynolds number or the heat flux is decreased (see Figure 15), the data can still be fitted by equation (4.4); the asymptotic resistance R_f^* then increases and the initial fouling rate yields no consistent pattern.

A danger in fitting data to equation (4.4) is that a reasonably good fit can be achieved for virtually any curve which extrapolates to a positive value of R_f at $t = 0$, provided dR_f/dt is not negative. If the view is taken that the use of equation (4.4) to fit the present data (which meet the above criteria) is not justified, the results can be replotted as shown in 4 runs in Figure 16, ignoring the zero point. The assumption now being made

Table XVIII

Effect of Heat Flux and Reynolds Number on Fouling Behaviour for Mixed-Size Ferric Oxide 2130 ppm Conc.

Run No.	Heat Flux (BTU/ft²-hr)	Reynolds Number	Run Duration (hrs)	Wall Temp Clean (F°)	ΔT Wall (F°)	W LB_m/sec	R_f^* ft²-hr-°F/BTU	b 1/Hour	$\left.\frac{\partial R_f}{\partial t}\right\|_{t=0}$
54	16540	10090	3.42	145.7	1.1	0.076	8.8	0.9	7.9
55	25800	15740	2.00	148.0	1.3	0.118	5.4	1.7	9.2
38	44360	19550	2.10	159.1	1.8	0.144	3.7	0.9	3.3
59	44360	19550	2.90	159.1	1.6	0.144	3.1	1.6	5.0
56	89860	20850	1.20	195.0	2.4	0.144	2.3	4.1	9.4
39	44870	25390	2.25	152.0	1.7	0.190	4.4	2.3	10.1
49	89750	26490	3.87	181.5	2.8	0.188	2.1	5.3	11.1
50	89750	26490	1.72	182.6	2.7	0.188	3.1	3.7	11.5
63	91400	26530	1.92	181.5	2.0	0.188	2.1	5.7	12.0
61	41970	33700	2.48	144.0	1.1	0.256	2.2	6.2	13.5
44	89900	37590	2.08	167.5	2.0	0.275	2.2	2.9	6.4

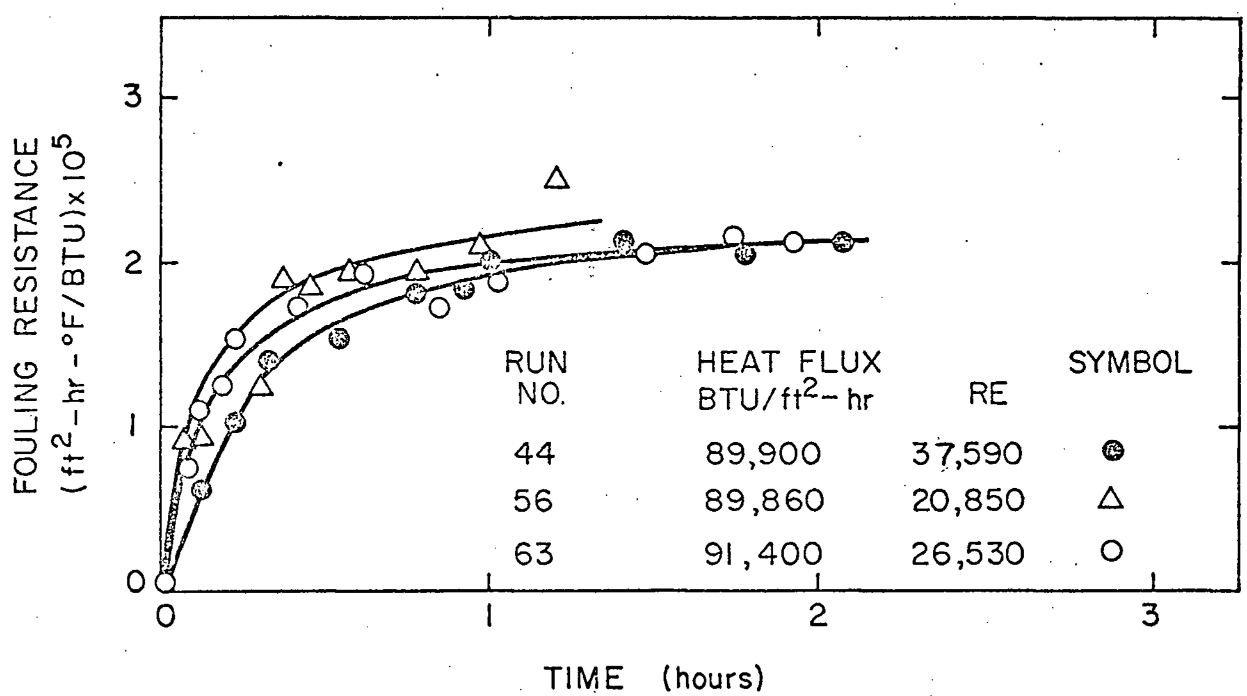


Figure 14. Influence of Reynolds Number on Fouling Curves at Heat Fluxes Near 90,000 BTU/ft^2-hr, Mixed-Size Ferric Oxide Conc. 2130 ppm.

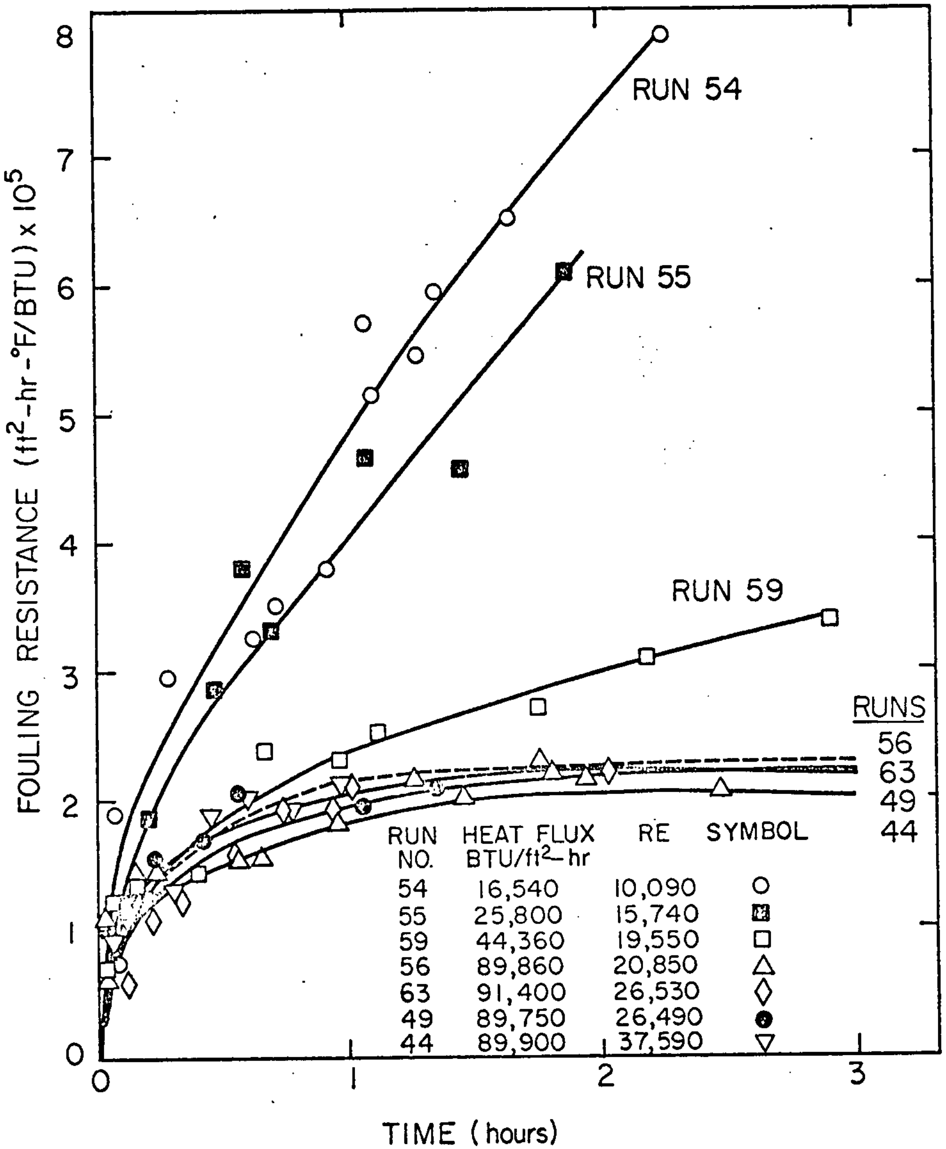


Figure 15. Effect of Heat Flux and Reynolds Number on Fouling Behaviour. Mixed-Size Ferric Oxide Conc. 2130 ppm.

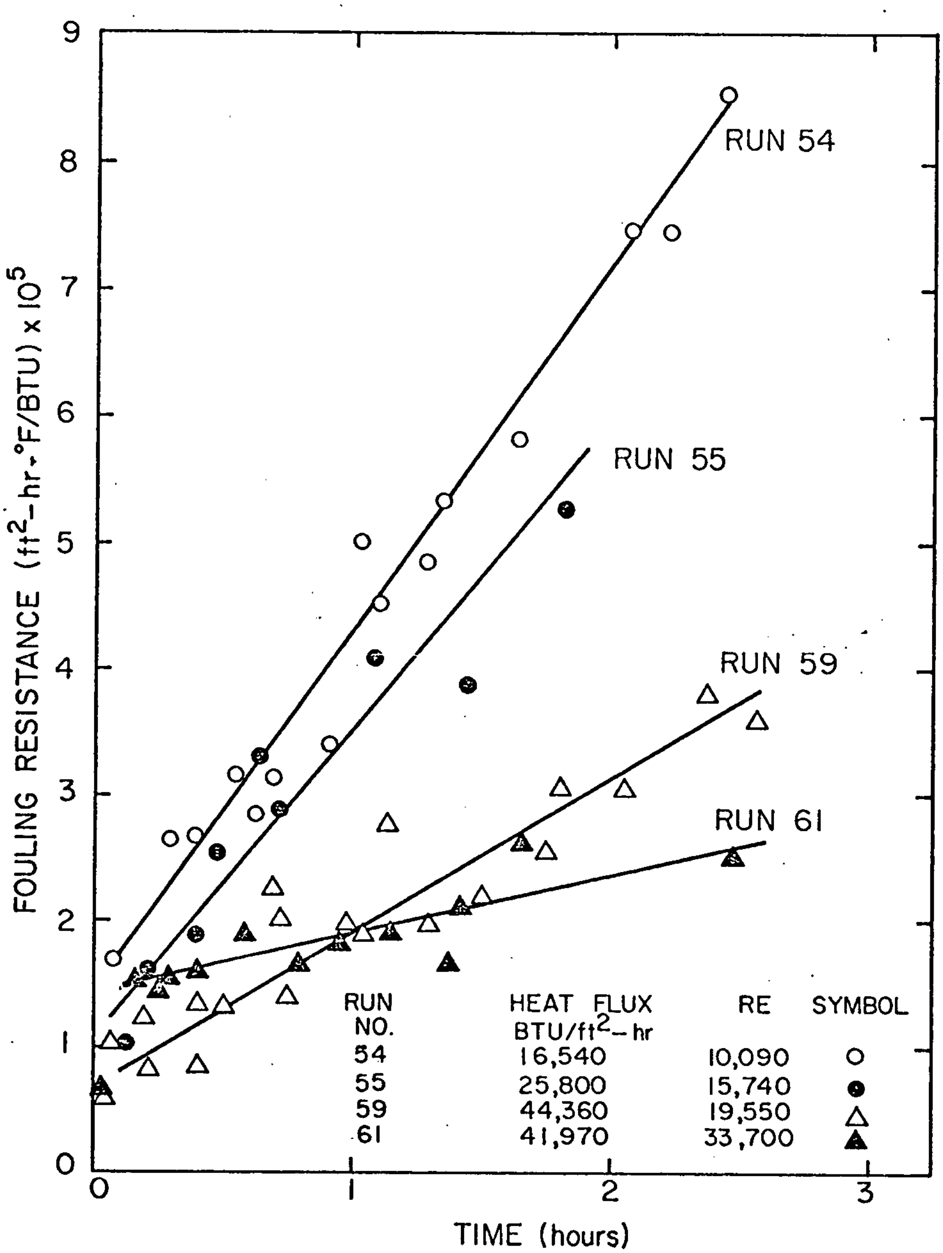


Figure 16. Effect of Heat Flux and Reynolds Number on Fouling Curves at Heat Fluxes ≤ 44,360 BTU/ft^2-hr, Mixed-Size Ferric Oxide Conc. 2130 ppm.

is that the first few minutes of a run show a fouling at a rapidly declining rate, following which the rate becomes constant. Under such an assumption, the data show that as either the heat flux or Reynolds number is decreased, the constant fouling rate increases.

It is believed that the reason for this behaviour is as follows: At time zero, when the tube wall is clean, ferric oxide particles adhere with difficulty. Increasing the Reynolds number increases the shear stress and hence the scouring action at the wall; consequently, the fouling rate decreases. The fact that increasing the heat flux similarly results in lower fouling rates is not as readily explained. At first it was thought that high heat fluxes resulted in a thermophoretic force on the particles which impeded their transport to the tube wall. However, as will be explained in Section 6.2.6, if the tube is pre-fouled at low heat flux prior to time zero and then high heat fluxes used, fouling occurs at a very rapid rate. Such behaviour would not be expected if thermophoresis were the sole reason for the inverse dependence of fouling rate on heat flux. A more probable explanation is that high heat fluxes are associated with high wall temperatures. Consequently, when operating with high heat flux, oxygen solubility is reduced near the tube wall. Since, as will be shown in Sections 6.2.9 and 6.2.7, the fouling rate decreases with increasing temperature, and use of an oxygen scavenger also reduces the fouling rate, the above explanation for the inverse dependence of fouling rate on heat flux appears to be reasonable.

With respect to the shape of the curves, it is believed that neither of the methods used here to fit the data is entirely sound. Use of the asymptotic type equation

$$R_f = R_f^* \left[1 - e^{-bt} \right] \qquad (4.4)$$

is difficult to justify as a generalization, since as outlined in Section 6.2.1, attempts to operate indefinitely at the asymptotic condition resulted in sharp drops in thermal resistance followed by refouling. Use of the method whereby the first few minutes of data are ignored and a linear equation applied for the remainder can be critized on the grounds that it simply does not fit all the data, though it does give a fair approximation of the fouling rate over much of the range covered. This aspect of fouling behaviour is discussed more fully in Section 7.0.

6.2.3 Effect of ferric oxide concentration on fouling curves.

The concentrations of mixed-size ferric oxide used in this study ranged from 15 ppm by weight to 3750 ppm, with 2130 ppm being the concentration most frequently tested. Pre-sized ferric oxide was used only at concentrations of 15 ppm because of the high cost of this material ($10 per gram). Consequently, the results presented here pertain to mixed-size ferric oxide only.

Below 100 ppm, thermal fouling could not be detected on a consistent basis, although sectioning of the tubes clearly showed the presence of spotty fouling deposits. In most trials, wall temperatures remained constant during the entire course of the run, some of which lasted as long as 7 days. During two runs (Runs 1 and 4), behaviour indicative of fouling took place at localized positions on the tube wall, but such results could not be reproduced.

For ferric oxide concentrations of approximately 750 ppm, thermal fouling could be detected but again, fouling curves were not reproducible and did not become so until a concentration in excess of 1750 ppm ferric oxide was used. At concentrations of 2130 ppm and higher, thermal fouling was readily detected and the resulting curves are reproducible within the limits shown by Table XIX (compare Runs 49 and 63).

Tables XIX and XX show the results of two series of fouling runs made at varying ferric oxide concentrations. The fouling curves themselves are shown in Figure 17 and 18. Again, as was the case with the dependence of fouling on heat flux and Reynolds number, the use of an asymptotic type relationship to fit these data is perhaps not entirely valid. However, the data clearly show that as the concentration of ferric oxide is increased, the extent of fouling increases, the effect being much more pronounced for the lower heat flux and lower Reynolds number (Figure 18), where the fouling rate is consistently higher for the higher concentration.

That the fouling rate should be a direct function of ferric oxide concentration was not unexpected. However, the fact that thermal fouling could not be detected at low concentrations (15 ppm) when operating times were extended for periods of up to two weeks (except occasionally at localized points) implies that the influence of concentration on fouling is not a simple relationship. If the reason for the inability to detect fouling at low concentrations was simply low mass transfer rate of ferric oxide towards the wall when the concentration driving force is

Table XIX

Influence of Ferric Oxide Concentration on Parameters b and R_f^* and Initial Fouling Rate, Obtained by Least Squares Fit of Fouling Data to the Equation $R_f = R_f^*(1 - e^{-bt})$. Heat Flux 90,000 BTU/ft²-hr (Approx.)

Re 26500 (Approx.)

Run No.	Ferric Oxide Conc. (ppm)	b (hr^{-1})	Asymptotic Fouling Resistance R_f^* $\frac{(ft^2)(hr)(°F)}{BTU}$	Initial Fouling Rate $\left.\frac{dR_f}{dt}\right\|_{t=0} = bR_f^*$ $\frac{(ft^2)(°F)}{BTU}$
45	250	0.5	0.5	1.1
46	750	0.5	0.6	0.3
47	1500	3.6	1.0	3.6
48	1750	3.4	0.4	1.4
49	2130	5.3	2.1	11.1
63	2130	5.7	2.1	12.0
52	3750	0.9	3.3	3.0

Table XX

Influence of Ferric Oxide Concentration on Parameters b and R_f^* and Initial Fouling Rate, Obtained by Least Squares Fit of Fouling Data to the Equation $R_f = R_f^*(1 - e^{-bt})$. Heat Flux 44,360 BTU/ft²-hr (Approx.)

Re 19,550

Run No.	Ferric Oxide Conc. (ppm)	b (hr^{-1})	Asymptotic Fouling Resistance R_f^* $\frac{(ft^2)(hr)(°F)}{BTU}$	Initial Fouling Rate $\left.\frac{dR_f}{dt}\right\|_{t=0} = bR_f^*$ $\frac{(ft^2)(°F)}{BTU}$
38	2130	0.9	3.7	3.3
53	3750	2.7	5.9	15.9

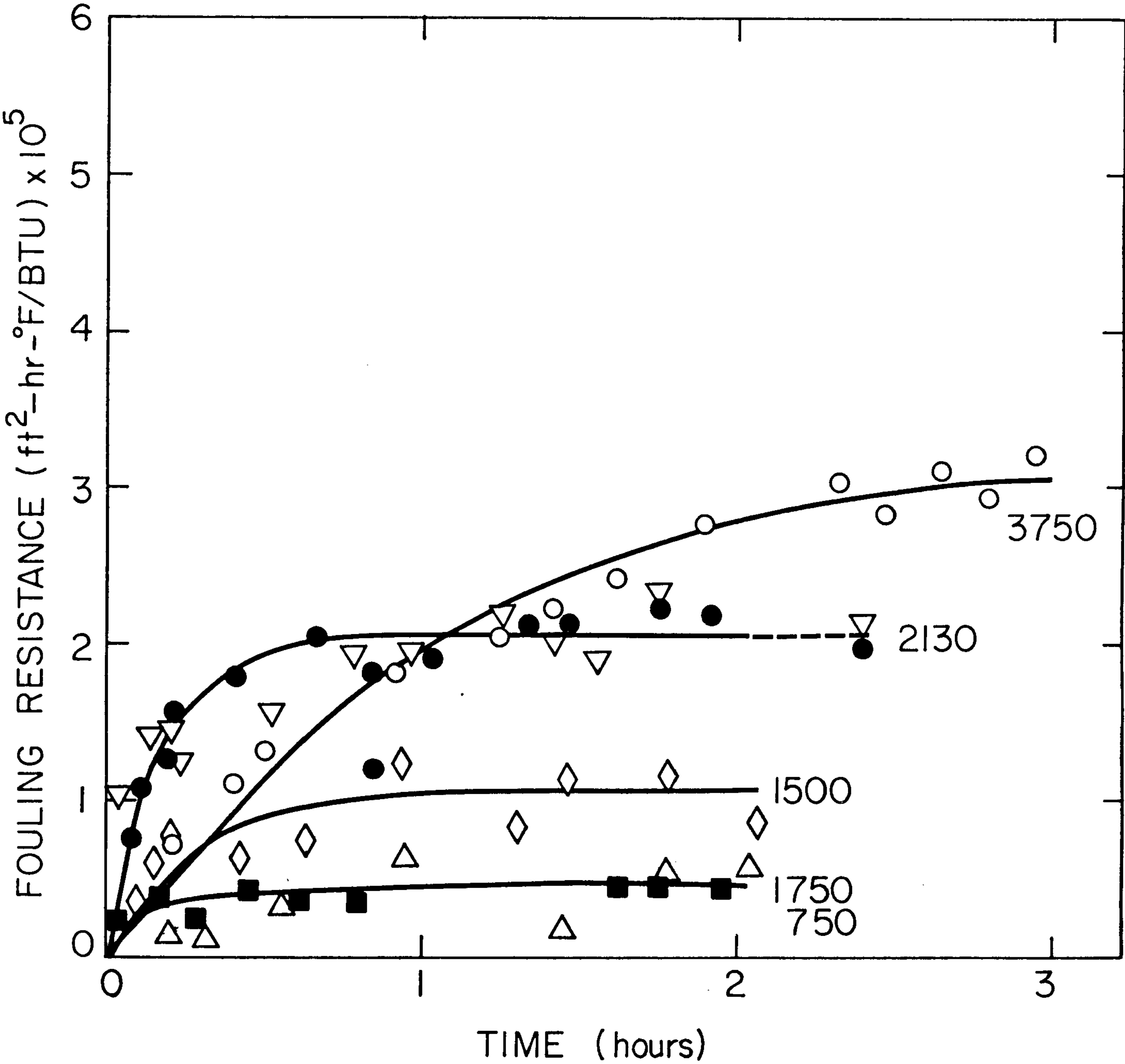


Figure 17. Effect of Mixed-Size Ferric Oxide Concentration on Fouling Behaviour, Heat Flux 90,000 BTU/ft^2-hr (Approx.), Re 26,500 (Approx.).

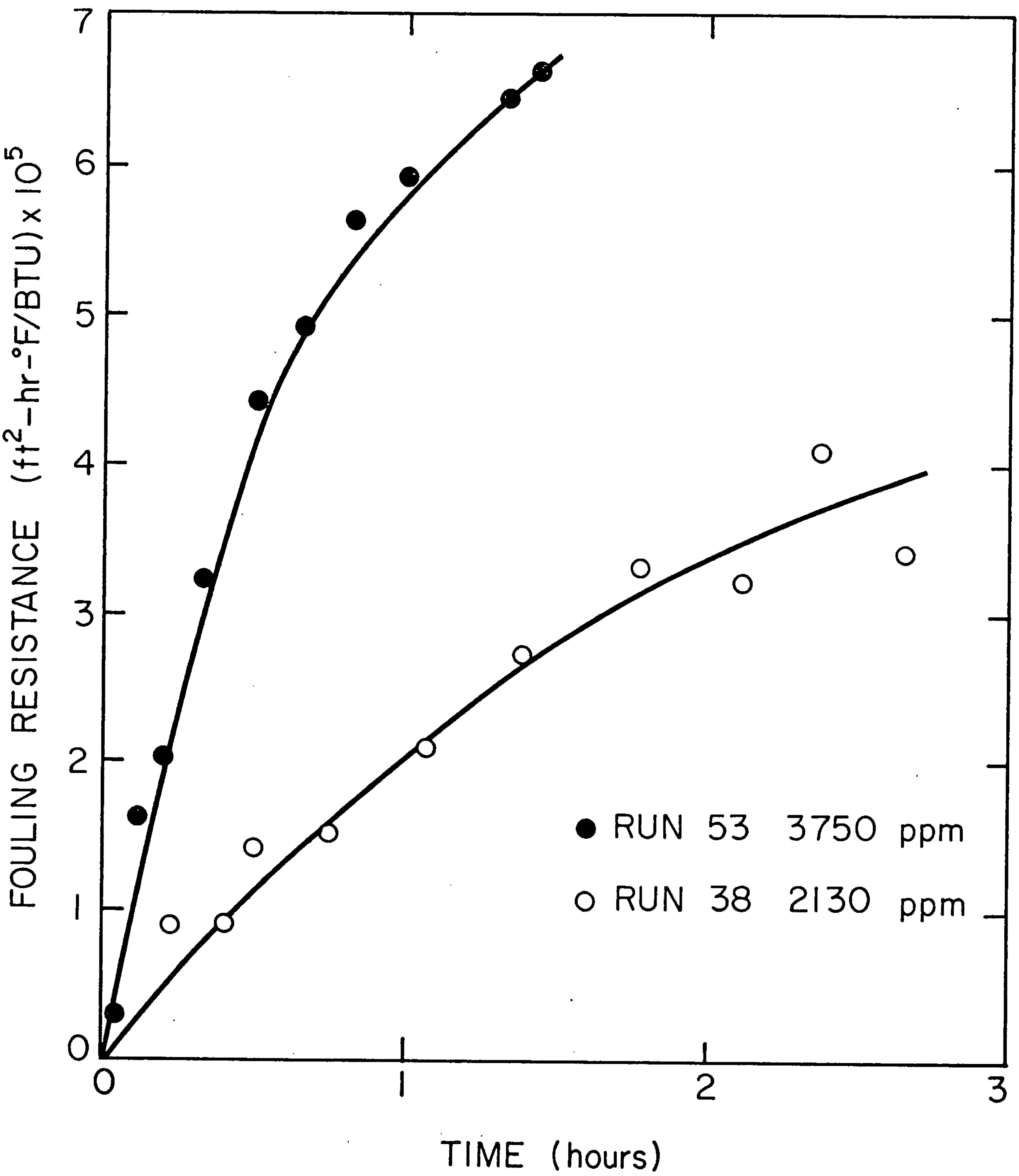


Figure 18. Effect of Mixed-Size Ferric Oxide Concentration on Fouling Behaviour, Heat Flux 44,360 BTU/ft^2-hr, Re = 19,550.

low, then one would not expect to find fouling in localized positions, and it should be possible to detect fouling thermally simply by extending operating times for the trials. Such was not the case. A possible explanation is that at low concentrations deposits build to some asymptotic level which cannot be detected thermally. Another possibility is that the fouling process requires a relatively large accumulation of particles on the tube wall to trigger a bonding reaction between particles and tube wall and at low concentrations such an accumulation never occurs. The results of microprobe examination of deposits coupled with fouling experiments using prefouled tubes indicate that the latter explanation is probably correct. Further discussion of this point is contained in Section 7.0.

6.2.4 Effect of residual tube wall deposits on fouling curves.

In some early trial runs, the assumption was made that if the wall temperature readings indicated no temperature rise over the clean wall condition, as established with a clean honed tube on solids-free water, there were no deposits on the tube wall and it was unnecessary to hone the tube prior to ferric oxide addition. When fouling data from Runs 31-38 were examined, however, it was found that reproducibility was better for those trials in which the tube was honed prior to time zero. To test whether deposits were present on the tube wall even though thermal data gave no indication of their presence, a fouled tube from a previous run was placed in the heat transfer loop and a "fouling" trial made using tap water. Thermal data gave no indication that the tube was in other than the clean wall condition. When the trial was stopped, the tube was honed and rinsed. Deposit was collected, which showed conclusively that thermal readings indicating clean wall temperatures did not necessarily signify the complete absence of deposits. It was therefore concluded that any tube used in a fouling run would always contain residual deposits unless the tube was honed prior to commencing a trial.

In order to determine the effect of residual deposits on thermal fouling versus time curves, following Run 40 the heat flux was shut off and the flow rate raised to the maximum possible (control valve fully open) for a period of three minutes. Original settings of heat flux and flow rate were then restored. When trial target conditions were re-established, and sufficient time had elapsed to remove thermal transients, thermocouple data showed the tube to be at the clean wall thermal condition. The trial run was then continued and the thermal fouling versus time curve generated.

Figure 19 shows this curve for the above trial (Run 41), as compared to a curve generated under identical conditions except that the tube was honed prior to time zero (Run 39). These curves clearly demonstrate that residual deposit, which has previously been shown to be present on the unhoned tube wall, promotes fouling. (Because of this behaviour, only trials in which the tube was honed prior to time zero were used to establish the effect of Reynolds number, heat flux and ferric oxide concentration on thermal fouling.)

It is believed that the return of the tube wall temperatures to the clean wall condition when the heat flux is shut off and the velocity increased is the result of deposit removal. It is postulated that the cooling of the tube cracks the deposit and the increased velocity tends to augment shearing and removal. The fact that the tap water trial on a fouled tube showed some deposit still to be present indicates that there is not 100% deposit removal by this procedure. Since such tubes foul at a higher initial rate than clean tubes, it appears that the fouling rate is a function of some process which is enhanced by the presence of spotty residual deposits on the

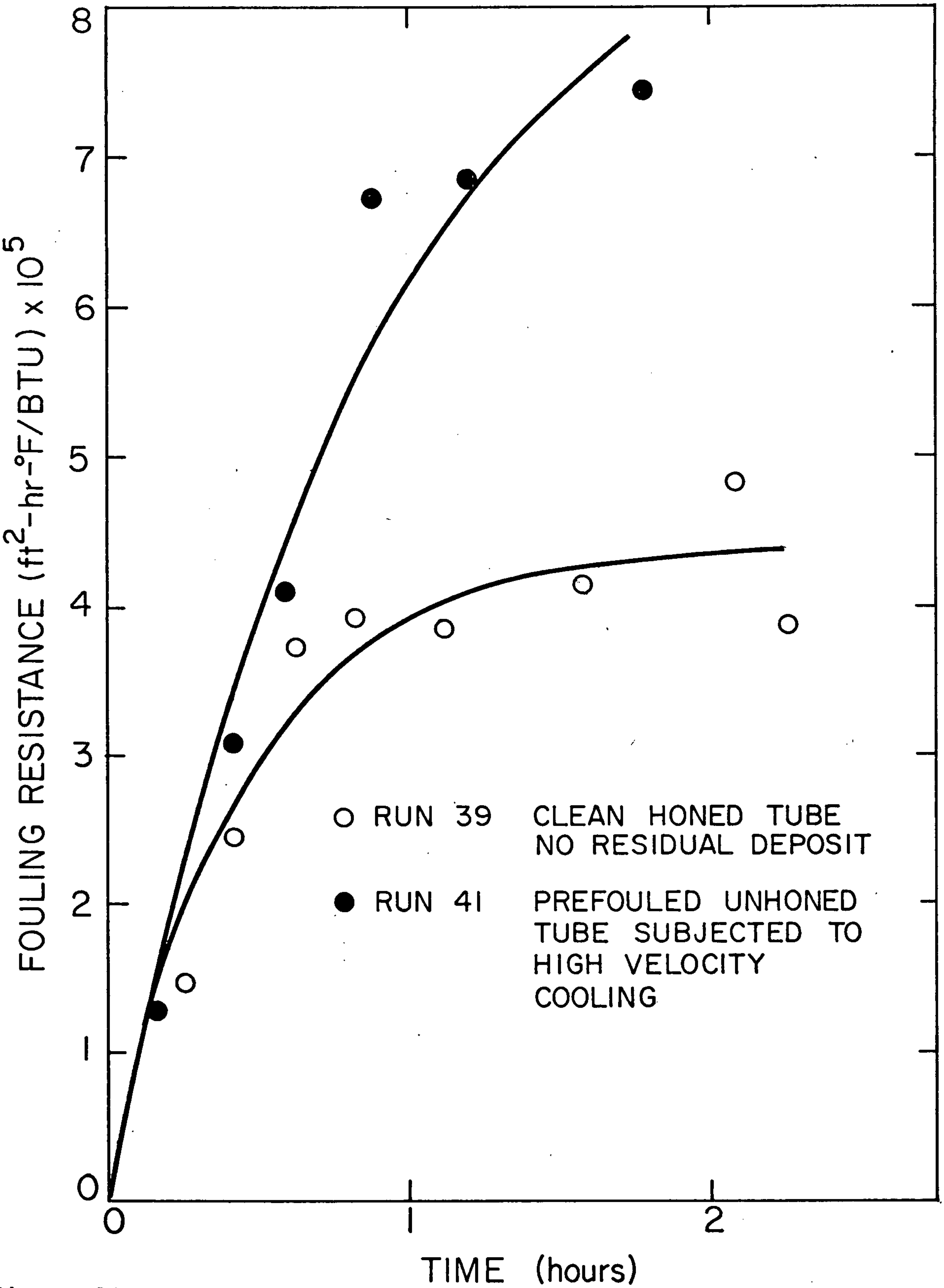


Figure 19. Comparison of Fouling Behaviour for a Clean Honed Tube (No Residual Deposit) with a Prefouled Tube Subjected to High Velocity Cooling. Heat Flux 44870 BTU/ft^2-hr, Re 25400, Mixed-Size Ferric Oxide Conc. 2130 ppm.

tube wall. As will be outlined in more detail later, it is believed that this process is crevice corrosion, and that the rate of this crevice corrosion is governed by the rate at which oxygen is reduced on the unfouled metal.

6.2.5 Effect of extended operating time on fouling curves.

It was stated in Section 6.2.1 that extension of fouling runs beyond approximately 3-4 hours resulted in an unsteady state fouling process. Typically, thermal data would indicate the tube to be either fouling or in an asymptotically fouled state, when suddenly wall temperatures at localized points would decrease and then gradually increase again. To study this behaviour in detail, Run 34 was made in which the operating time was extended over a period of 45 hours. Figure 20 shows a plot of the fouling resistance as a function of time for this run. Comments on this plot follow:

During the first three hours of the trial, the tube fouled at a rapid rate. At 3 hours and 10 minutes following time zero, the wall temperature in the upper half of the test section decreased almost to the clean wall level. The fouling resistance then began to rise again and after 24 hours had risen to the same level as after 3 hours. It was then decided to hone the deposit from the

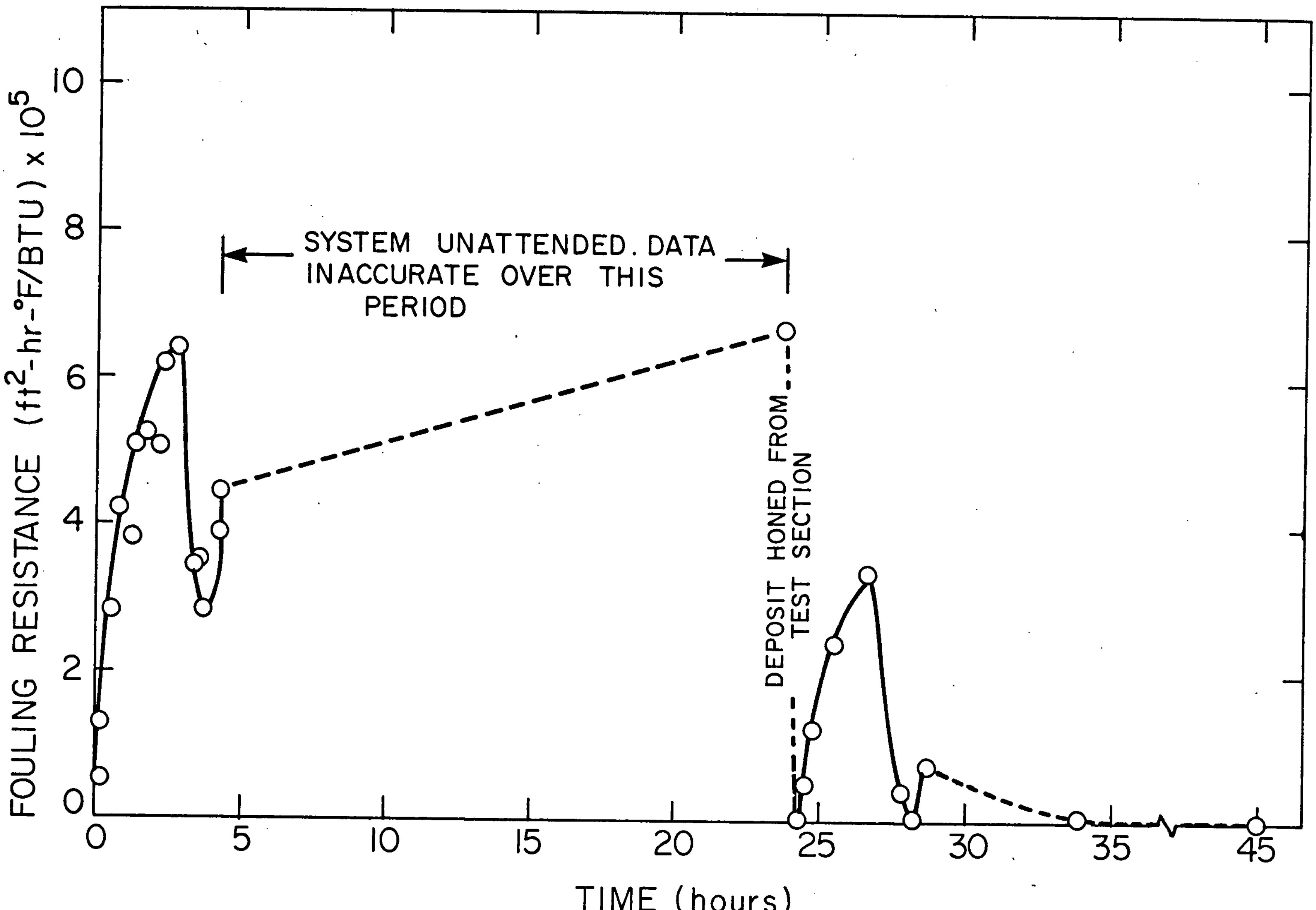


Figure 20. Fouling Behaviour over an Extended Time Period for Run 34. Heat Flux 44,360 BTU/ft^2-hr, Re 19,550, Mixed-Size Ferric Oxide Conc. 2130 ppm.

test section and repeat the trial. Rapid fouling again occurred but did not reach its original levels. After 2 hours wall temperatures again dropped suddenly and then rose again slightly.

The results of trial 34 suggested that sudden wall temperature drops were indicative of a loss of fouling deposit from the tube wall, and that once this happened refouling would occur. However, the results of this trial were not sufficiently precise to enable refouling rates to be accurately measured, because during much of the run the equipment was unattended and operating variables were not well controlled. It was therefore decided to study deposit release and refouling in a more direct manner by fouling a tube under carefully controlled conditions, honing the deposit from one-half of the tube only, and then continuing the fouling run. Since the series of trials involving this run was perhaps the most important series made, the procedure and results are presented here in detail, with data given in Table XXI and plotted in Figure 21 and 22.

The first run of this series, Run No. 39, was a carefully controlled trial made at a ferric oxide concentration of 2130 ppm, a heat flux of 44,870 BTU/ft^2-hr and a Reynolds number of 25,390. After 2.25 hours, the run

Table XXI

Parameters b and R_f^* and Initial Fouling Rate Obtained by Least Squares Fit of Fouling Data to the Equation $R_f = R_f^*(1 - e^{-bt})$ for Runs 39, 40 and 41. Heat Flux 44870 BTU/ft²-hr, Re 25390, Mixed-Size Ferric Oxide Conc. 2130 ppm

Run No.	b (hr^{-1})	Asymptotic Fouling Resistance R_f^* (ft^2-hr-°F/BTU) x 10^5	Initial Fouling Rate $\left.\frac{\partial R_f}{\partial t}\right\|_{t=0}$ (ft^2-°F/BTU) x 10^5	Tube Surface Condition at Zero Time
39 Upper Portion	2.6	4.2	10.9	Honed of all Deposit
39 Lower Portion	2.1	4.4	9.2	Honed of all Deposit
40 Upper Portion	2.4	4.8	11.5	Honed of all Deposit
40 Lower Portion	1.4	8.8	12.3	Contains Residual Deposit from Run 39
41 Upper Portion	1.7	7.3	12.4	Contains Residual Deposit from Run 40 Only
41 Lower Portion	0.9	10.6	9.5	Contains Residual Deposit from Runs 39 and 40

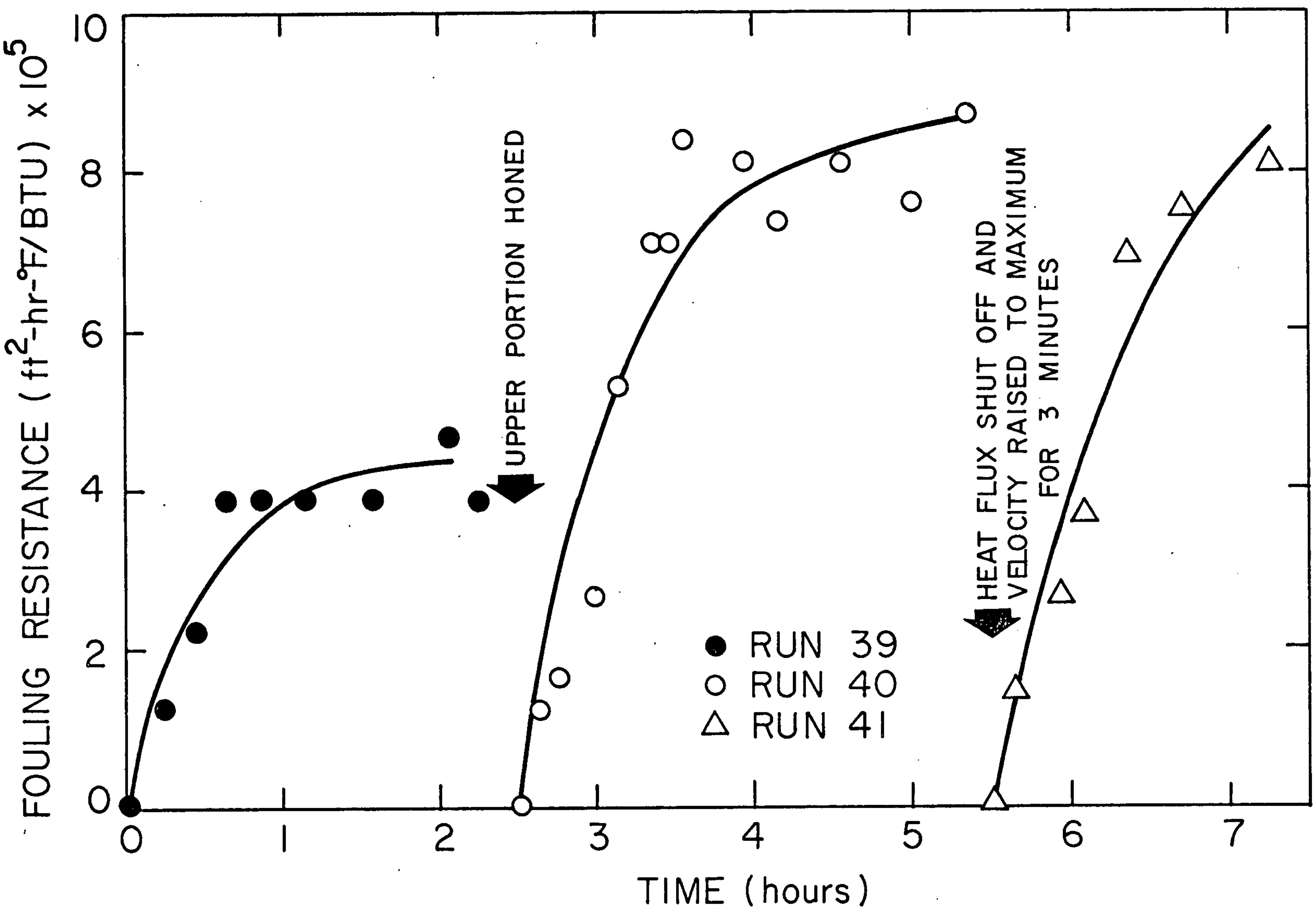


Figure 21. Lower Portion of Test Section Fouling Behaviour Following Honing of Upper Portion at 2.5 Hours, and High Velocity Cooling at 5.5 Hours. Heat Flux 44,870 BTU/ft^2-hr, Re 25,390, Mixed-Size Ferric Oxide Conc. 2130 ppm.

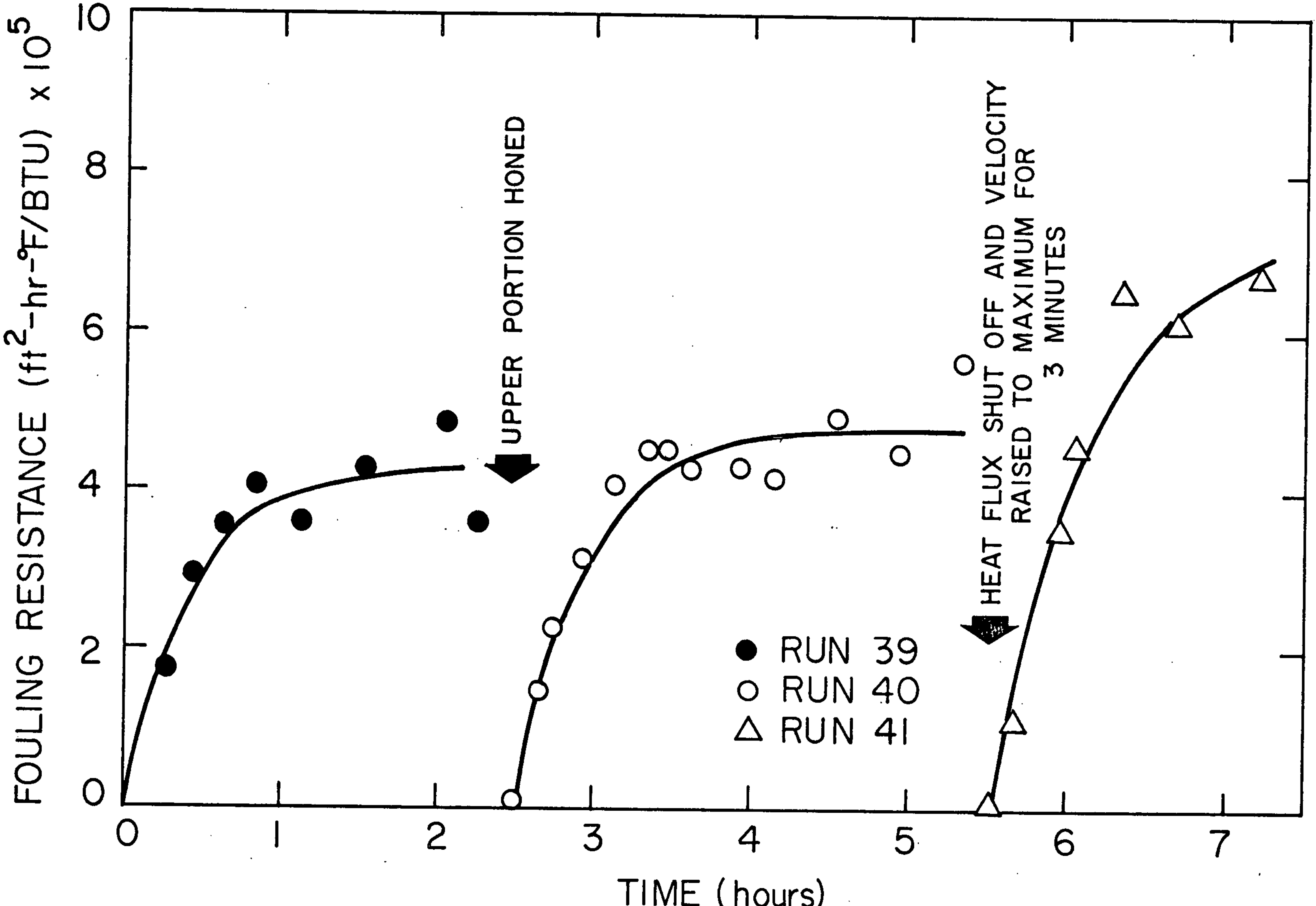


Figure 22. Upper Portion of Test Section Fouling Behaviour Following Honing at 2.5 Hours, and High Velocity Cooling at 5.5 Hours. Heat Flux 44,870 BTU/ft^2-hr, Re 25,390, Mixed-Size Ferric Oxide Conc. 2130 ppm.

was stopped and the deposit honed from the upper portion of the test section only. Dismantling, honing and reassembly of the equipment took 3 minutes. Run 40 then commenced under identical operating conditions to Run 39. Three minutes after start-up, the period found by experience on tap water to be sufficiently long to remove the thermal transient caused by shut-down, time zero was established. At this point it was noted that all thermocouples, those for the honed as well as for the unhoned portions of the test section, were at the clean wall condition. As the run progressed, the honed upper section retraced the previous fouling curve of Run 39. The unhoned lower section, during the same time period fouled to a higher level.

At the end of Run 40, the test section was cooled by shutting off the heat flux for a period of 3 minutes while allowing the fluid to circulate at maximum velocity. When heating was restarted, original flow conditions restored, and the thermal transient removed, the complete test section was found to be at the clean wall thermal condition. Run 41 was then made under identical conditions to Runs 39 and 40. During this run both upper and lower portions of the test section fouled to still higher levels.

This series of trials showed that:

(1) Unhoned sections of the tube wall apparently do contain deposit which causes fouling to proceed to higher levels than for the honed tube wall.

(2) The presence of a honed section of the tube adjacent to an unhoned section apparently results in fouling to levels on the unhoned section which are at least as high if not higher than when the unhoned section is adjacent to another unhoned section which has been subjected to cooling at high velocity. (Compare Run 40-lower portion with Run 41-lower portion and Run 41-upper portion.)

(3) High velocity cooling of the tube wall removes some, but not all, of the fouling deposit.

At this stage in the investigation the idea developed that the rate of fouling of 304 stainless steel tubes with ferric oxide was not being controlled by fluid dynamic factors affecting the rate at which particles were being deposited and released from the tube wall, but rather by some other factor. Since microprobe results had clearly shown that crevice corrosion was occurring beneath the deposit, it was speculated that the fouling rate was being controlled by the rate at which corrosion product immobilized any potential deposit at the wall, rather than by the transport rate of ferric oxide particles. Since crevice corrosion theory (see Section 7.2) predicts no corrosion when the tube wall is clean, and no corrosion when the tube wall is completely covered, such a mechanism would readily explain the results obtained up to that stage in the investigation. For example, the high shear stress at the wall associated with high Reynolds number would inhibit the initial deposition and hence make it difficult to obtain a crevice. High heat fluxes would tend to reduce oxygen solubility near the tube wall, which should predictably tend to reduce the rate of crevice corrosion. With this hypothesis, the experimental results presented in this section are also readily explainable, since the half of the tube unhoned would have crevices at time zero, and the half of the tube which was honed would serve as a site for oxygen reduction, thereby enhancing the rate of crevice corrosion.

To test the validity of this hypothesis, it was decided to attempt control of the crevice corrosion rate by conducting a series of experiments using a prefouled tube at time zero, and another experiment using sodium sulfite as an oxygen scavenger. The results of these experiments are given in Sections 6.2.6 and 6.2.7.

6.2.6 Fouling behaviour using a prefouled tube.

In the previous section, it was reported that if residual deposits were left on the tube wall, fouling occurred at a higher rate than when the fouling run was started with a clean tube. However, as the fouling run progressed, the fouling rate declined and in many cases the fouling resistance approached an asymptotic value. Most investigators who have obtained fouling curves of this type have interpreted the asymptotic condition as being due to a balance of deposition and release rates, the latter taken as proportional to deposit thickness. Kern and Seaton (6), for example, use this approach, as does Watkinson (7). In the ferric oxide-stainless steel system studied here, it was reasoned that if asymptotic fouling curves were the result of a balance between deposition and release rates, then at equilibrium some wall temperatures would fall as material was locally released while others would rise as material was locally deposited. Although the latter situation has been found, for example in Run 34 (see Appendix IV), it no longer corresponds to an asymptotic condition. Instead, for this situation the tube refouls, as reported in Section 6.2.5. It was therefore postulated that asymptotic fouling behaviour is the result of a suppression of fouling rather than a balance between deposition and removal rates, and that this suppression is the result of a diminution of crevice corrosion as the tube fouls.

A clue to the nature of the suppression mechanism was discovered accidently when it was found that if the wall temperature of an asymptotically fouled tube was increased suddenly, the tube would commence fouling at a nearly constant rate. Since during the earlier experimental runs every attempt was made to hold conditions steady, sudden increases in wall temperatures were seldom encountered.

In Run 64, a decrease in the cooling water inlet temperature to the system resulted in a drop in wall temperature which went undetected for about 6 hours. When conditions were returned to normal, it was found that fouling occurred and persisted at a very rapid rate. This implied that the mechanism which caused fouling rates to decrease with time as fouling progressed was no longer operative.

To study this phenomenon in a more controlled manner, Run 70 was made in which the fouling suspension was allowed to circulate through the test section for 6 hours at zero heat flux and then heating started. Results, which are plotted in Figure 23, show that fouling under this condition proceeds at a constant rate. For comparative purposes, the results of Run 63 are included. Run 63 was

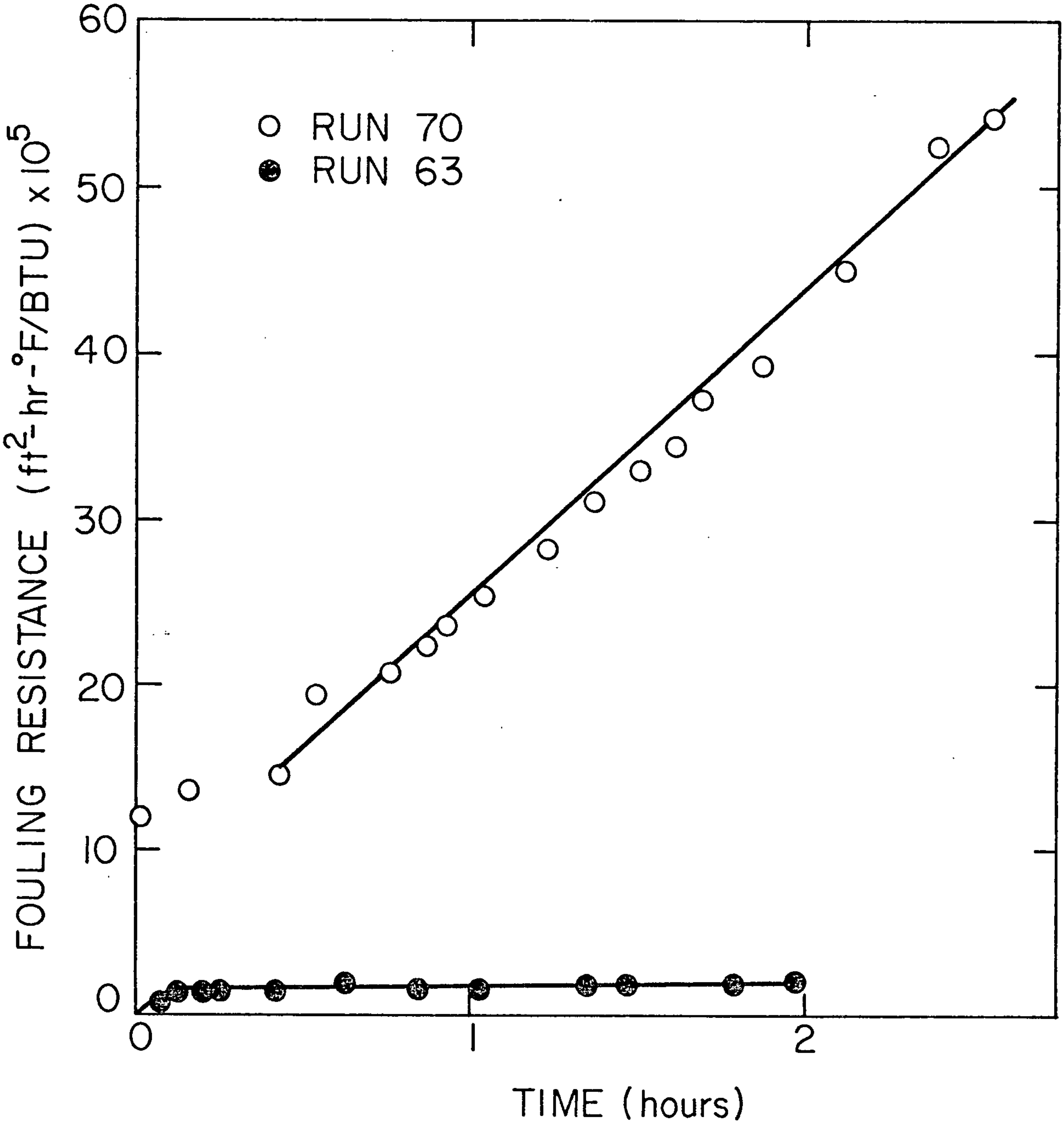


Figure 23. Effect of Tube Condition at Time Zero on Fouling Behaviour. Mixed Size Ferric Oxide Conc. 2130 ppm, Heat Flux 89,670 BTU/ft^2-hr, Re = 26,580.

made under identical conditions to Run 70 except that the tube wall was initially honed and therefore clean at zero time.

The following is offered to explain why prefouling a tube at zero heat flux and then heating leads to rapid linear fouling: When deposition occurs from the fluid to the honed clean wall, crevices are produced which result in crevice corrosion and the production of iron, nickel and chromium corrosion products. These corrosion products diffuse through the deposit, precipitate, and serve to strengthen the bond between the ferric oxide particles. (According to Charlesworth (11), it is well known that the incorporation of nickel in an iron oxide deposit results in a hard, tightly bonded structure.) As fouling proceeds, the clean wall area becomes progressively reduced and crevice corrosion ceases due to suppression of the cathode reaction

$$O_2 + 2H_2O + 4\,\bar{e} \rightarrow 4OH^-$$

at the clean wall. (For the fundamentals of crevice corrosion, see Section 7.2.)

With a cold prefouled tube, the situation is quite different. When the heat flux is turned on, the tube and deposit expand, the deposit to a smaller degree than the metal tube. It is postulated that this results in a cracked deposit with exposed clean wall areas. It is furthermore suggested that these cracks are sufficiently small that they cannot be penetrated by the ferric oxide particles to block the clean wall sites, but readily allow the transport of oxygen to the surface of the metal. Consequently, oxygen reduction at the clean wall does not fall off as the tube fouls and fouling occurs at a constant rate.

A conclusion which logically follows from the above hypothesis is that use of an oxygen scavenger should significantly change the fouling rate when the system is placed in the linear fouling condition, since this would block the cathode reaction

$$O_2 + 2H_2O + 4\,\bar{e} \rightarrow 4OH^- \quad .$$

The results of an experiment to test this corollary are given in the next section.

6.2.7 Effect of an oxygen scavenger (Na_2SO_3) on fouling behaviour.

To test the effect of oxygen concentration on fouling behaviour, the test section was made to foul at a constant rate by methods described in Section 6.2.6. After 3.28 hours, the air line to the suspension storage, which had the dual purpose of providing mixing and insuring that at all times the suspension was saturated with oxygen, was switched to a nitrogen cylinder. Forty-five minutes later 300 grams of sodium sulfite were added to the tank. After another 30 minutes, it was found that the system was still in a state of linear fouling, but that the rate had changed to less than one-half that of the previous rate.

The results of this experiment are plotted in Figure 24. Included are curves made under identical conditions of heat flux, particle concentration and Reynolds number, but differing in that curve 1 involved starting with a honed clean tube, curve 2 was for a prefouled tube placed in a situation conducive to linear fouling with the system saturated with oxygen, and curve 3 was for the same situation but with the system scavenged of oxygen. It is concluded from these results that the fouling of 304 stainless steel with ferric oxide under the usual conditions investigated here is associated with the presence of oxygen in the suspension. Furthermore, the hypothesis that the rate of fouling is controlled by the rate at which crevice corrosion proceeds, which is in turn controlled by oxygen transport to the tube wall, is strengthened by the above results.

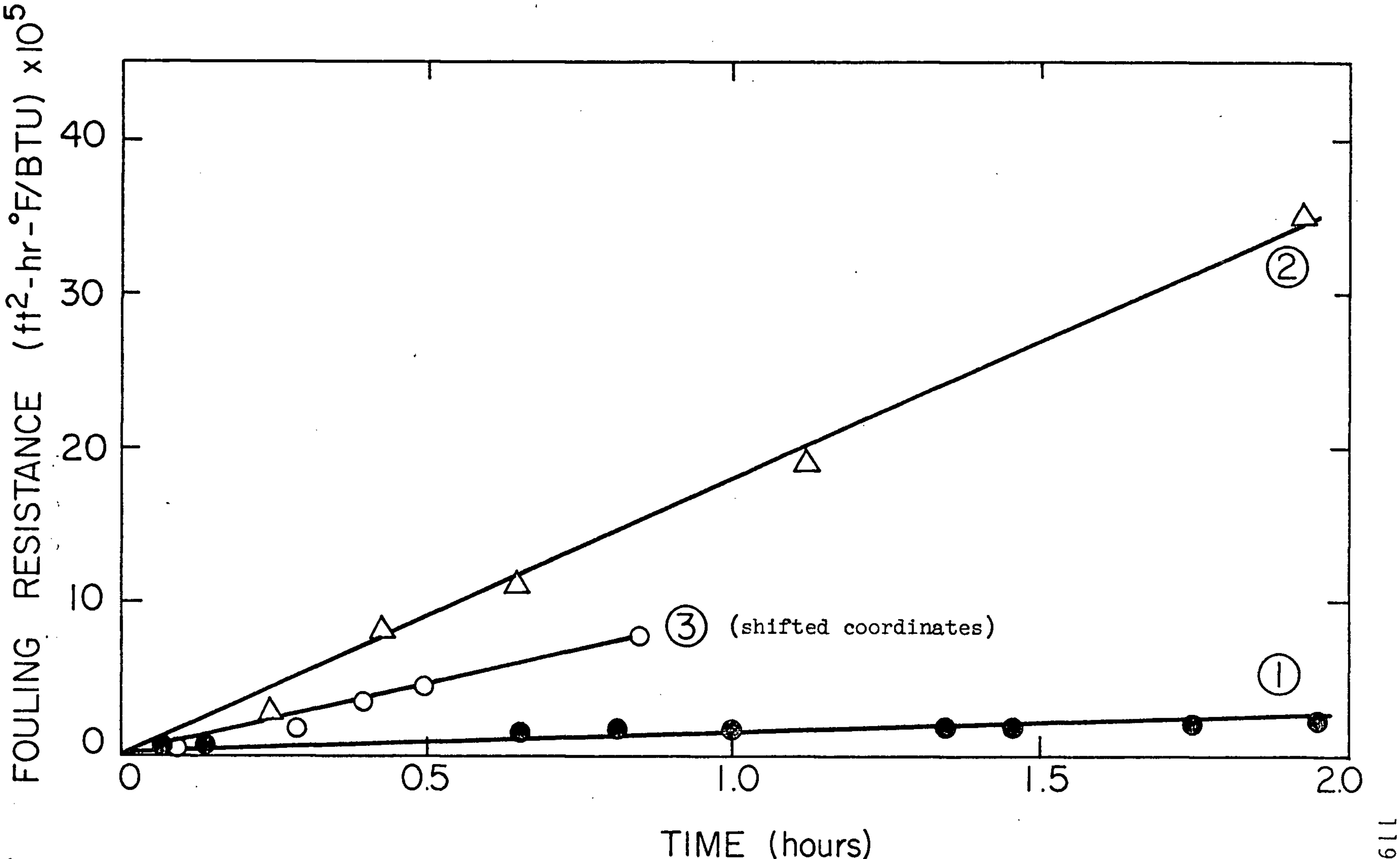


Figure 24. Comparison of Fouling Rates for a Clean Honed Tube (Curve 1), a Prefouled Tube with an Oxygen Scavenger in the System (Curve 3), a Prefouled Tube with no Oxygen Scavenger (Curve 2). Mixed-Size Ferric Oxide 2130 ppm, Heat Flux 89,670 BTU/ft^2-hr, Re 26,580.

Mahato (36), in his study of the corrosion of iron pipes in city water, concluded that the rate of corrosion was a function of the rate at which oxygen could be transported through the rust layer to the metal surface. In Mahato's case, as the rust layer became thicker the diffusion of oxygen was correspondingly reduced with the result that the corrosion rate decreased.

Although the explanation of Mahato can be used to account for the asymptotic type of fouling behaviour found here, it does not explain the linear fouling situation. For the latter situation, it is believed that oxygen transport is not significantly impeded as the fouling deposit grows because of cracks in the deposit induced by thermal expansion when heat is applied to a prefouled tube — a prerequisite for obtaining linear fouling. Also, the linear fouling situation would reasonably create new cracks in the deposit as a result of increases in wall temperature as the tube fouls. Consequently the mechanism proposed here, inasmuch as it depends upon oxygen delivery to the tube wall, is considered to be reasonable. The fact that the linear fouling rate did not fall to zero in the absence of oxygen is probably due to the occurrence of the alternative cathode reaction (37)

$$2H^{+} + 2\bar{e} \rightarrow H_2\uparrow \ .$$

6.2.8 Effect of ferric oxide particle size on fouling behaviour.

The first trial carried out in this study was made using mixed size ferric oxide at a concentration of 16 ppm, a heat flux of 91,660 BTU/ft^2-hr and a Reynolds number of 24,700. No evidence of thermal fouling was found, although sectioning of the tube after the trial showed it to contain a spotty deposit having a maximum thickness of approximately 100 microns. Hindsight suggests that the conditions for this trial were perhaps the worst that could have been selected, since later work showed that such a low ferric oxide concentration and high heat flux would result in minimal fouling. However, this was not known at that time and it was assumed that the fouling process was limited by transport to the wall of ferric oxide particles, which were presumed too large to result in the minimum deposition rates necessary to cause thermal fouling. There were two reasons for this belief:

(I) A cursory examination of the mixed size ferric oxide suggested its typical size to be in the range of 10 microns. Particles of this size are insignificantly subjected to Brownian motion, a factor which was considered essential to obtaining a high flux of particles through the laminar sublayer to the tube wall.

(2) Particles of this size are prone to gravity settling, and it was felt that if such a particle did approach the wall, it would tend to settle rather than become attached to the vertical tube wall.

To test the hypothesis that the fouling process was particle transport limited, presized ferric oxide was purchased in two batches, one with a specified particle size range of 0.3-0.8μ and the other with a specified range of 0.3-3.7μ. Fouling trials were made as summarized in Table XXII, with results as follows:

Run 19 was made using presized particles of 0.3-0.8μ at a concentration of 15 ppm. Following a trial of 48 hours, during which time no thermal fouling was detected, the tube was sectioned. No deposit could be found in the heated section of the tube although a spotty deposit was found in the unheated exit section. Repeating Run 19 with zero heat flux (Run 20) resulted in a tube having spotty deposits with thicknesses of about 70 microns. Runs 21, 22 and 23 were then made using the larger particle size (0.3-3.7 microns), with similar results. That is, at high heat flux no deposit could be detected when the tube was sectioned, while at zero heat flux a spotty deposit was found.

Table XXII

Effect of Particle Size on Fouling Behaviour.
Ferric Oxide Conc. 15 ppm
Re 25,000 (Approx.)

Run No.	Trial Duration (hrs)	Heat Flux (BTU/ft^2-hr)	Particle Size (microns)	Deposit Thickness (microns)
19	48	92,310	0.3-0.8	0*
20	72	0	0.3-0.8	70 (spotty)
21	24	90,000	0.3-3.7	0
22	168	90,000	0.3-3.7	0
23	96	0	0.3-3.7	70 (spotty)

*A deposit was found in the exit section of the tube, but none in the heated section.

In an attempt to find a rationale for these observations, a review was made of selected papers concerning the deposition of small particles from turbulent streams, concentrating primarily on the work of Beal (16,29). Beal's work was of particular interest since it suggested that particles differing only slightly in size could have greatly different rates of deposition.

Beal developed an equation for particle flux to a tube wall by integrating Fick's equation for turbulent flow. That is

$$N = (D + \varepsilon)\frac{dC}{dy} \tag{6.1}$$

where N = flux of particles

D = diffusivity

ε = eddy diffusivity

$\frac{dC}{dy}$ = particle concentration gradient

By using the correlation of Lin *et al.* (30) for eddy diffusivity:

$$\varepsilon = \phi(y^+) \tag{6.2}$$

Reynolds analogy:

$$\frac{dC}{dy} = \frac{N}{\tau}\rho\left(\frac{du}{dy}\right) \tag{6.3}$$

and the Lin universal velocity profile, he was able to integrate equation (6.1) to find an expression for particle flux to the tube wall. He expressed his final result in terms of a deposition coefficient,

$$K = \frac{N_w}{C_{avg}} = \frac{Kpv}{K + pv} \tag{6.4}$$

where $K = U_b \cdot \psi(f,\ Sc,\ S^+,\ h^+)$

N_w = flux of particles to the wall

C_{avg} = average particle concentration

f = Fanning friction factor

Sc = Schmidt number

S^+ = dimensionless Stokes stopping distance

h^+ = dimensionless pipe spacing = $hU_b\sqrt{f/2}/\nu$

p = sticking probability

v = radial velocity of a particle

Beal then evaluated v by assuming that the particle velocity is the sum of two components, one due to Brownian motion and one due to fluid motion. These were computed based upon the work of Jeans (31) and Laufer (32), respectively. The Schmidt number, Sc, was based upon the Brownian diffusion coefficient, D.

A computer program was written incorporating Beal's equation for the deposition coefficient, including his simplifying assumption that p = 1 (see Appendix II). An attempt was made to regenerate his Figure 3, to insure that the computer program contained no errors. For a bulk velocity of 100 cm/sec, the computed curve fitted Beal's curve for 30 cm/sec. However, Beal does not state the density of his particles or the pipe diameter, both of which bear upon the results. Consequently, the fit obtained was not considered unreasonable, and the program was assumed to be correct.

Table XXIII shows the computed data for ferric oxide particles in water for conditions approximating those used in Runs 19-23. Comments are as follows:

(1) In the range of 0.1-4 microns, the deposition coefficient as computed from Beal's equation lies between 0.16×10^{-3} and 1.0×10^{-3} cm/sec. Hence in the range of interest, the deposition rate as calculated by Beal's method is not overly sensitive to particle size changes since a 40-fold change in particle size results in only a 6-fold change in deposition coefficient. Consequently, the particle size-particle transport dependence,

Table XXIII

Deposition Coefficients for Ferric Oxide as a Function of Particle Size as Computed From Beal's Equation. Tube Reynolds Number 25,360, Bulk Velocity 3.28 ft/sec, Fluid temp 212°F

Particle Size (microns)	Schmidt No.	Stokes Stopping Distance (microns)	Brownian Diffusion Coefficient cm^2/sec	Deposition Coefficient cm/sec
0.001	151	0.0005	0.19×10^{-4}	0.11×10^{-1}
0.01	1512	0.005	0.19×10^{-5}	0.23×10^{-2}
0.10	15,120	0.050	0.19×10^{-6}	0.48×10^{-3}
1.0	151,200	0.55	0.19×10^{-7}	0.16×10^{-3}
2.0	302,300	1.20	0.97×10^{-8}	0.24×10^{-3}
3.0	453,500	1.96	0.64×10^{-8}	0.53×10^{-3}
4.0	604,700	2.82	0.48×10^{-8}	0.10×10^{-2}
5.0	755,900	3.77	0.38×10^{-8}	0.18×10^{-2}
6.0	907,000	4.83	0.32×10^{-8}	0.30×10^{-2}
7.0	1,058,000	6.00	0.27×10^{-8}	0.47×10^{-2}
8.0	1,209,000	7.26	0.24×10^{-8}	0.70×10^{-2}
9.0	1,361,000	8.63	0.21×10^{-8}	0.99×10^{-2}
10.0	1,512,000	10.09	0.19×10^{-8}	0.13×10^{-1}
100.0	15,120,000	559.3	0.19×10^{-9}	0.99×10^{-0}

as postulated by Beal, does not explain why at high heat flux the mixed size ferric oxide resulted in a deposit, albeit spotty, while the 0.3-0.8μ and 0.3-3.7μ particles gave no deposit whatsoever.

(2) Beal's approach, which does not contain heat flux as a parameter, sheds no light on why high heat fluxes gave minimal or no deposits, while a spotty deposit could always be found at zero heat flux. In the experiments run here, the higher the heat flux the higher is the average bulk fluid temperature. Raising the heat flux should therefore reduce viscosity and raise the Stokes stopping distance. Also, higher temperatures would raise the Brownian diffusion coefficient. Consequently, the deposition coefficient should be higher at higher temperatures, which is in direct conflict with the experimental results. It is therefore concluded that the ferric oxide deposition process studied here is not controlled by the transport mechanism proposed by Beal.

An alternate possible explanation as to why high heat fluxes result in minimal or no fouling for the presized particles follows from the work of McNab (33). McNab was able to demonstrate experimentally that thermophoresis can exist in liquids, and that micron-size particles, when exposed to a thermal gradient migrate away from the hot surface at a velocity given by

$$V_{th} = -0.26 \frac{k_f}{2k_f + k_p} \cdot \frac{u}{\rho T_k} \nabla T \qquad (6.5)$$

where V_{th} = thermophoretic velocity

k_f = fluid thermal conductivity

k_p = particle thermal conductivity

u = fluid viscosity

ρ = fluid density

T_k = absolute temperature

∇T = temperature gradient

An order of magnitude calculation based on equation (6. 5) shows that for a heat flux of 91,400 and a Reynolds number of 26,490, a particle in the vicinity of the tube wall would migrate away from the wall a distance of 3.7 microns in one second (see Appendix III). A one-micron ferric oxide particle in water at 70°F would migrate an average distance of 0.7 microns due to Brownian motion and approximately 1.5 microns due to gravitational settling during the same time period. See Perry (35). Consequently, thermophoresis could well be a significant factor in the fouling process studied here, retarding fouling when the tube is hotter than the fluid and enhancing fouling for the reverse situation.

The work done here with respect to particle size and fouling was beset with many difficulties not foreseen when the investigation was originally planned. Firstly, great difficulty was encountered in determining the size of particles used in the study. Sizing with millipore filters indicated the mean particle size of the mixed size ferric oxide to lie in the range of 10-100μ. The micro-probe photographs at a magnification of 500 indicated a particle size of about 5 microns, while the scanning electron microscope showed the particles to consist of agglomerates with a basic particle size of about 0.2 microns and an agglomerate size of approximately 3 microns. Consequently, no precise estimate of particle size was obtained for the mixed-size particles. Secondly, even if a precise estimate of particle size could be made, it would not be correct to assign this size to the depositing particle because of the tendency of ferric oxide to agglomerate. As pointed out by Adamson (34), colloidal ferric oxide particles sense the presence of each other at great distances and tend to settle out in platelets. Also, the high dipole moment of ferric oxide would tend to result in an agglomerate which would be relatively stable. To estimate the size of such an agglomerate would be a difficult task.

For reasons outlined above, the work done in this investigation with respect to the influence of particle size on fouling is quite inconclusive. Mixed-size particles gave spotty deposits at high heat fluxes, whereas presized particles of 0.3-0.8μ and 0.3-3.7μ did not. No adequate explanation could be offered for these results.

6.29. Influence of local wall temperature on fouling behaviour.

When heat transfer is effected at constant heat flux, the condition used for all runs in this investigation, the wall temperature increases in the direction of fluid flow. Consequently, by plotting the local fouling resistance at selected points along the tube wall against local wall temperature it is possible to determine the influence of local wall temperature on fouling behaviour. Results for two distinctly different operating conditions are shown in Tables XXIV and XXV, and plotted in Figure 25.

The interesting aspect of these data is that for the lower Reynolds number, lower heat flux condition, where

Table XXIV

Local Fouling Resistances After One Hour as a Function of Tube Wall Position (and Hence Wall Temperature). Heat Flux 90,000 BTU/ft^2-hr, Re 26500. Mixed-Size Ferric Oxide Conc. 2130 ppm

	Local Fouling Resistances (ft^2-hr-°F/BTU) x 10^5				
Run No. / Position	49	50	63	$R_f$avg	Local Wall Temperature at t = 0 °F
T235	2.6	3.9	2.2	2.9	174
T255	2.2	3.1	2.2	2.5	174
T275	0.4	3.1	1.7	1.7	182
T295	0.4	2.6	1.3	1.4	182
T315	1.7	3.1	2.1	2.3	183
T335	2.6	3.1	2.2	2.6	178
T355	2.6	3.1	2.6	2.7	178
T375	-	-	-	-	-
T395	2.2	2.2	1.7	2.0	186
T415	1.7	2.2	1.3	1.7	192

Table XXV

Local Fouling Resistances After One Hour as a Function of Tube Wall Position (and Hence Wall Temperature). Heat Flux 44,360 BTU/ft^2-hr, Re 19,550, Mixed-Size Ferric Oxide Conc. 2130 ppm

	Local Fouling Resistances (ft^2-hr-°F/BTU) x 10^5				
Run No. Position	36	38	59	$R_f$avg	Local Wall Temperature at t = 0 °F
T235	4.5	4.5	5.4	4.8	154
T255	3.6	3.6	4.5	3.9	154
T275	2.7	3.6	3.6	3.3	159
T295	1.8	2.7	2.7	2.4	159
T315	0.9	2.7	0.9	1.5	160
T335	0.9	1.8	0	0.9	157
T355	1.8	1.8	2.7	2.1	156
T375	-	-	-	-	-
T395	0	1.8	2.7	1.5	162
T415	0	1.8	0	0.6	167

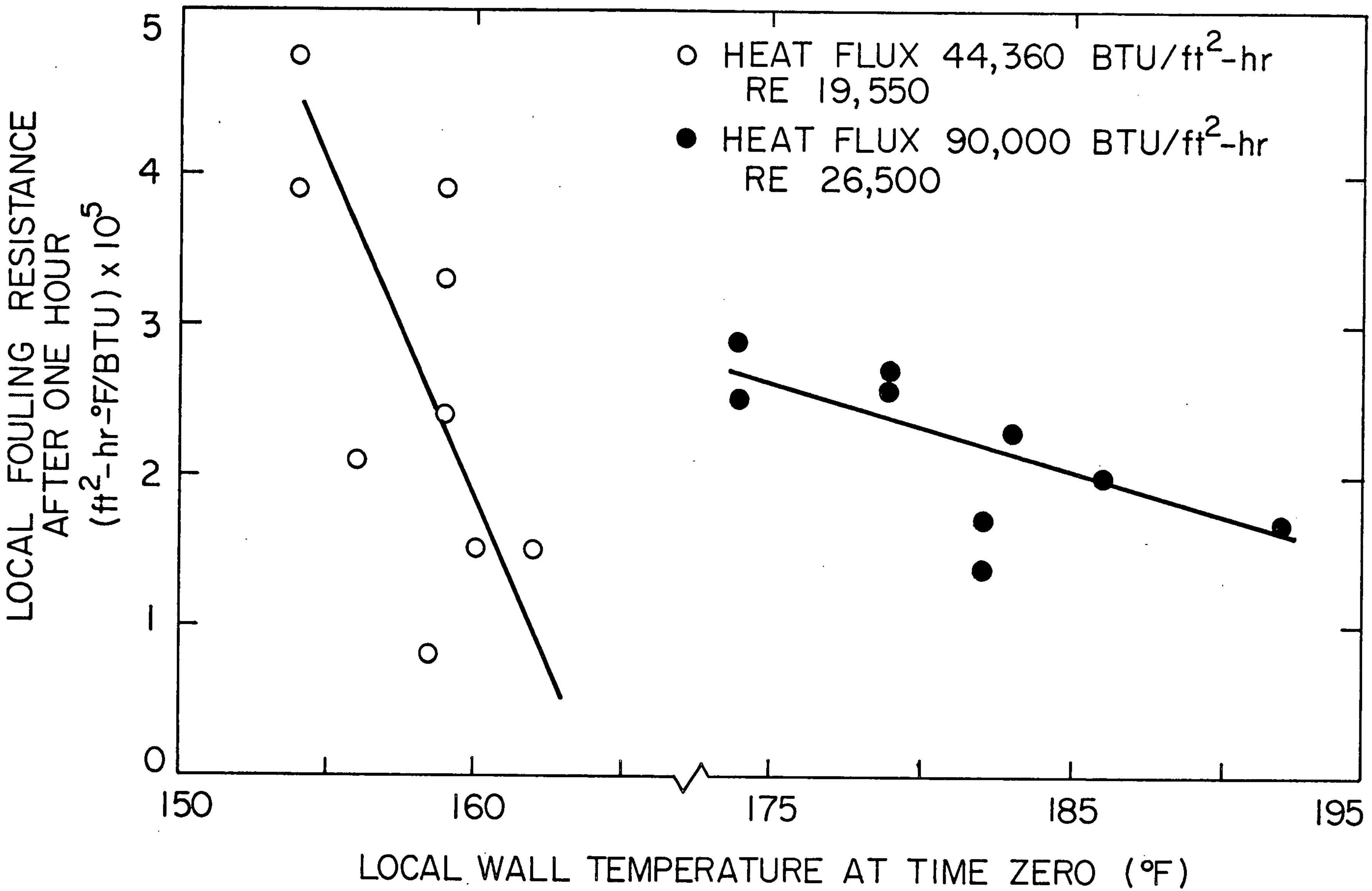


Figure 25. Local Fouling Resistance After One Hour Versus Local Wall Temperature at Time Zero. Mixed-Size Ferric Oxide Conc. 2130 ppm.

local wall temperatures ranged between 154 and 167°F, there is a sharp decrease in fouling resistance as a function of local wall temperature. For the higher heat flux, higher Reynolds number situation, where local wall temperatures ranged from 174 to 192°F, this effect is not as pronounced.

The reason for the inverse dependence of fouling rate on wall temperature is believed to be associated with the reduction in the solubility of oxygen at the tube wall as the temperature rises. This would tend to reduce the corrosion rate and thereby reduce the fouling rate. Since the <u>rate</u> of decrease of oxygen solubility with temperature between 174-192°F is only about one-third the <u>rate</u> of decrease in oxygen solubility between 154-167°F [see Perry (35)], this would explain the difference in slope between the two conditions. These results further strengthen the belief that the fouling of 304 stainless steel with ferric oxide is controlled by the rate at which oxygen can be supplied to the tube wall.

6.3 Pressure Drop vs. Time Fouling Behaviour

During early runs, an attempt was made to use the pressure drop across the test section as an index of fouling. Usually, this resulted in failure since for most runs in which thermal fouling occurred, no significant pressure drop change could be noted. However, for the linear fouling situation encountered in Run 64, large and significant pressure drop changes occurred. Results are plotted in Figure 26, with results from Run 63 included for comparative purposes.

The following comments apply to Figure 26. For Run 63, in which typical asymptotic type fouling was displayed, the change in pressure drop is of the same order of magnitude as the manufacturer's stated error of the pressure transducer. Consequently, the slight upward trend may or may not be significant. For Run 64, in which the tube fouled thermally at a linear rate, the pressure drop change is large but is not linear with time. It is important to note that during the 24 hour period between Runs 63 and 64, when fluid was circulated at zero heat flux, no pressure drop change occurred. Since thermal fouling, by the procedure used in this study, is calculated from heat flux and wall temperature readings, there is no record of fouling behaviour during the 24 hour circulating period at zero heat flux. The fact that the pressure drop did not change until after the heat flux was turned on is evidence that linear thermal fouling is associated with the heating of the tube, and that the thermal results obtained

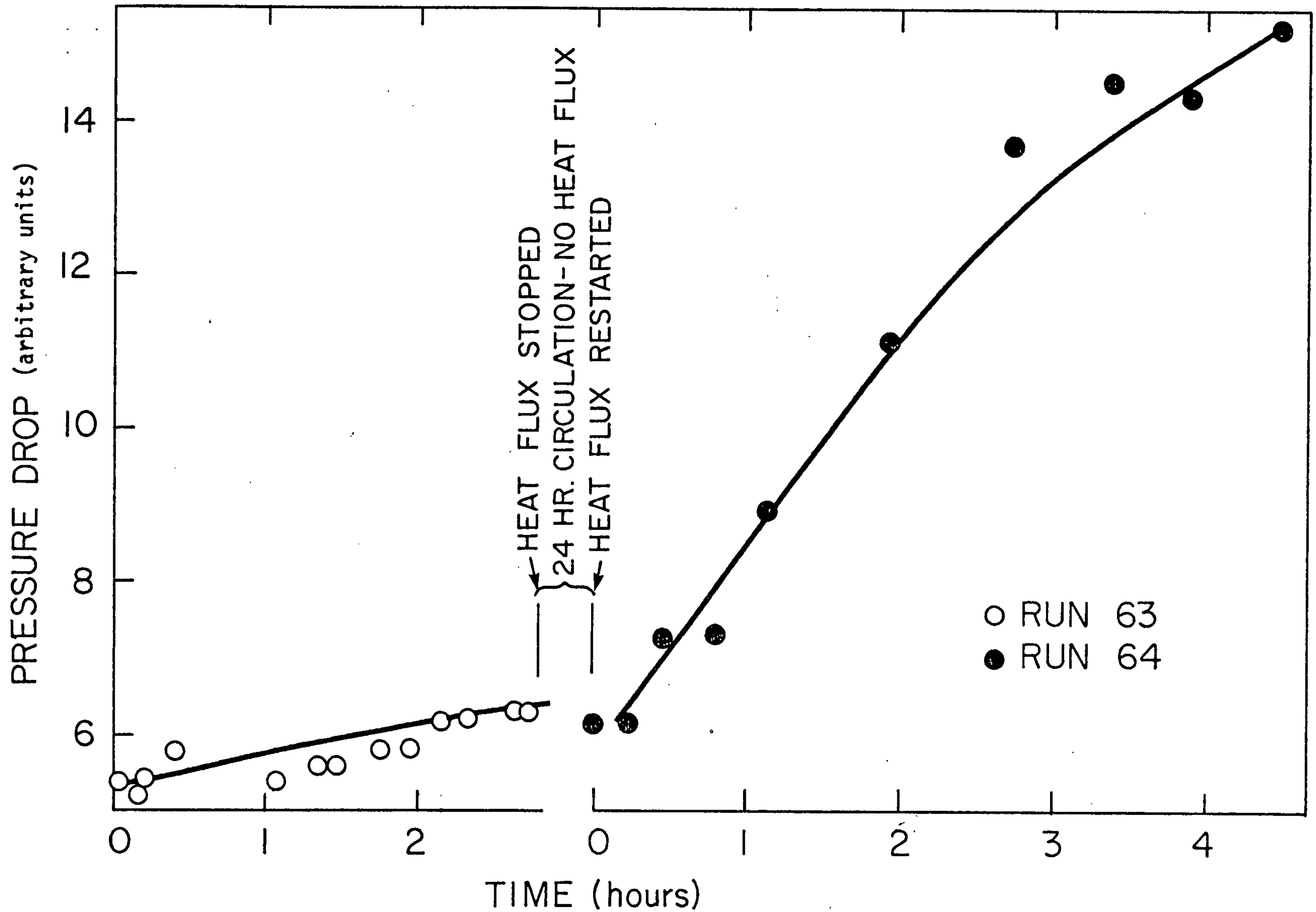


Figure 26. Pressure Drop Increase as a Function of Time for an Asymptotic Type Fouling Run (Run 63) and a Linear Fouling Run (Run 64). Heat Flux 89,860 BTU/ft^2-hr, Re 20,850, Mixed-Size Ferric Oxide Conc. 2130 ppm.

are not a transient response to a possible fouling build-up during the 24 hour period at zero heat flux. In fact, the non-change in the pressure drop readings taken immediately before and immediately after the 24 hour period indicates that any additional fouling which may have occurred during this period of zero heat flux was small compared with the subsequent linear fouling.

6.4 Fouling Deposit Examination Results

6.4.1 Type of information obtained.

Fouling deposits from selected trial runs were examined 'in situ,' as well as on polyester cores pressed from fouled tubes, using

(1) a Zeiss light microscope,

(2) a scanning electron microscope, and

(3) an electron microprobe.

Procedures covering the preparation and examination of samples have already been given in Section 3. From the light microscope, the physical nature of the deposit could readily be observed. However, because of the granular nature of the deposits, problems with depth of field were encountered and no attempt was made to obtain photographs.

For a permanent record, photomicrographs of deposits were obtained with the scanning electron microscope. While this instrument gives no problem with depth of field, the photomicrographs are 'black and white.' Since the deposits themselves could be highly coloured, these photomicrographs are not entirely satisfactory.

The electron microprobe gave three separate sources of information. These were:

(1) An electron photomicrograph showing the physical appearance of the deposit. This is referred to as the absorbed electron image (AEI).

(2) An electron photomicrograph showing the topography of the deposit. This is referred to as the back-scattered electron image (BEI).

(3) X-ray intensity photomicrographs which show, in a qualitative way, the concentration of an element at any point in the deposit. In addition, through measurement of X-ray intensities, a quantitative analysis of the deposit was obtained.

6.4.2 Results of light and electron microscopic examination of deposits.

When ferric oxide from an aqueous suspension fouls a 304 stainless steel tube, light and electron microscopic examination of the deposits, when viewed in cross-section, yielded the following results:

(1) For fouling runs in which no thermal fouling was detected, deposits invariably were spotty, that is, they did not cover the entire circumference or the entire length of the tube. They could, however, be quite thick at localized points, with measured thicknesses of up to 70 microns. In all cases, these deposits were black in colour, in marked contrast to the ferric oxide (hematite) feed material, which showed as a brilliant red.

(2) For fouling runs which yielded asymptotic type fouling curves, deposits were more uniformly distributed around the circumference and length of the tube. Thicknesses were in the range of 100 microns. These deposits consisted of a black layer adjacent to the tube wall followed by a red layer at the fluid-deposit interface.

(3) For fouling runs which gave constant fouling rates, deposits were quite thick, 100 microns and upward, and were predominantly red in appearance.

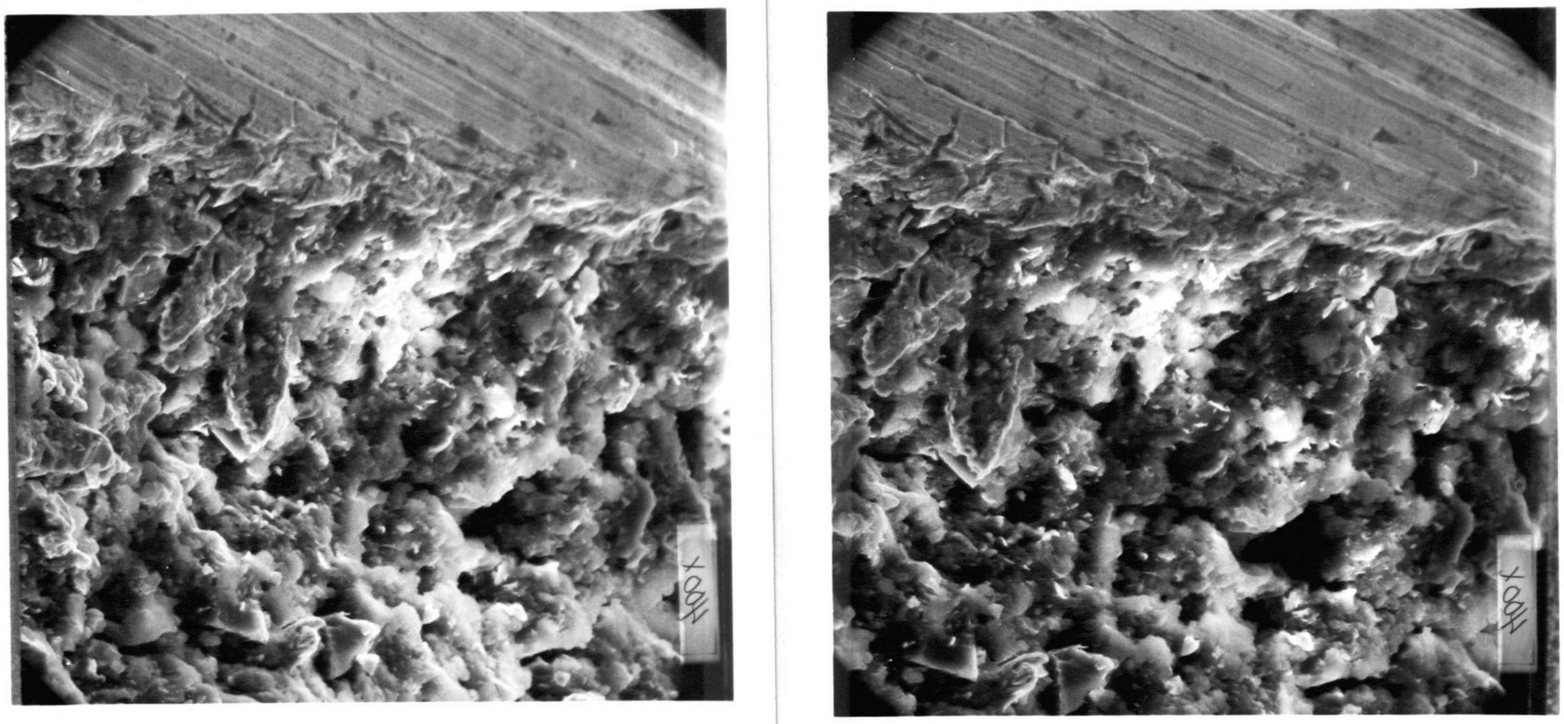
Although the colour of the deposits varied according to the type of fouling curve obtained, the physical nature of the deposit did not vary. Deposits tended to be granular in appearance, as shown in Figure 27.

The pressed core samples, when viewed in both the light microscope and the electron microprobe, give a much different appearance in comparison to the cross-sectional samples. Figure 28 shows a typical photomicrograph. These samples are characterized by black 'islands' in a red matrix. Cores from runs which yielded no thermal fouling, asymptotic type fouling and linear fouling all had the same general appearance, except that the red matrix in the linear fouling case was thicker and therefore more intense.

6.4.3 Electron microprobe results.

6.4.3.1 Qualitative nature of fouling deposits.

Following selected experimental runs, the fouled tube was removed from the heat transfer loop, sectioned according to the procedures given earlier and examined in the J.E.O.L. electron microprobe. This resulted in the following information concerning the deposits:



400X

Figure 27. Scanning Electron Photomicrograph Showing the Nature of the Deposit Resulting from the Fouling of Aqueous Ferric Oxide Suspensions on 304 Stainless Steel. (The above photomicrographs are a stereo pair.)

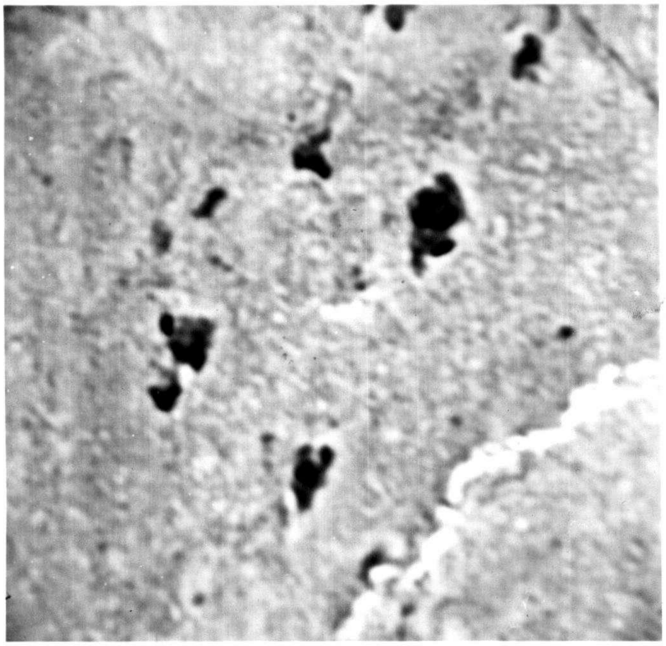


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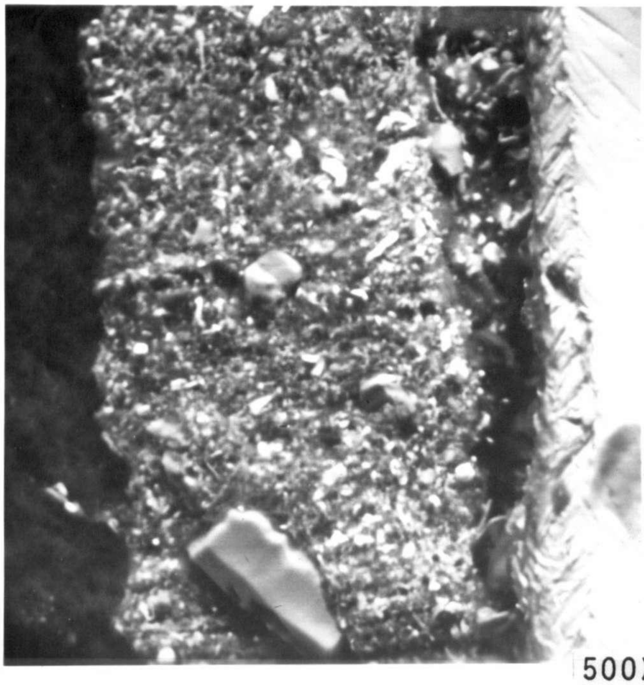
Figure 28. Image of a Core Sample Obtained with the Electron Microprobe. (Dark areas are black under light microscopy, grey areas are red.)



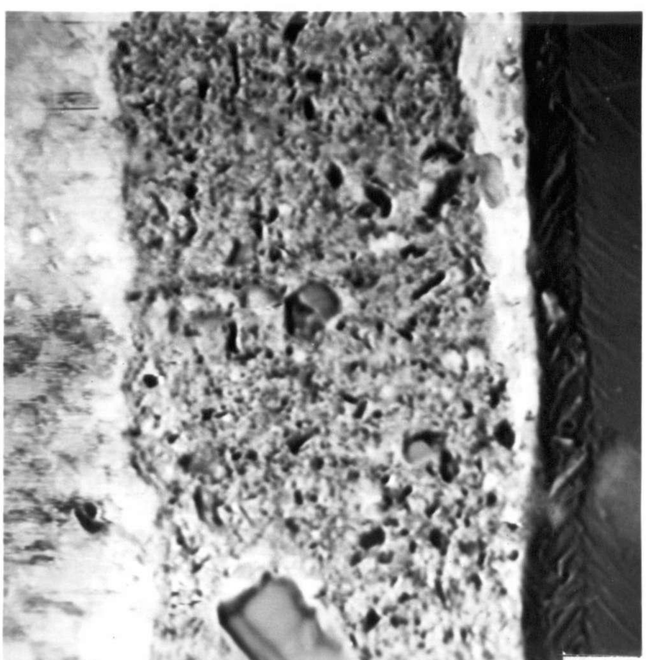


Figure 29. Electron Microprobe Photomicrographs of a Typical Deposit Showing the Back Scattered Electron Image or Topography (Above) and the Absorbed Electron Image or Physical Composition (Below).

(1) Photographs showing the "in situ" appearance of the deposit. See Figure 29. These photographs, which are essentially electron photomicrographs, are in the case of the upper photograph in Figure 29, the topography of the deposit and in the case of the lower photograph, the physical appearance of the deposit. The essential features to note here are that the fouling deposit is rough and granular in nature and that there is a separation between the tube wall and the deposit. This separation, which was present in virtually all samples examined, is believed to be due to the difference in the thermal expansion characteristics of stainless steel and those of the deposit.

(2) X-ray intensity photomicrographs showing the concentration of a particular element at any position in the sample relative to its concentration at any other position. Figures 30-32 show typical X-ray intensity photomicrographs for iron, nickel, chromium and oxygen. These photomicrographs cover the same area as the electron photomicrographs of Figure 29. Not surprisingly, the X-ray photomicrographs show the deposit to contain the constituents of ferric oxide, iron and oxygen. However, the deposits were also found, in all cases, to contain nickel and chromium, as typified by Figure 30 (lower

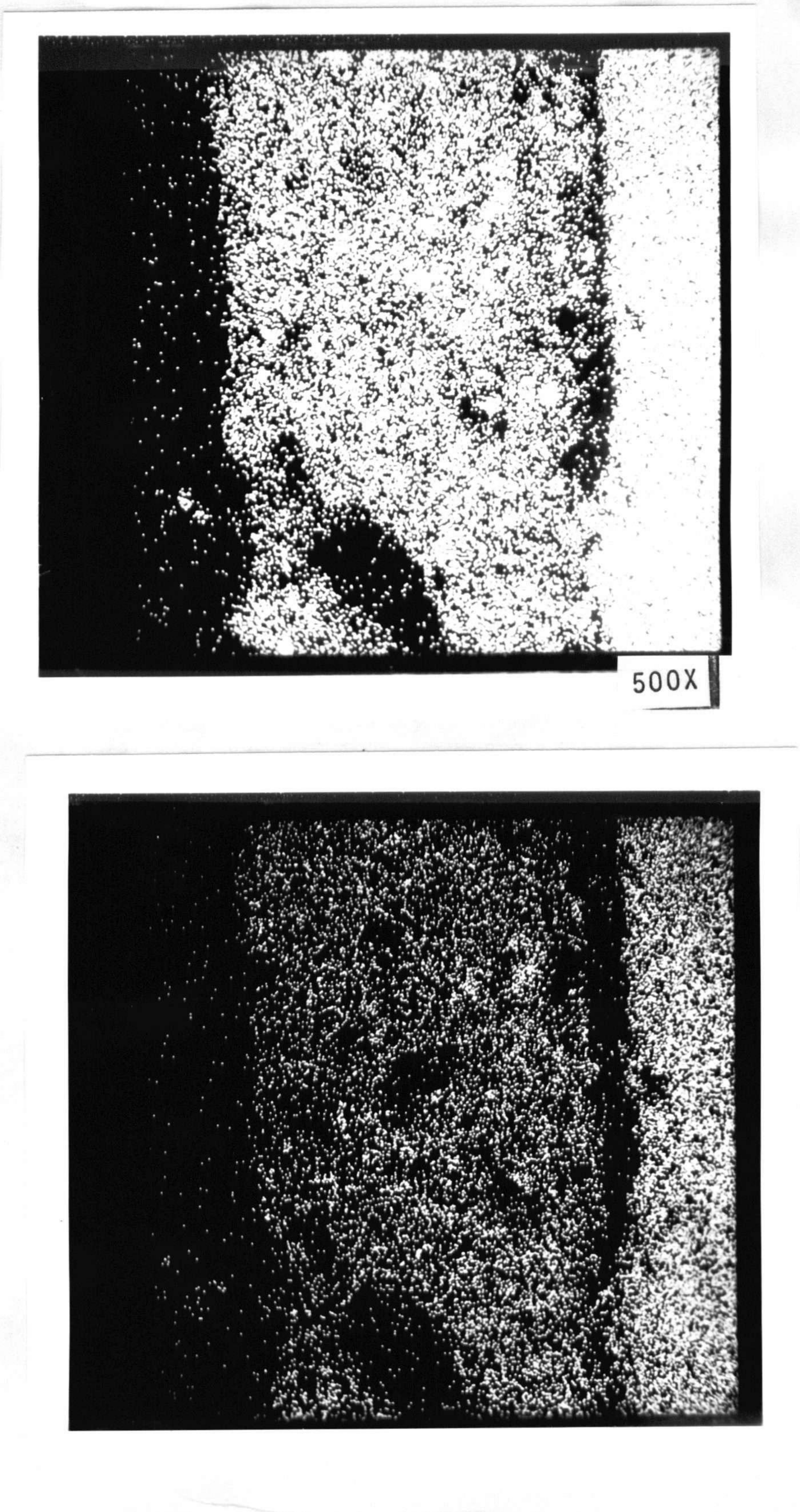


Figure 30. Electron Microprobe X-Ray Intensity Photomicrographs of a Typical Deposit Showing the Distribution of Iron (Above) and Nickel (Below).

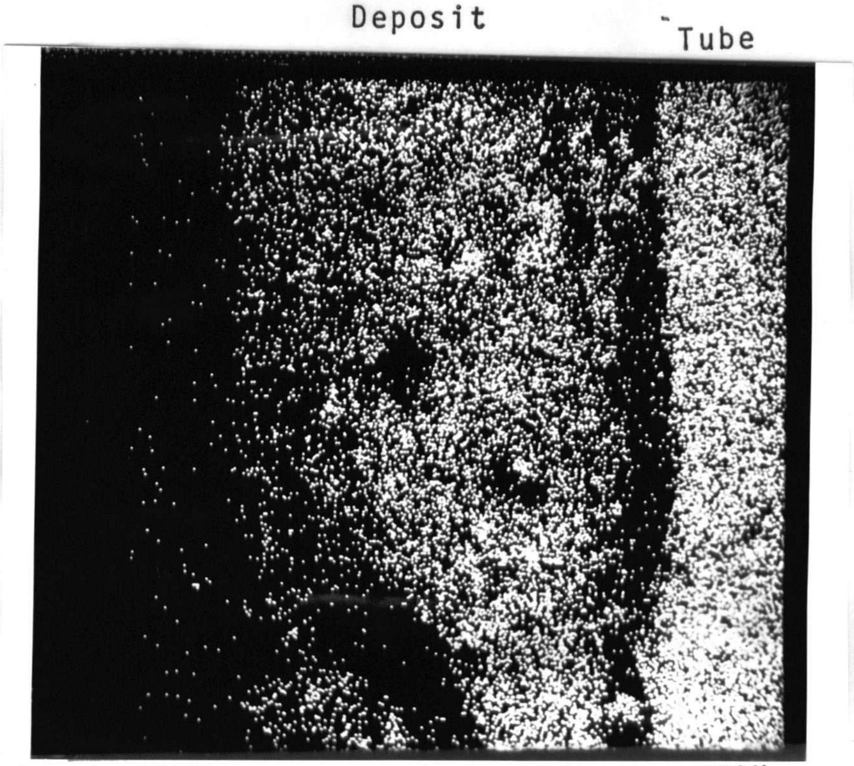
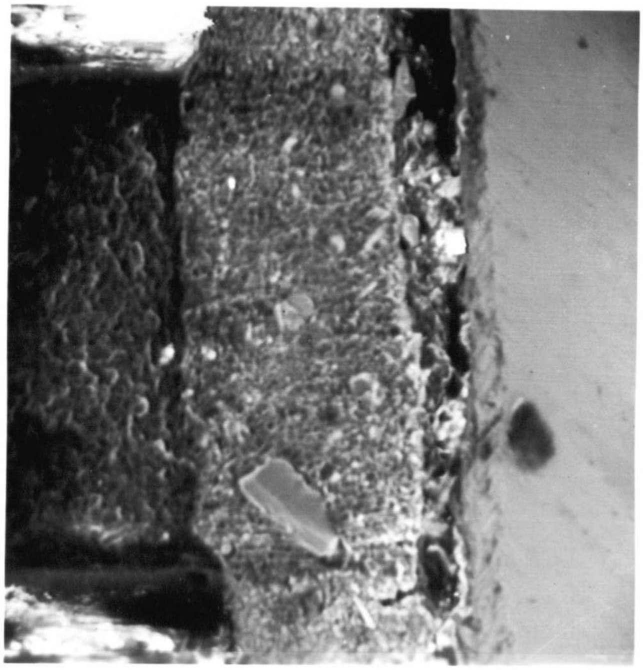


Figure 31. Electron Microprobe X-Ray Intensity Photomicrograph of a Typical Deposit Showing the Distribution of Chromium.



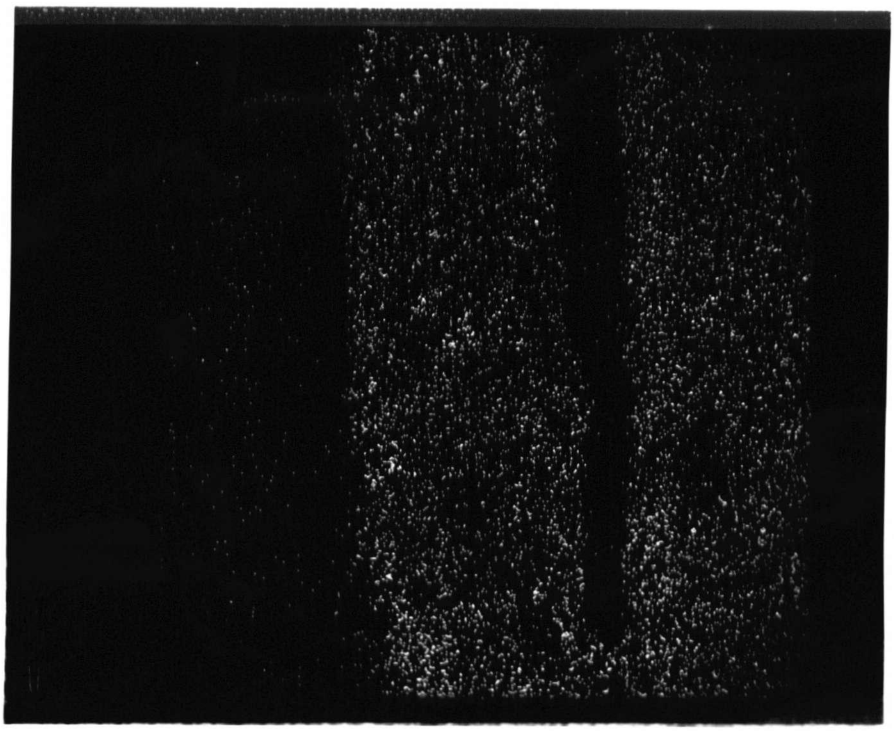


Figure 32. Electron Microprobe Photomicrographs Showing for a Typical Deposit the Absorbed Electron Image (Above) and the Corresponding X-Ray Intensity Photomicrograph Depicting Oxygen Concentration (Below).

photograph) and Figure 31. In examining these photomicrographs, it should be noted that chromium concentration is greatest near the tube wall, and least at the edge of the deposit. The latter corresponds to the surface in contact with the circulating fluid. Nickel shows a similar pattern to chromium, but the concentration differences are not as pronounced. Iron and oxygen do not show such concentration gradients.

For comparative purposes, a photomicrograph of an unfouled tube is included (Figure 33). This was done as a precaution to insure that the nickel and chromium found in the deposit was not the result of the specimen preparation procedure, which involved grinding the tube, deposit and polyester resin simultaneously. The absence of tube material in the polyester matrix (Figure 33, lower photograph, shows only background intensity in the matrix) is an indication that the specimen preparation procedure did not invalidate the results.

6.4.3.2 Quantitative analysis of fouling deposits - transverse sections.

By measuring X-ray intensity as a function of position, it is possible to obtain concentration profiles

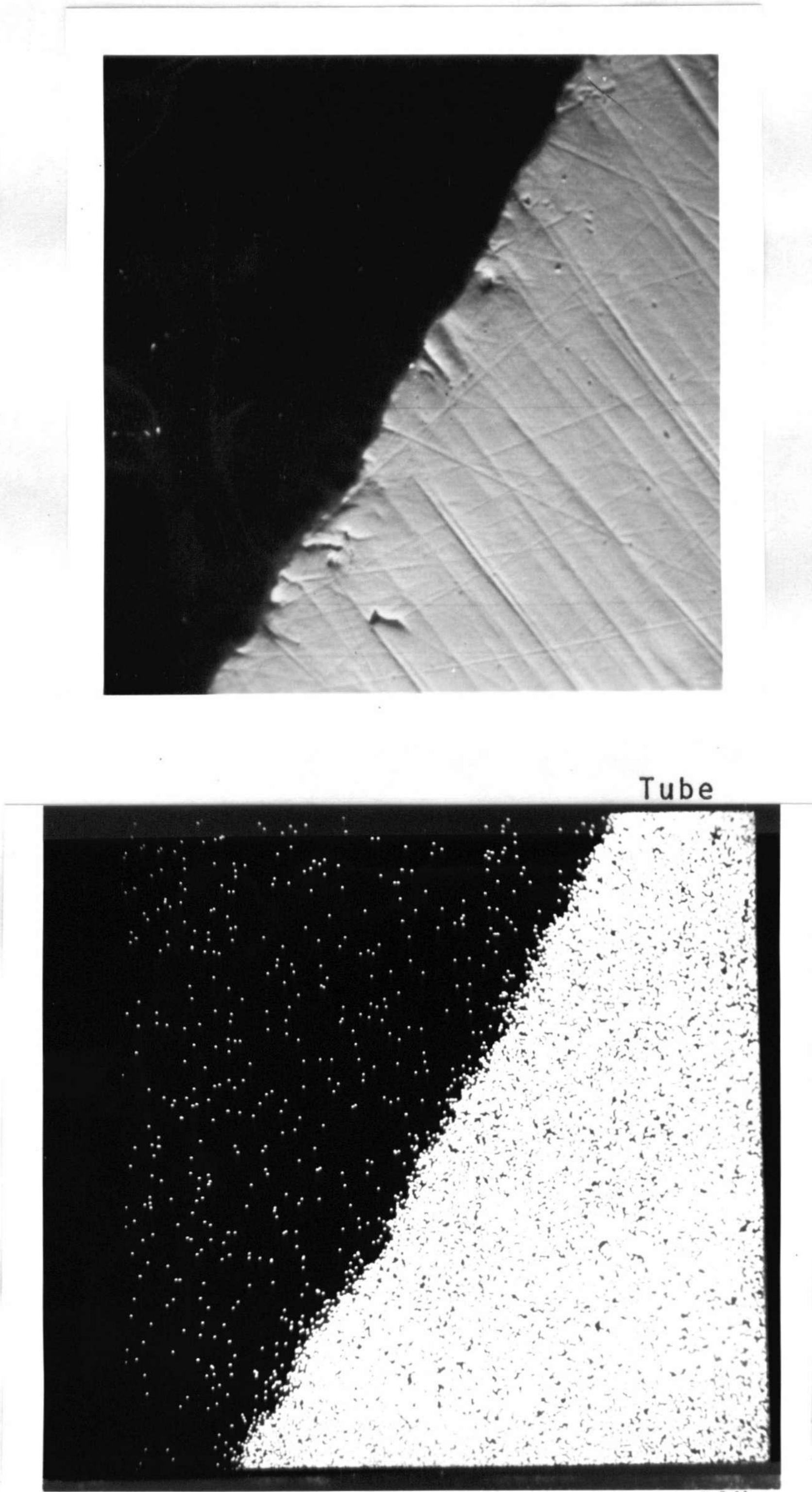


Figure 33. Electron Microprobe Photomicrographs of a Clean Tube Showing the Back-Scattered Electron Image (Above) and the Corresponding X-Ray Intensity Photomicrograph Depicting Iron Concentration (Below).

for the various elements contained in a fouling deposit. Examples of such profiles are contained in Figure 34, which shows the results of scans on a specimen from a trial run in which asymptotic fouling was observed. Profiles similar to these were obtained for the following:

(1) Run 15, in which no thermally detectable fouling resulted.

(2) Run 31, which resulted in asymptotic type fouling.

(3) Run 70, in which linear fouling occurred.

Unfortunately, concentration profiles for iron are not particularly informative since any iron released from the tube wall and precipitated in the deposit is indistinguishable from the iron in the ferric oxide depositing from suspension. This problem does not exist with nickel and chromium. To facilitate comparison, chromium profiles alone have been replotted for each type of run in Figure 35. Figure 35 shows that for spotty deposits (no thermal fouling detectable) chromium concentration at the tube wall is quite high, about 8% by weight, and shows a slight concentration gradient throughout the deposit. The chromium profile for the asymptotic type

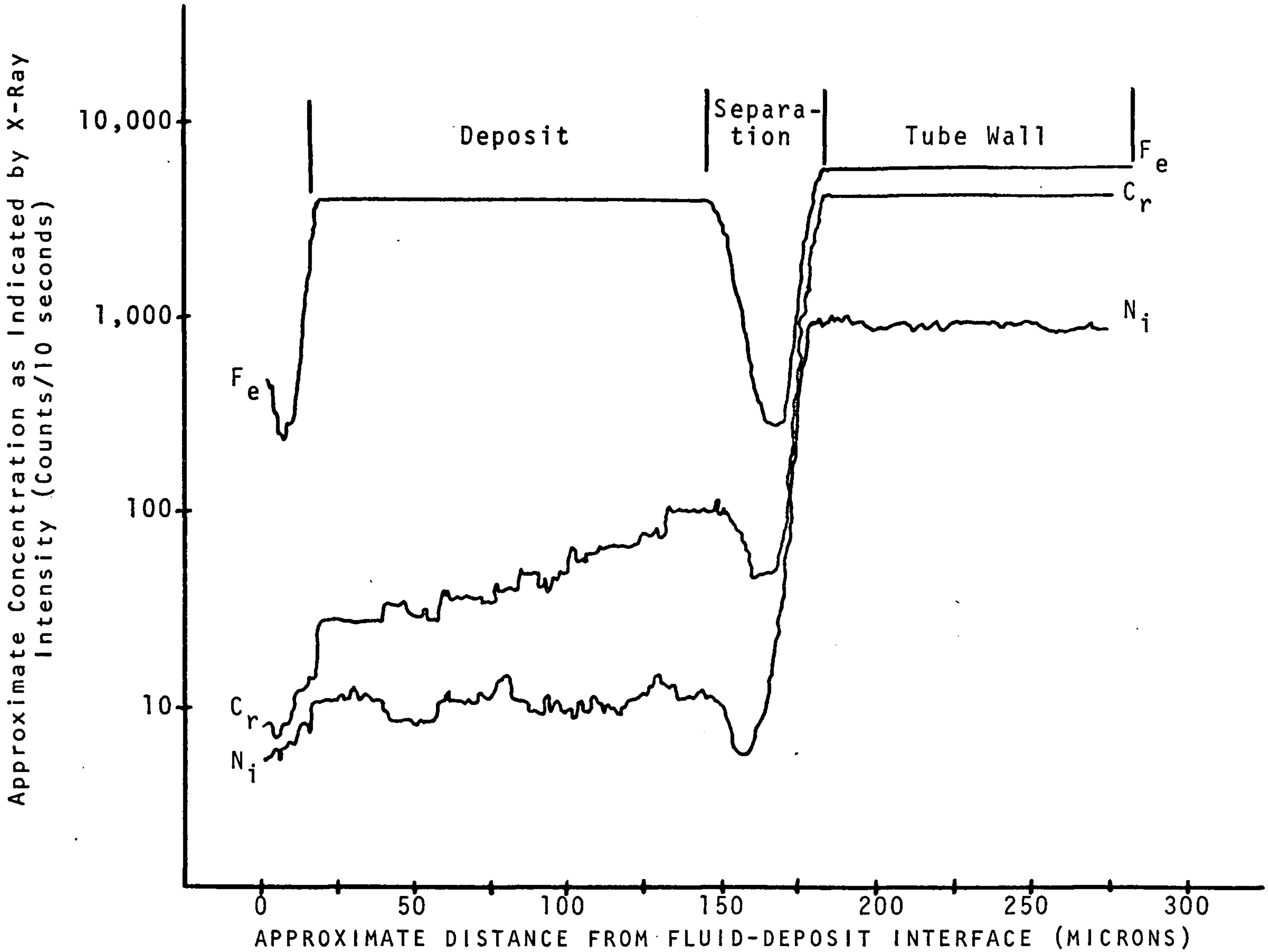


Figure 34. Concentration Profiles for Iron, Nickel and Chromium for Run 70 - A Run Which Showed Linear Fouling.

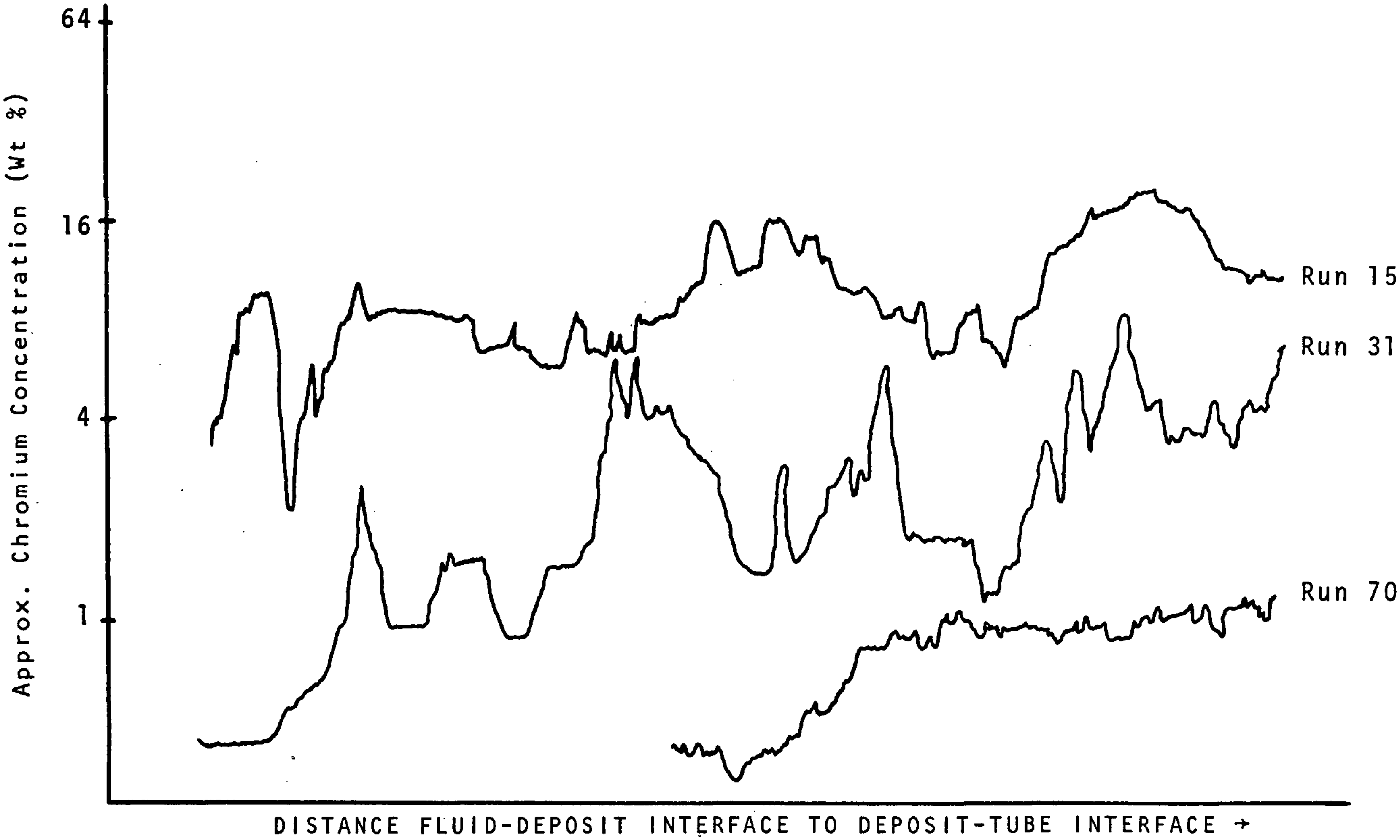
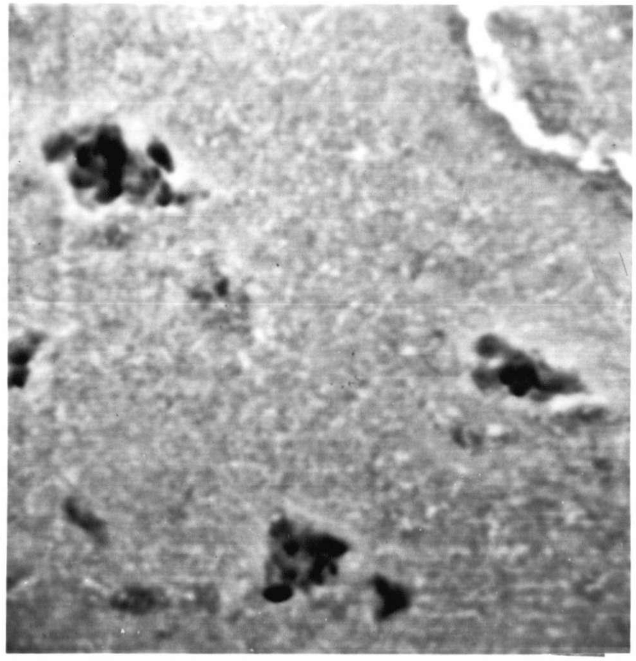


Figure 35. Chromium Concentration Profiles for Deposits from Run 15 - No Thermal Fouling Detected, Run 31 - Asymptotic Fouling, and Run 70 - Linear Type Fouling (Distance Scale is Arbitrary).

fouling deposit is much more pronounced than for the spotty deposit. At the tube wall, the two profiles approach each other. At the deposit-fluid interface, however, the chromium concentration of the asymptotic type deposit approaches zero, while the spotty deposit is in excess of 4%. The linear fouling type of deposit is characterized by relatively low concentrations of chromium, below 1%, and a gradient from the tube wall to the deposit-fluid interface which is not particularly pronounced. The nickel concentration profiles were found to behave similarly, but concentration levels were lower than for chromium and gradients were not as distinct.

6.4.3.3 Qualitative and quantitative analysis of deposits - core samples.

For purposes of analyzing the surface of deposits in contact with the tube wall, core samples containing the fouling deposits were examined in the electron microprobe. To illustrate the nature of the deposit when viewed in this manner, sections from Run 70, a linear fouling run, have been selected as an example. Figures 36-39 are a series of photomicrographs showing the physical appearance of the core samples (upper photomicrograph), and the relative concentrations of iron, chromium, nickel and oxygen



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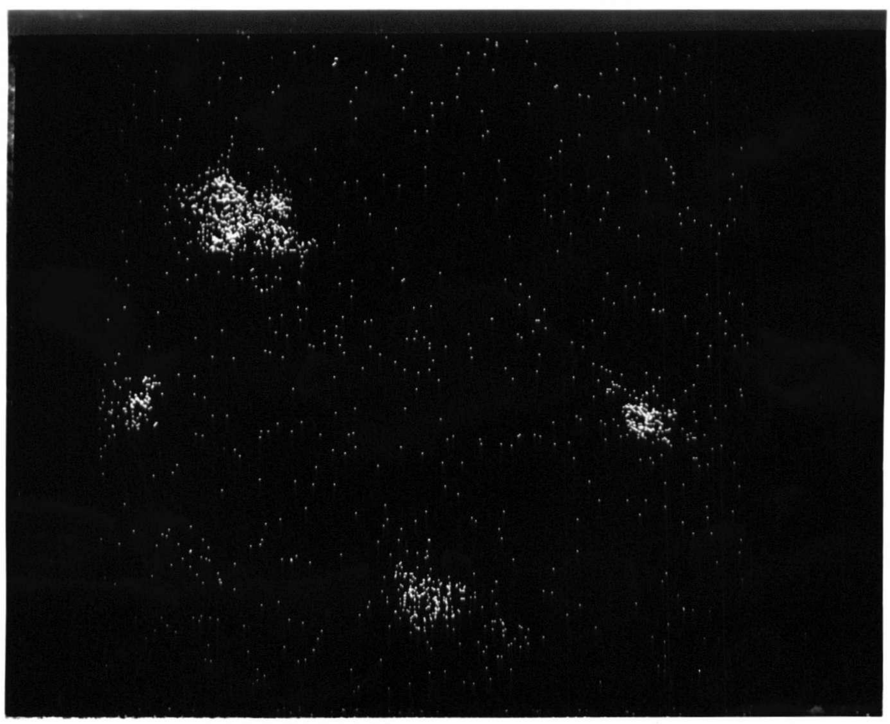


Figure 36. Physical Appearance of Core Sample (Upper Photomicrograph) and Relative Distribution of Chromium (Lower Photomicrograph).

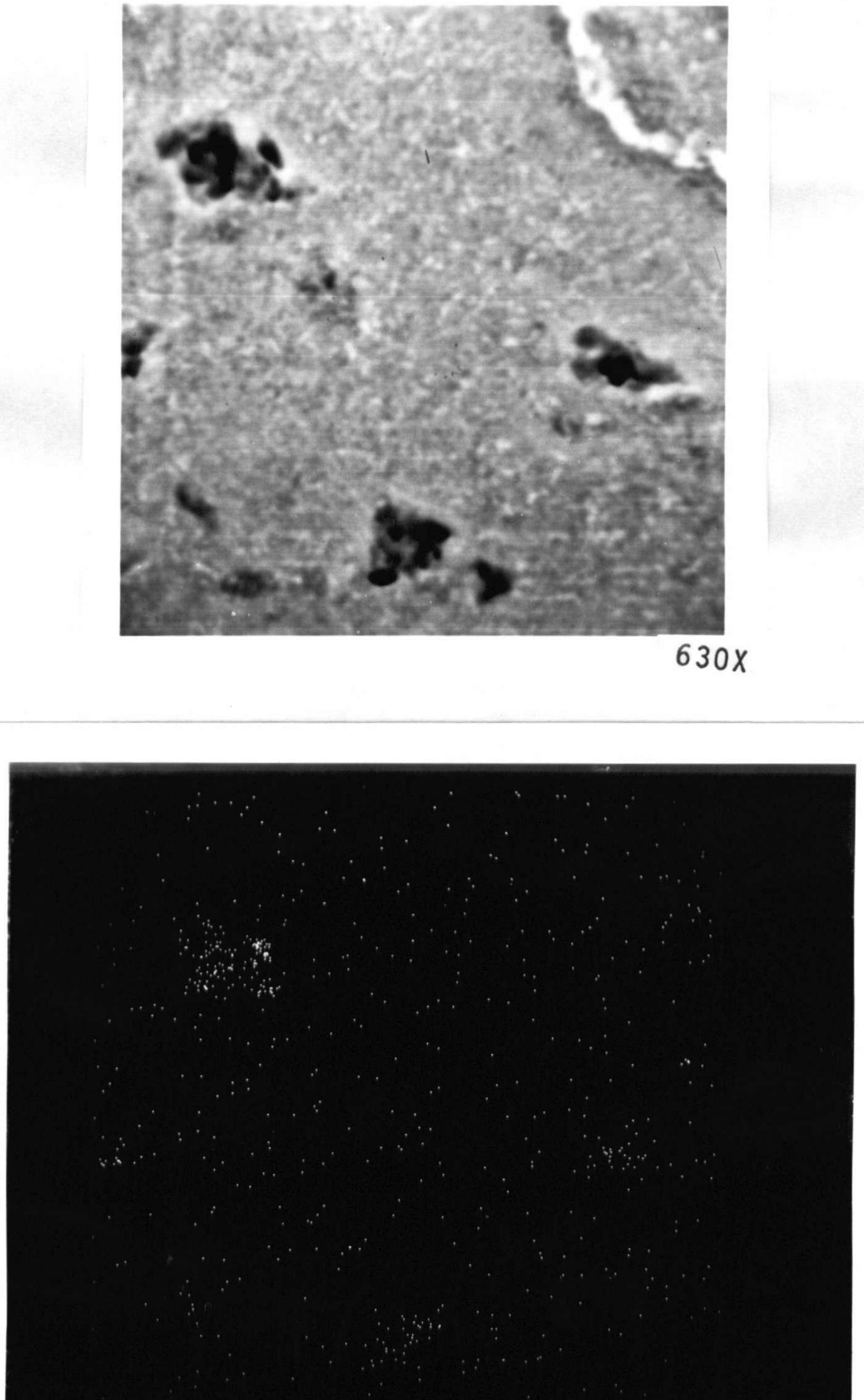
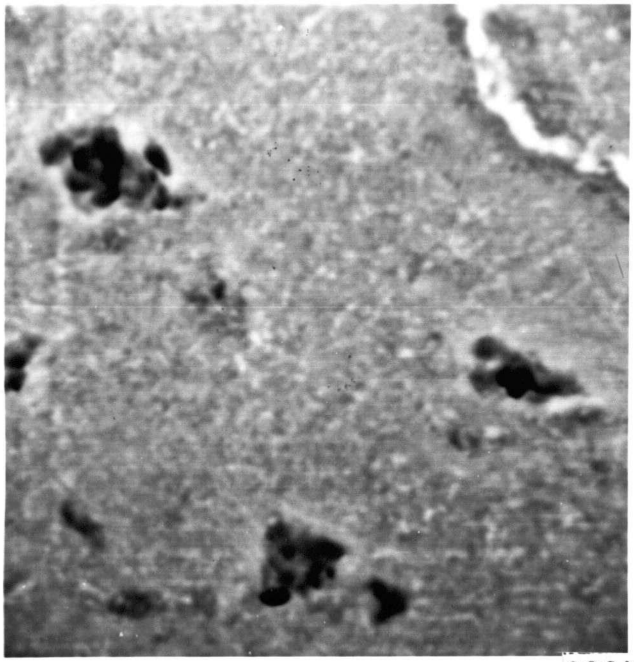


Figure 37. Physical Appearance of Core Sample (Upper Photomicrograph) and Relative Distribution of Nickel (Lower Photomicrograph).



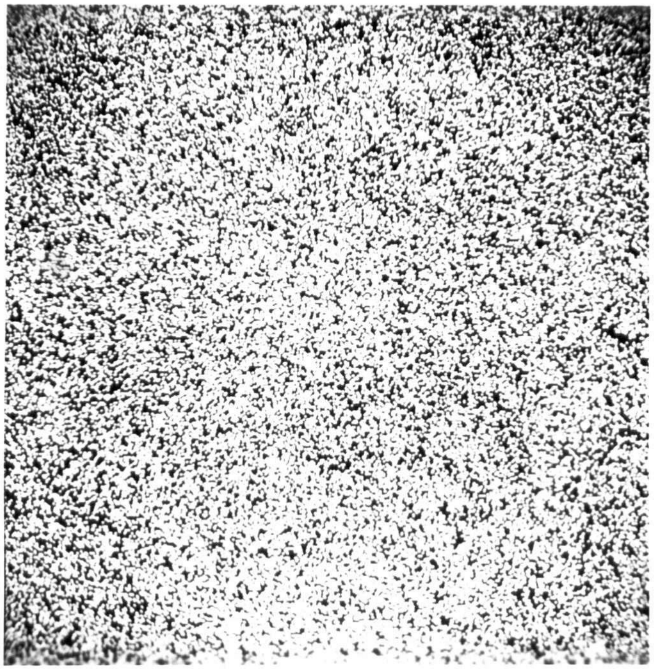
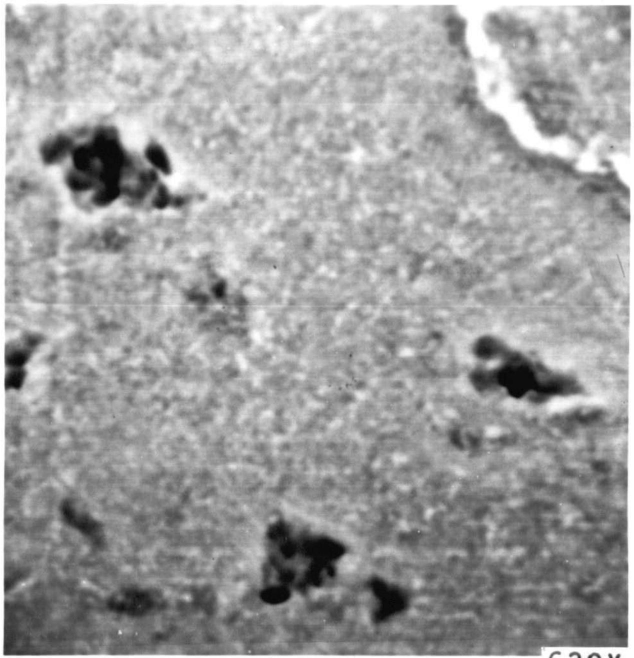


Figure 38. Physical Appearance of Core Sample (Upper Photomicrograph) and Relative Distribution of Iron (Lower Photomicrograph).



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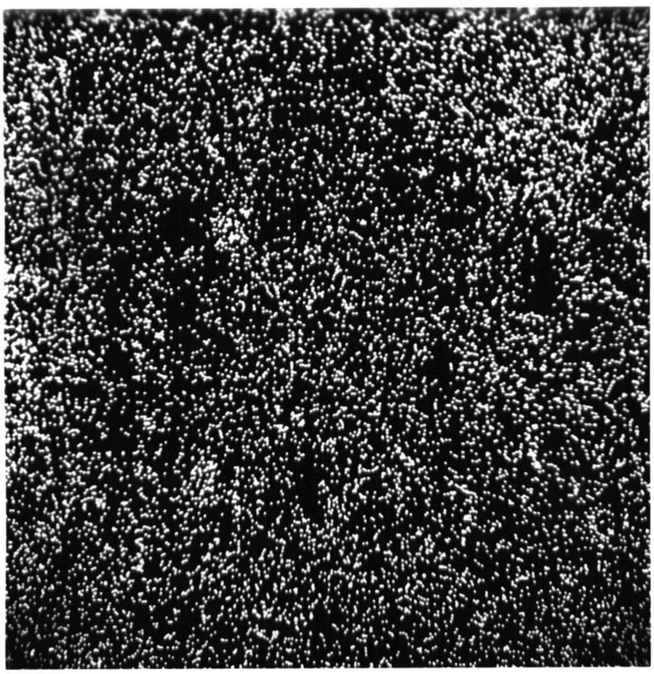


Figure 39. Physical Appearance of Core Sample (Upper Photomicrograph) and Relative Distribution of Oxygen (Lower Photomicrograph).

contained in the deposit (lower photomicrograph). As mentioned in Section 6.4.2., the black areas of Figure 36, when viewed in the light microscope, appear black, and the grey areas have the characteristic red appearance of ferric oxide. From Figure 36-39 it may be seen that the black islands, though primarily iron, are rich in chromium and contain significant, but small, concentrations of nickel. There is some evidence that portions of these black areas are deficient in oxygen. However, oxygen profiles covering these areas, gave conflicting results. Since oxygen, because of its low atomic number, is not determined accurately with the microprobe, the above evidence is considered inconclusive.

In order to place the information contained in Figures 36-39 on a quantitative basis, scans were made across core samples from Run 70. Results, which appear as Figure 40, show the following:

(1) Nickel-rich areas only exist in areas having both a high chromium and a high iron content.

(2) Chromium-rich areas exist only in conjunction with iron-rich areas.

(3) Iron-rich areas can exist without any detectable chromium or nickel present.

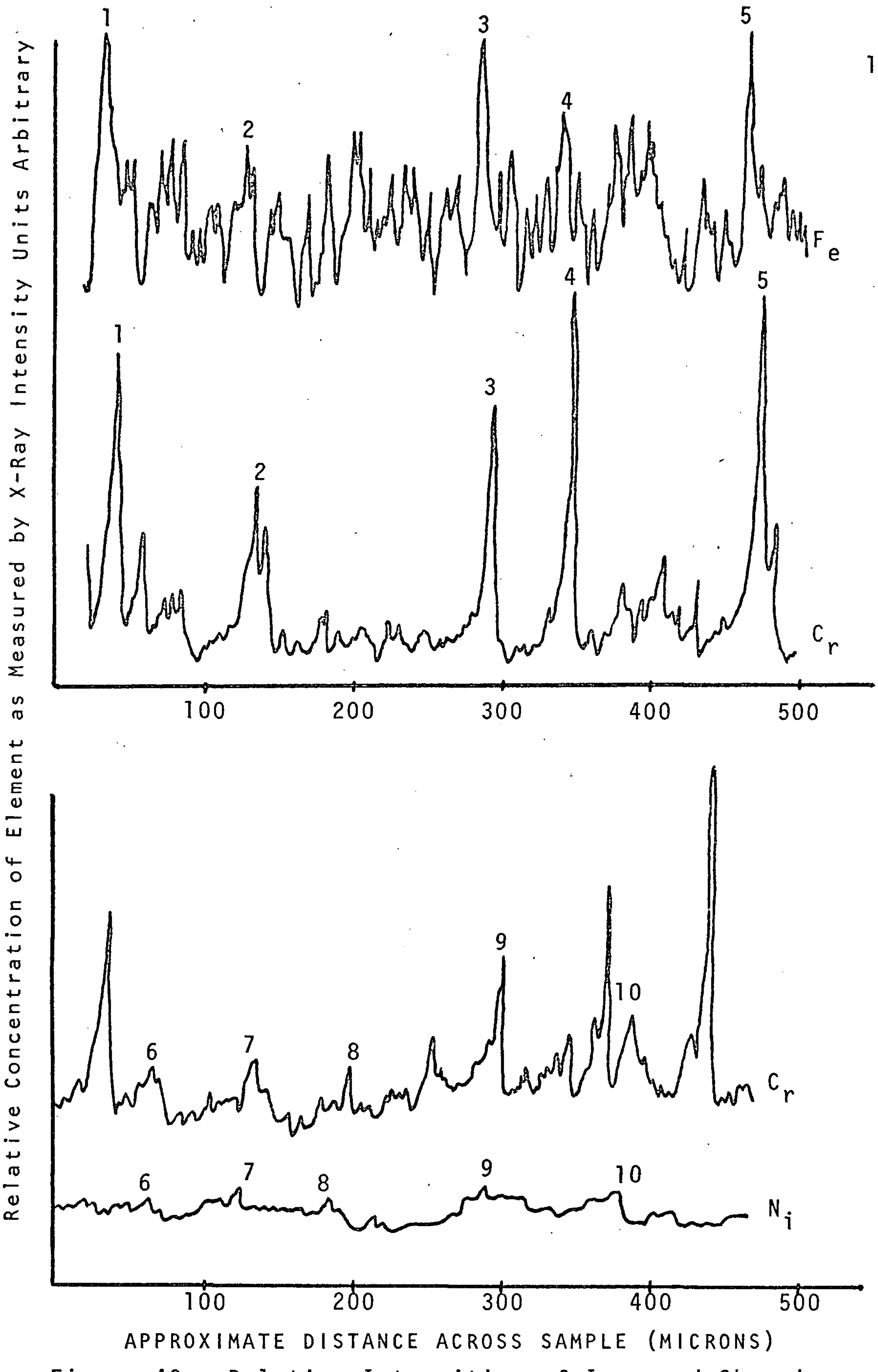


Figure 40. Relative Intensities of Iron and Chromium, and Nickel and Chromium for a Scan over a Core Sample from Linear Fouling Run 70 (Numbers indicate corresponding locations).

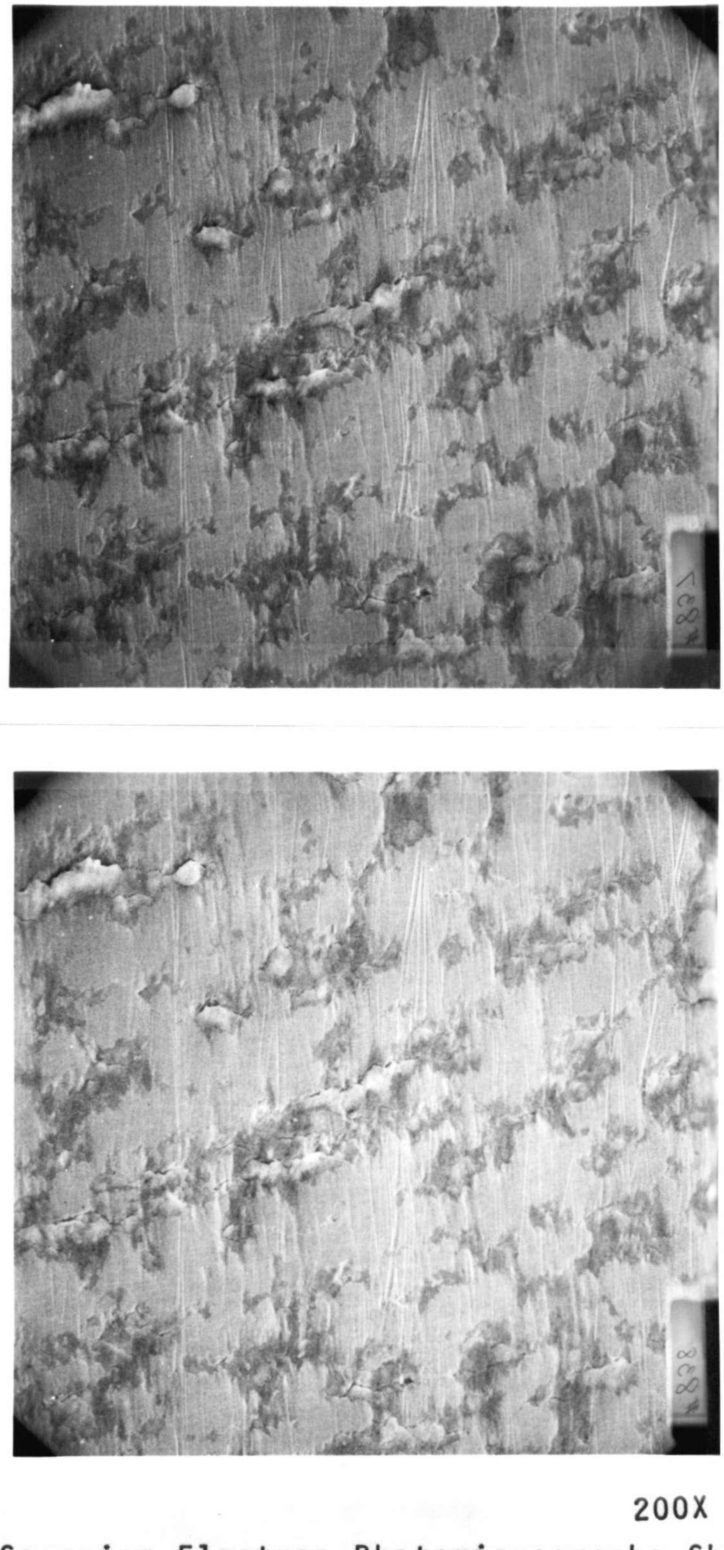
These results add further supporting evidence to the view that the fouling of 304 stainless steel by ferric oxide is associated with corrosion in crevices formed between the deposit and the tube wall.

Regular transverse striations were observed on core samples and these were suggestive of deposit cracking due to thermal stress.

6.4.4 Examination for pitting of tube used in fouling runs 32-70.

Because the presence of nickel and chromium in fouling deposits suggests corrosion, a portion of the test section used in Runs 32-70 was examined for evidence of pitting. The procedure used was as follows: A section of the fouled tube was honed with a bronze brush to remove the deposit, and then split longitudinally to expose the inner surface. Likewise, a section of unused tube was honed and split to serve as a standard. After cleaning them with alcohol in a sonic bath, both specimens were examined in a scanning electron microscope and stereo photomicrographs obtained. These are shown in Figure 41 and 42 respectively.

Results clearly show slight but unmistakable pitting in the sample used for the fouling runs. The material in the pits is fouling deposit (including corrosion products) immobilized by polyester resin. Probe examination



200X

Figure 41. Scanning Electron Photomicrographs Showing the Appearance of the Tube Wall of a Tube Used in 38 Fouling Runs. (The above photomicrographs are a stereo pair.)

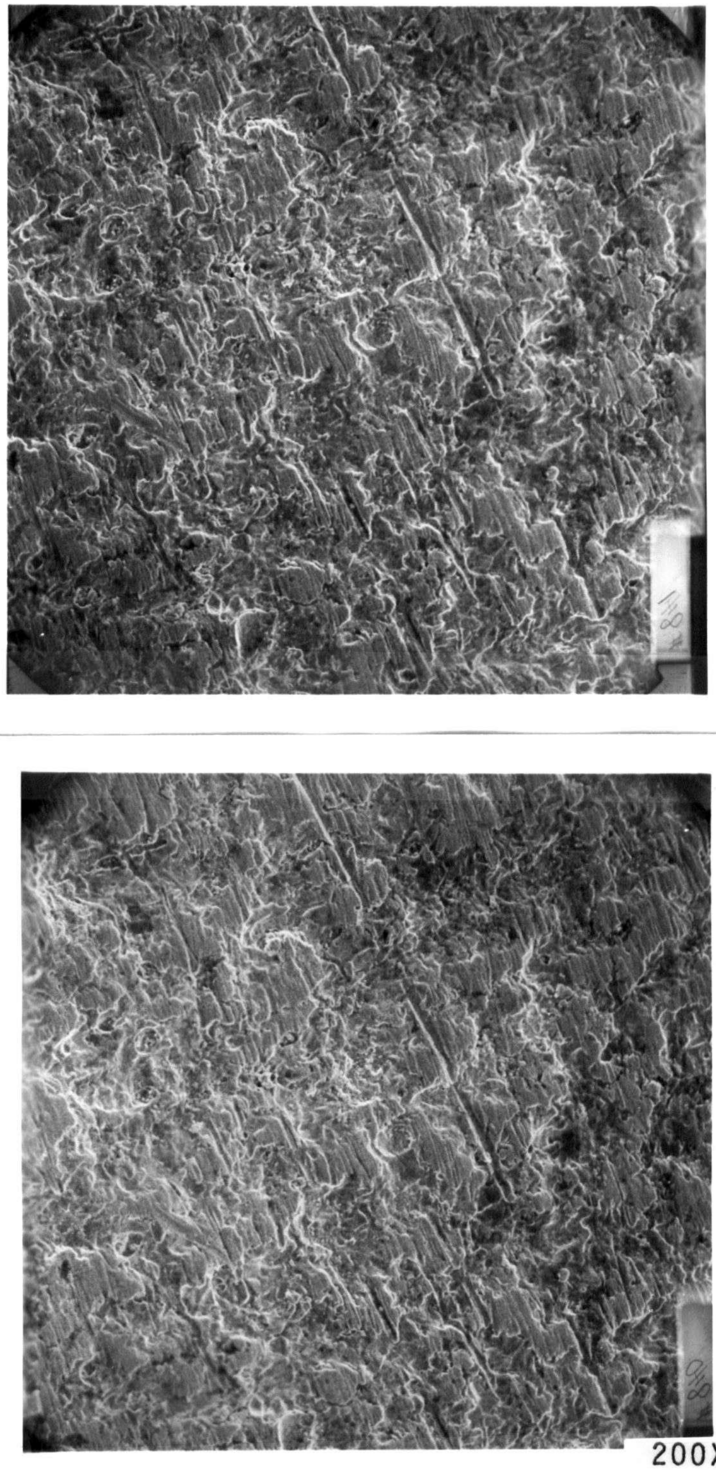


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Figure 42. Scanning Electron Photomicrographs Showing the Appearance of a Clean Tube Never Used in Fouling Experiments. (The above photomicrographs are a stereo pair.)

showed it to be rich in chromium and nickel. The unused standard specimen shows an irregular surface, but no evidence of pits.

6.4.5 Deposit crystal structure.

In order to determine if the black material observed in core samples could be magnetite or some other spinel, scrapings were analyzed using X-ray diffraction techniques. Results failed to indicate the presence of a material having a spinel structure. In addition, a sample of deposit honed from a tube was tested for magnetic properties using a 30 kilogauss magnet. No response was obtained indicating the absence of magnetite. It is therefore believed that black material observed in the samples, rather than being magnetite, results from the incorporation of chromium into the deposit probably as an oxide or hydroxide.

Chapter 7

CORROSION CONTROLLED FOULING - A PROPOSED HYPOTHESIS

7.1 Outline of Working Hypothesis

The presence of nickel and chromium in the fouling deposits, the presence of pits in the tube wall, and the fact that use of an oxygen scavenger reduces the fouling rate, all point to ferric oxide fouling of 304 stainless steel as being intimately associated with stainless steel corrosion. In order to explain the fouling results obtained in this investigation, a hypothesis based upon crevice corrosion theory has been developed. This hypothesis is presented in a general form below, expanded upon in Sections 7.2 and 7.3, and used as the basis for two mathematical models in Section 7.4.

The hypothesis explaining fouling of 304 stainless steel with ferric oxide is as follows:

(I) The initial process involves the physical adhesion of ferric oxide particles to the stainless steel. The transport of ferric oxide particles to the tube wall is believed to be controlled by such variables as particle concentration, flow rate and heat flux. The release of particles from the tube wall is believed to be a function of the shear stress and the energy of adhesion between the depositing particle and the substrate. Watkinson and Epstein (13), and Kern and Seaton (6), use this approach to develop their fouling models.

(2) Because spotty deposits have been found on the tube wall, particularly at low ferric oxide concentrations, it is believed that the fouling process is not one of uniform growth in deposit thickness. Rather, as is the case for crystallization, localized deposits are first formed and these serve as nucleation sites for further fouling. These sites then grow in area and thickness, eventually forming a deposit which completely covers the heat transfer surface. Consequently, during much of the fouling process there can be a relatively thick fouling deposit in one area which is in close proximity to another area having no fouling deposit. This results in differential oxygen concentration cells on the tube wall with fouled tube surfaces being less accessible to dissolved oxygen than unfouled surfaces. This sets up crevice corrosion in which the fouled areas undergo an anodic reaction resulting in tube wall corrosion, and the unfouled

areas undergo the cathodic reaction of oxygen reduction. The corrosion products generated under the fouling deposit diffuse through the deposit and become incorporated into it chemically, thereby serving to immobilize it.

(3) Provided the cathodic reaction of oxygen reduction can be maintained, the fouling deposit will continue to grow. If, however, the unfouled area becomes reduced in size, the cathodic reaction rate falls. This causes a drop in corrosion rate which in turn reduces the rate at which the deposit becomes immobilized. The fouling rate then declines as the deposition and release of particles to and from the fouling deposit come into balance.

7.2 Fundamentals of Crevice Corrosion

According to Fontana and Greene (37), stainless steels are particularly prone to crevice corrosion in aqueous media provided the following conditions prevail:

(1) There is, on the surface of the metal, a deposit which can create a stagnant area.

(2) There exists in the fluid an aggressive ion such as the chloride ion. Trace amounts are sufficient.

(3) A relatively large cathodic area is available to consume electrons generated at the anode.

All of these conditions are met in the ferric oxide-stainless steel system studied here. The spotty fouling deposits postulated and frequently observed create stagnant areas, with the unfouled areas available as a cathode. Since tap water was used for the experiments, there is a source of chloride ion.

Under the above conditions, stainless steel corrodes according to the following two electrode reactions:

anode $M \rightarrow M^{n+} + n\bar{e}$ (M = Fe, Ni, Cr)

cathode $O_2 + 2H_2O + 4\bar{e} \rightarrow 4OH^-$

overall $M + O_2 + 2H_2O \rightarrow M^{n+} + nOH^-$

Ordinarily, these reactions go on all over the stainless steel surface, and exposed metal is quickly attacked to form a metal ion. This metal ion then forms an insoluble oxide on the stainless steel surface which protects the metal from the corroding environment:

$$M^{n+} + nOH^- \rightarrow M(OH)_n$$

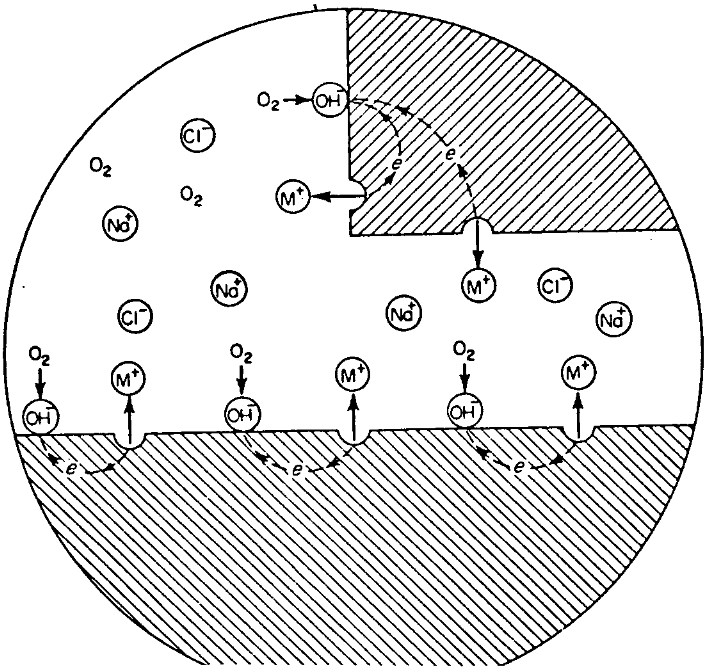
In the stagnant area under a deposit, however, the oxygen soon becomes depleted (see Figure 43). Consequently, the metal ions produced do not form oxides, but remain in the stagnant area as positive ions, which are neutralized by the migration of the mobile chloride ions into the crevice. The chloride ion then attacks the protective oxide film exposing fresh metal surface.[1] There is then within the crevice an anodic area, connected through the metal with a large cathodic area over the tube surface which has no deposit. Crevice corrosion therefore proceeds with a build-up of metal chloride within the crevice. This metal salt then hydrolzes in water according to the reaction:

$$M^+ Cl^- + H_2O \rightarrow MOH \downarrow + H^+ Cl^-$$

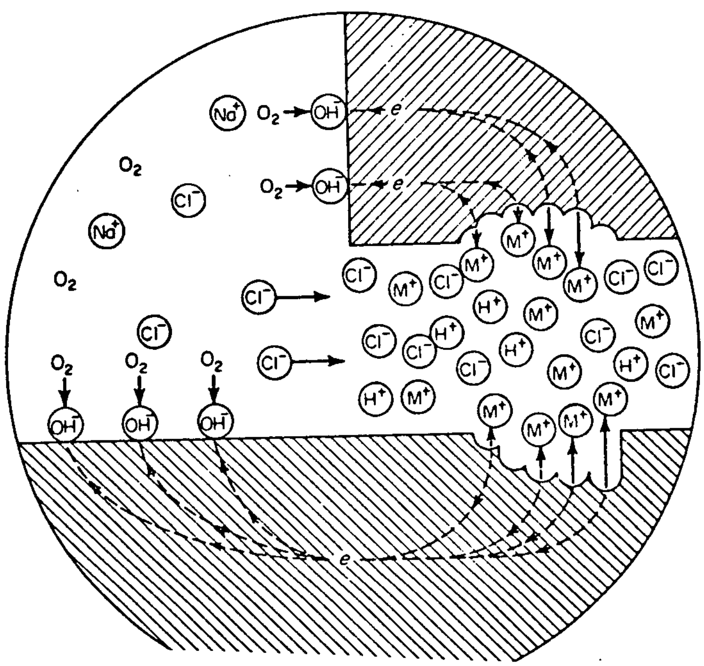
The net result is that the metal ion is removed from solution within the crevice and the hydrogen and chloride ions remain and promote further attack.

---

[1]The reason for accelerated corrosion of stainless steel in the presence of chloride ion has long been a subject of concern to corrosion scientists. A current theory, according to Vijh (38), is that the chloride ion penetrates the lattice to form a chloro-complex of iron or chromium which is susceptible to dissociation in solution. The chloride ion is thus regenerated and trace amounts are therefore capable of "portering" substantial amounts of metallic ions from the metal surface.



Crevice Corrosion - Initial Stage



Crevice Corrosion - Later Stage

Figure 43. Mechanism of Crevice Corrosion According to Fontana and Greene (37).

7.3 Proposed Mechanism for Ferric Oxide Fouling of 304 Stainless Steel

In order to explain how the working hypothesis outlined in Section 7.1 leads to the type of fouling versus time behaviour obtained in this investigation, Figure 44 has been constructed showing a typical fouling curve. Superimposed on this figure are sketches of the fouling deposit as predicted by the hypothesis for various stages of the fouling process. The figure, which is not to scale, is divided into three regions as follows:

(1) An induction region

(2) A fouling region

(3) An asymptotic region.

During the induction period, it is considered that ferric oxide physically adheres to the tube wall, forming crevice corrosion sites. During this period, there is too much unfouled wall present for the fouling deposit to cause detectable changes in fouling resistance. Since no appreciable induction period was actually observed during this investigation for runs exhibiting thermal fouling, it is concluded that this period was of short duration in the present experiments. The reason for postulating its existence is that crevice corrosion cannot occur until a crevice site has been formed.

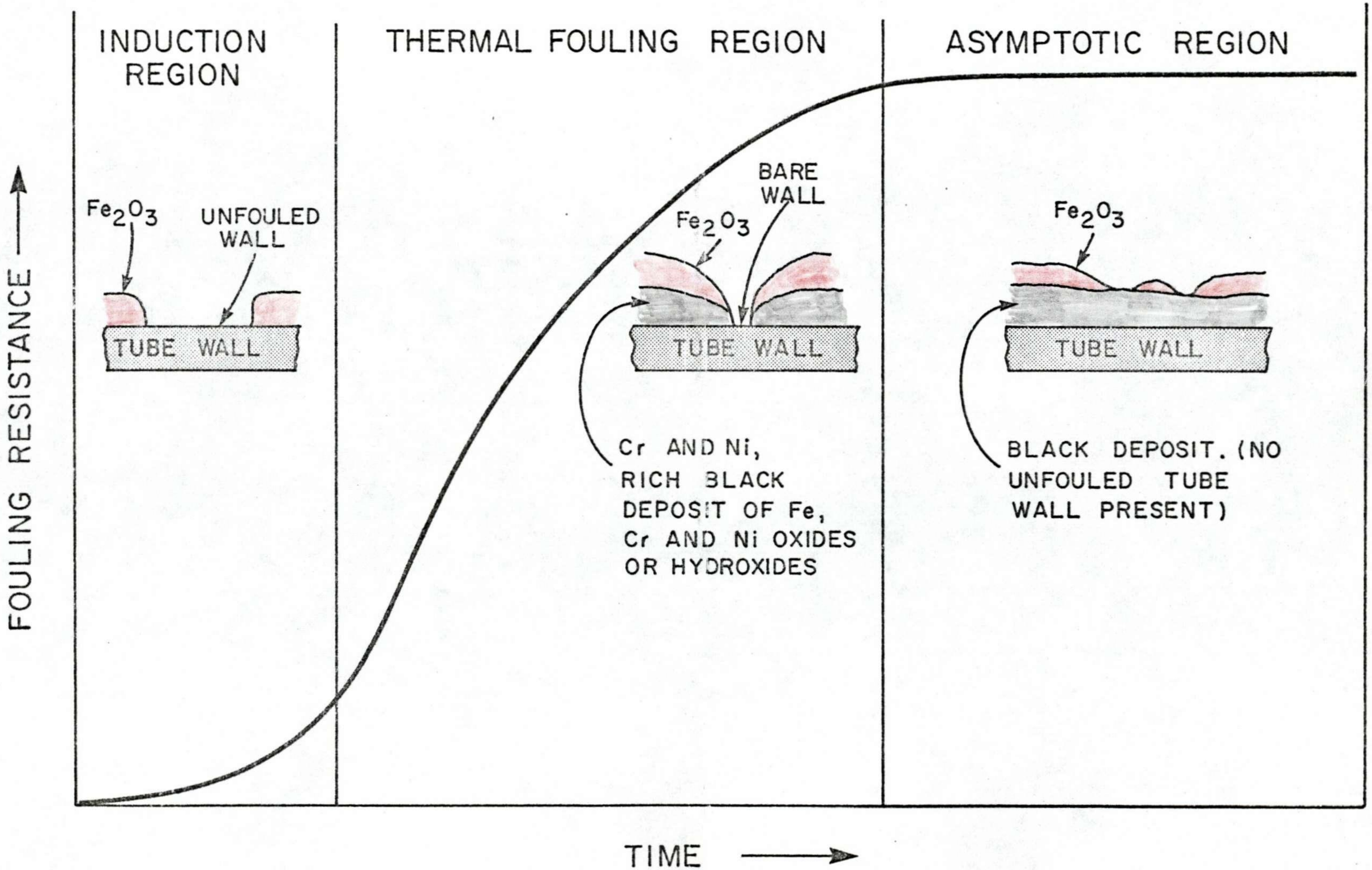


Figure 44. Idealized Fouling Curve Illustrating the Nature of the Fouling Deposit at Various Times According to the Crevice Corrosion Hypothesis.

In the fouling region, crevice corrosion occurs as outlined in Section 7.2, with the corrosion product becoming incorporated into the deposit. During this period, fouling can be detected thermally and proceeds at a declining rate as the deposit grows, thereby reducing the unfouled wall area and progressively blocking the reduction of oxygen to hydroxl ions.

In the asymptotic region, the tube wall has fouled to such an extent that oxygen reduction is eliminated. No further corrosion occurs and the deposition and release of physically held ferric oxide come into balance.

There is a great deal of evidence to support the proposed fouling mechanism:

(1) Ferric oxide readily adheres to stainless steel, as can be observed by preparing a slurry of ferric oxide in a stainless steel beaker. Also, since the surface of stainless steels consists of iron, nickel and chromium oxides which have large dipole moments, the large dipole moment of ferric oxide would predictably result in a strong physical bond. Hence a brief induction period involving physical adhesion of ferric oxide to the surface is not an unreasonable assumption.

(2) The coexistence of relatively thick deposits and clean wall areas side by side is also a reasonable

assumption. Tubes in which no thermal fouling was detected showed spotty deposits with thicknesses up to 70 microns. Also, in time lapse films of calcareous fouling of water-cooled heat exchangers, Taborek (15) shows conclusively that unfouled areas do coexist with relatively thick deposits. This point is essential to the hypothesis proposed here, since uniform deposition would imply that the deposit could not grow beyond a single layer, thus leaving no clean wall area to promote oxygen reduction.

(3) The existence of an asymptotic region in which crevice corrosion is essentially blocked is also reasonable, since it has been shown experimentally that the fouling rate can be reduced with an oxygen scavenger and increased by honing a portion of the tube, thereby increasing the clean wall area. It should be pointed out here that the deposit itself cannot serve as a site for the cathode reaction since the ferric oxide, when tested, was found to be extremely non-conducting electrically.

(4) The existence of linear fouling lends support to the hypothesis since a prerequiste for linear fouling is that an initially fouled tube be subjected to zero heat flux and then heated in order to obtain the linear fouling condition. Such a procedure is believed to produce cracks

in the deposit due to thermal stress, thereby making the tube wall accessible to dissolved oxygen from the fluid. Since under linear fouling the wall temperature increase is large (for Run 64, 11F° in one hour), it is reasonable to assume that cracking of the deposit will continue, and that dissolved oxygen will continue to be transported to the tube wall and the corrosion reaction thereby maintained.

7.4 Mathematical Models

7.4.1 Model I.

Let N_R = the number of ferric oxide particles in the deposit held by physical forces per unit area of tube surface.

and

Let N_B = the number of ferric oxide particles in the deposit held by chemical forces due to the precipitation of corrosion product on and around the particles per unit area of tube surface.

If it is assumed that only particles of the N_R type are originally deposited and subject to release, and that particles of the N_B type are all formed from N_R type particles already in the deposit and that when formed, N_B type particles are not subject to release, the following differential equation can be written:

$$\frac{dN_R}{dt} = \phi_D - \phi_R - \frac{dN_B}{dt} \tag{7.1}$$

where ϕ_D = rate of deposition of type N_R particles per unit area

ϕ_R = rate of release of type N_R particles per unit area

$\frac{dN_B}{dt}$ = rate of conversion of type N_R particles to type N_B particles per unit area

If N_T represents the total number of particles making up the deposit per unit area, then

$$N_T = N_R + N_B \tag{7.2}$$

Equation (7.1) then becomes

$$\frac{dN_T}{dt} = \phi_D - \phi_R \tag{7.3}$$

that is, the rate of accumulation of all particles in the deposit is the difference between the deposition and release rates of type N_R particles only. Equation (7.3) has been used by many investigators, notably Kern and Seaton (6), Watkinson and Epstein (13), Taborek *et al.* (1) and Charlesworth (11), as the starting point for their models. In the Kern-Seaton model, for example, N_T is interpreted as being proportional to the mean deposit thickness, x, $\phi_D = K_1CW$ and $\phi_R = K_2\tau x$,

where K_1 and K_2 are constants

C = particulate concentration

W = mass flow rate

τ = shear stress

Then

$$\frac{dx}{dt} = K_1CW - K_2\tau x \qquad (7.4)$$

or

$$x = \frac{K_1CW}{K_2\tau}\left[1 - e^{-K_2\tau t}\right] \qquad (1.6)$$

In the Kern-Seaton approach, the assumption is made that the fouling thickness is uniform and that the deposition rate is not a function of fouling deposit thickness but that the release rate is.

In the mathematical models developed here, the assumption that the deposition rate, ϕ_D, is independent of the number of particles in the deposit, is retained. The release term however is not assumed to be proportional to the total number of particles in the deposit, N_T, but to the number of particles in the deposit held by physical (as opposed to chemical) forces, N_R. The form of the release term is retained, and it is assumed that $\phi_R = K_2 \tau N_R$. The differential equation describing corrosion controlled fouling then becomes

$$\frac{dN_T}{dt} = \phi_D - K_2 \tau N_R \tag{7.5}$$

Equation (7.5) can readily be solved provided a functional relationship between N_T and N_R can be found. To find this relationship, equation (7.5) is differentiated to yield

$$\frac{d^2 N_T}{dt^2} = - K_2 \tau \frac{dN_R}{dt} \tag{7.6}$$

Since

$$N_T = N_R + N_B \tag{7.2}$$

$$\frac{dN_R}{dt} = \frac{dN_T}{dt} - \frac{dN_B}{dt} \tag{7.7}$$

Substituting this result into equation (7.6) gives

$$\frac{d^2N_T}{dt^2} = -K_2\tau\left[\frac{dN_T}{dt} - \frac{dN_B}{dt}\right] \tag{7.8}$$

According to the hypothesis concerning corrosion controlled fouling presented in Section 7.1, the rate of formation of immobilized particles N_B is controlled by the amount of unfouled wall area available to serve as a cathode for oxygen reduction. The assumption is therefore made that

$$\frac{dN_B}{dt} \propto \frac{U_m}{S_0} = \frac{hU_m}{S_0} \tag{7.9}$$

where h = rate constant

U_m = number of unfouled sites per unit area

S_0 = total number of sites per unit area.

Substitution of equation (7.9) into equation (7.8) gives

$$\frac{d^2N_T}{dt^2} = -K_2\tau\left[\frac{dN_T}{dt} - \frac{hU_m}{S_0}\right] \qquad (7.10)$$

The problem is thereby reduced to finding a relationship between the fraction of unfouled area of the tube, U_m/S_0, and the total number of particles forming the deposit, N_T.

To find an expression relating U_m/S_0 to N_T, a probability method similar to that employed by Langmuir (39) in his adsorption studies is adopted. In this method, a unit area of the metal surface is divided into an arbitrary number of adhesion sites, S_0. It is then assumed that the probability that any specified site will be occupied by a depositing particle is proportional to the interaction energy (the energy of adhesion) between the particle and the surface of the site. If U_m/S_0 is the fraction of unfouled sites on the tube, the probability of a depositing particle occupying an unfouled site is

$$P_{pm} = A\ E_{pm}\frac{U_m}{S_0} \qquad (7.11)$$

where

P_{pm} = probability of a depositing particle occupying any site

A = proportionality constant

E_{pm} = energy of adhesion between a particle and the tube wall.

Similarly, the probability of a depositing particle occupying a site on the fouling deposit is

$$P_{pd} = A\ E_{pd}\left[1 - \frac{U_m}{S_0}\right] \qquad (7.12)$$

Since a particle which deposits must occupy either a site on the deposit or a site on the unfouled tube wall

$$P_{pd} + P_{pm} = 1 \qquad (7.13)$$

Hence

$$A\ E_{pd}\left[1 - \frac{U_m}{S_0}\right] + A\ E_{pm}\frac{U_m}{S_0} = 1 \qquad (7.14)$$

Eliminating A between equations (7.14) and (7.11) gives

$$P_{pm} = \frac{U_m \, E_{pm}}{U_m \, E_{pm} + [S_0 - U_m] \, E_{pd}} \qquad (7.15)$$

If at any time there are N_T particles in the deposit, and U_m unfouled sites, then an alternate way of expressing the probability that a depositing particle will settle on the unfouled metal is given by the differential equation

$$- \frac{dU_m}{dN_T} = P_{pm} \qquad (7.16)$$

Equating this expression for P_{pm} with that given by equation (7.15) yields

$$- \frac{dU_m}{dN_T} = \frac{U_m \, E_{pm}}{U_m \, E_{pm} + (S_0 - U_m) \, E_{pd}} \qquad (7.17)$$

Integrating equation (7.17) using the initial condition that at $N_T = 0$, $U_m = 0$, yields

$$N_T = \left(1 - \frac{E_{pd}}{E_{pm}}\right) S_0 - \left(1 - \frac{E_{pd}}{E_{pm}}\right) U_m - S_0 \, \frac{E_{pd}}{E_{pm}} \, \ell n \left[\frac{U_m}{S_0}\right] \qquad (7.18)$$

If it is assumed that E_{pm} and E_{pd} are very nearly equal, then

$$\left(1 - \frac{E_{pd}}{E_{pm}}\right) S_0 - \left(1 - \frac{E_{pd}}{E_{pm}}\right) U_m \simeq 0 \tag{7.19}$$

Equation (7.18) then becomes

$$U_m = S_0 e^{-\frac{N_T}{S} \cdot \frac{E_{pm}}{E_{pd}}} \tag{7.20}$$

Substitution of this result into equation (7.10) gives

$$\frac{d^2 N_T}{dt^2} + K_2 \tau \frac{dN_T}{dt} - K_2 \tau h e^{-\frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}}} = 0 \tag{7.21}$$

This differential equation is non-linear and cannot be solved in terms of familiar functions. An approximate solution can be obtained by expressing the exponential term as a series and truncating after two terms in the series, that is,

$$K_2 \tau h e^{-\frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}}} = K_2 \tau h \left[1 - \left[\frac{N_T}{S_0} \quad \frac{E_{pm}}{E_{pd}} \right] + \frac{1}{2!} \left[\frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}} \right]^2 - \cdots \right]$$

$$\simeq K_2 \tau h \left[1 - \frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}} \right] \qquad (7.22)$$

Substituting this approximation into equation (7.21) gives

$$\frac{d^2 N_T}{dt^2} + K_2 \tau \frac{dN_T}{dt} + K_2 \tau h \frac{E_{pm}}{E_{pd}} \cdot \frac{N_T}{S_0} = K_2 \tau h \qquad (7.23)$$

The solution to this differential equation is of the form

$$N_T = C_1 e^{-\frac{(x + \sqrt{x^2 - 4y})t}{2}} + C_2 e^{+\frac{(x - \sqrt{x^2 - 4y})t}{2}} + C_3 \qquad (7.24)$$

where $x = K_2 \tau$, $y = K_2 \tau h \cdot \frac{E_{pm}}{E_{pd}} \cdot \frac{1}{S_0}$

For the initial conditions $N_T = 0$ at $t = 0$ and

$$\left.\frac{dN_T}{dt}\right|_{t=0} = \phi_D$$

the constants in equation can be readily evaluated.

A major disadvantage of the analytical solution to equation (7.23) offered by equation (7.24), however, is that the approximation upon which equation (7.23) is based, namely

$$e^{-\frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}}} \simeq 1 - \frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}}$$

is only valid if $\frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}} << 1$.

As fouling proceeds and N_T increases, the above inequality becomes progressively more invalid. Consequently, in general, equation (7.24) cannot be relied upon to hold, and therefore it offers no advantage over a numerical solution of equation (7.21).

7.4.2 Model II.

If it is assumed that crevices must first be formed before thermal fouling can be detected, or alternately that ferric oxide deposition and release rates are very much higher than the rate at which ferric oxide particles become immobilized to form a permanent structure, then an induction period followed by a time dependent fouling period can be assumed. If, during the induction period, no immobilization of ferric oxide is considered to occur, equation (7.1) can be written as

$$\frac{dN_R}{d\theta} = \phi_D - K_2 \tau N_R \tag{7.25}$$

where θ = time of induction

Integrating, using the initial condition that $N_R = 0$ at $\theta = 0$, gives

$$N_R = \frac{\theta_D}{K_2\tau}\left[1 - e^{-K_2\tau\theta}\right] \tag{7.26}$$

If $K_2\tau\theta$ is assumed to be large, the number of mobile ferric oxide particles in the deposit will be a constant given by

$$N_R = \frac{\phi_D}{K_2 \tau} \qquad (7.27)$$

Assuming, as in Model I, that the uncovered metal fraction can be expressed as

$$\frac{U_m}{S} = e^{-\frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}}} \qquad (7.20)$$

and that the rate of particle immobilization is given by

$$\frac{dN_B}{dt} = \frac{h\ U_m}{S_0} \qquad (7.9)$$

where t = time of thermal fouling (following induction period)

then combining equations (7.20) and (7.9) results in

$$\frac{dN_B}{dt} = h\ e^{-\frac{N_T}{S_0} \cdot \frac{E_{pm}}{E_{pd}}} \qquad (7.28)$$

Since

$$N_T = N_B + N_R \qquad (7.2)$$

combining equations (7.28), (7.2) and (7.27) yields

$$\frac{dN_B}{dt} = h\, e^{-\frac{\phi_D}{K_2\tau} \cdot \frac{1}{S_0} \cdot \frac{E_{pm}}{E_{pd}}} \cdot e^{-\frac{N_B}{S_0} \cdot \frac{E_{pm}}{E_{pd}}} \tag{7.29}$$

Integrating equation (7.29), using as the initial condition that $N_B = 0$ at $t = 0$, leads to the result

$$N_B = S_0\frac{E_{pd}}{E_{pm}}\, \ell n\left[S_0\frac{E_{pd}}{E_{pm}}\, h\, e^{-S_0\frac{E_{pd}}{E_{pm}} \cdot \frac{\phi_D}{K_2\tau}} \times t + 1\right] \tag{7.30}$$

Since $N_T = N_R + N_B$, and $N_R = \frac{\phi_D}{K_2\tau}$,

if follows that

$$N_T = S_0\frac{E_{pd}}{E_{pm}}\, \ell n\left[S_0\frac{E_{pd}}{E_{pm}}\, h\, e^{-S_0\frac{E_{pd}}{E_{pm}} \cdot \frac{\phi_D}{K_2\tau}} \times t + 1\right] + \frac{\phi_D}{K_2\tau} \tag{7.31}$$

It should be noted that when t = 0,

$$N_T = \frac{\phi_D}{K_2\tau} = N_R \tag{7.32}$$

which is consistent with the initial condition, $N_B = 0$ at t = 0.

7.4.3 Linear fouling.

As stated in Section 6.2.6, linear fouling is believed to be a result of expanding the tube to create uncovered metal sites which are protected from mobile ferric oxide by the deposit, but can still serve as sites for the cathode reaction

$$O_2 + 2H_2O + 4\,\bar{e} \rightarrow 4(OH^-)$$

Under such a hypothesis, U_m/S_0, the fraction of uncovered sites is constant with time. Thus

$$\frac{dN_B}{dt} = \frac{h\ U_m}{S_0} \tag{7.9}$$

integrated directly to obtain

$$N_B = \frac{h\ U_m}{S_0} t + C_1 \qquad (7.33)$$

When $t = 0$, $N_B = 0$, and hence $C_1 = 0$. The total number of particles on the surface, N_T, then becomes

$$N_T = \frac{h\ U_m}{S_0} t + \frac{\phi_D}{K_2 \tau} \qquad (7.34)$$

Here, consistent with results, thermal fouling shows a linear dependence with respect to time.

Again, by use of an oxygen scavenger, h should be reduced by a constant amount due to an abrupt change in the cathode reaction, giving a lower constant rate of fouling. This prediction is also consistent with the experimental data.

7.4.4 Compatilibity of fouling model equations with experimental data.

Since the Kern-Seaton type of equation, $R_f = R_f^*(1 - e^{-bt})$, was routinely fitted to the fouling data for each run, it was decided to test this equation first against the experimental data to see whether the Kern-Seaton model would correctly predict the dependence of R_f^* and b on mass flow rate. In the Kern-Seaton model,

$R_f^* = K_1CW/K_2\tau$ and $b = K_2\tau$, where K_1 and K_2 are constants, C is the concentration, W is the mass flow rate and τ is the shear stress. Assuming the Blasius expression for friction factor to hold, then

$$\tau = \rho U_b^2 \frac{f}{2} = \frac{0.79}{2} \rho U_b^2 \left(\frac{DU_b\rho}{\mu}\right)^{-0.25} \qquad (7.35)$$

or

$$\tau \propto U_b^{1.75} \propto W^{1.75}$$

Hence, the Kern-Seaton model predicts the asymptotic fouling resistance, R_f^*, to vary as $W^{-0.75}$ and the initial fouling rate (bR_f^*) to vary directly with W.

In an attempt to determine whether the data bear out this predicted dependence, log-log plots of initial fouling rate and asymptotic fouling resistance were made against mass flow rate for four Runs (Runs 54, 55, 39, 61) using a mixed-size ferric oxide at a concentration of 2130 ppm (see Figure 45 and 46). The reason for limiting the analysis to these runs is that they showed a three-fold range in mass flow rate, with the clean wall temperature at time zero being relatively constant (148 ± 4°F). Since,

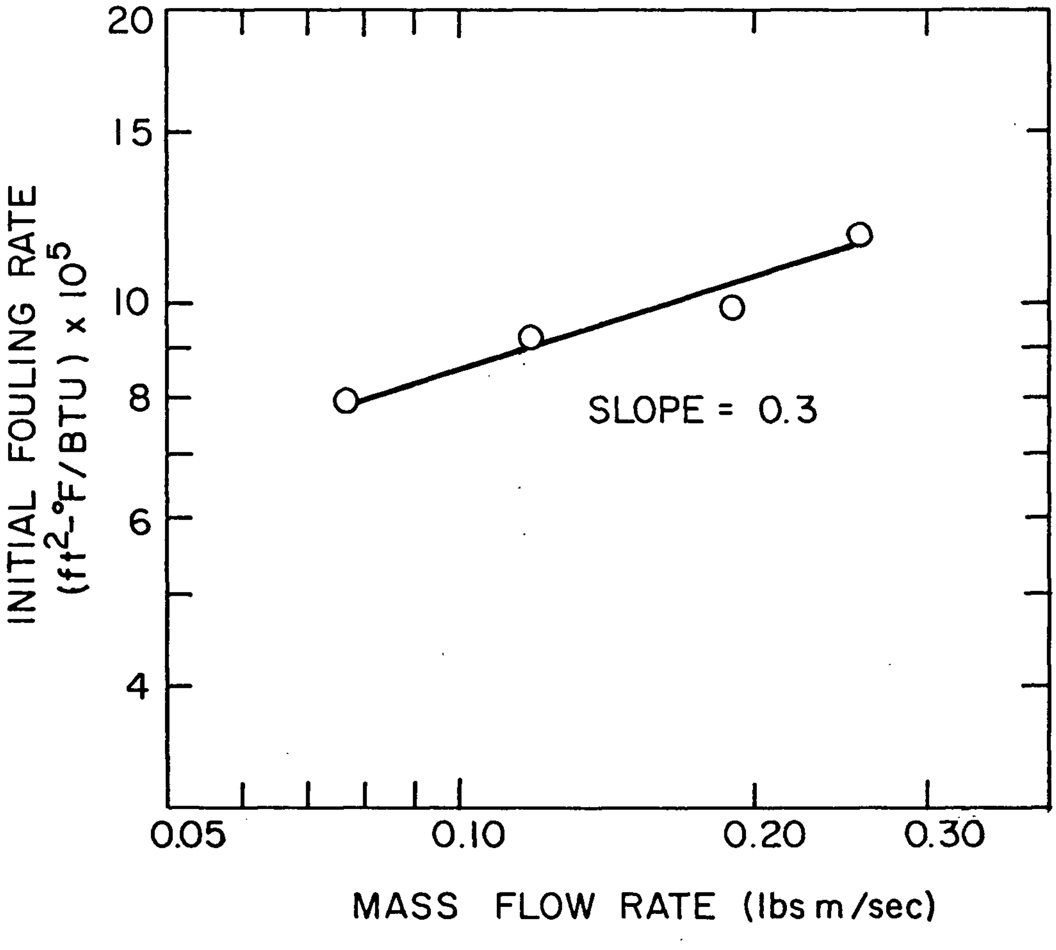


Figure 45. Dependence of Initial Fouling Rate on Mass Flow Rate For Runs 54,55,39 and 61. Mixed-Size Ferric Oxide Conc. 2130 ppm. Wall Temperature at Time zero, 148°F ± 4.

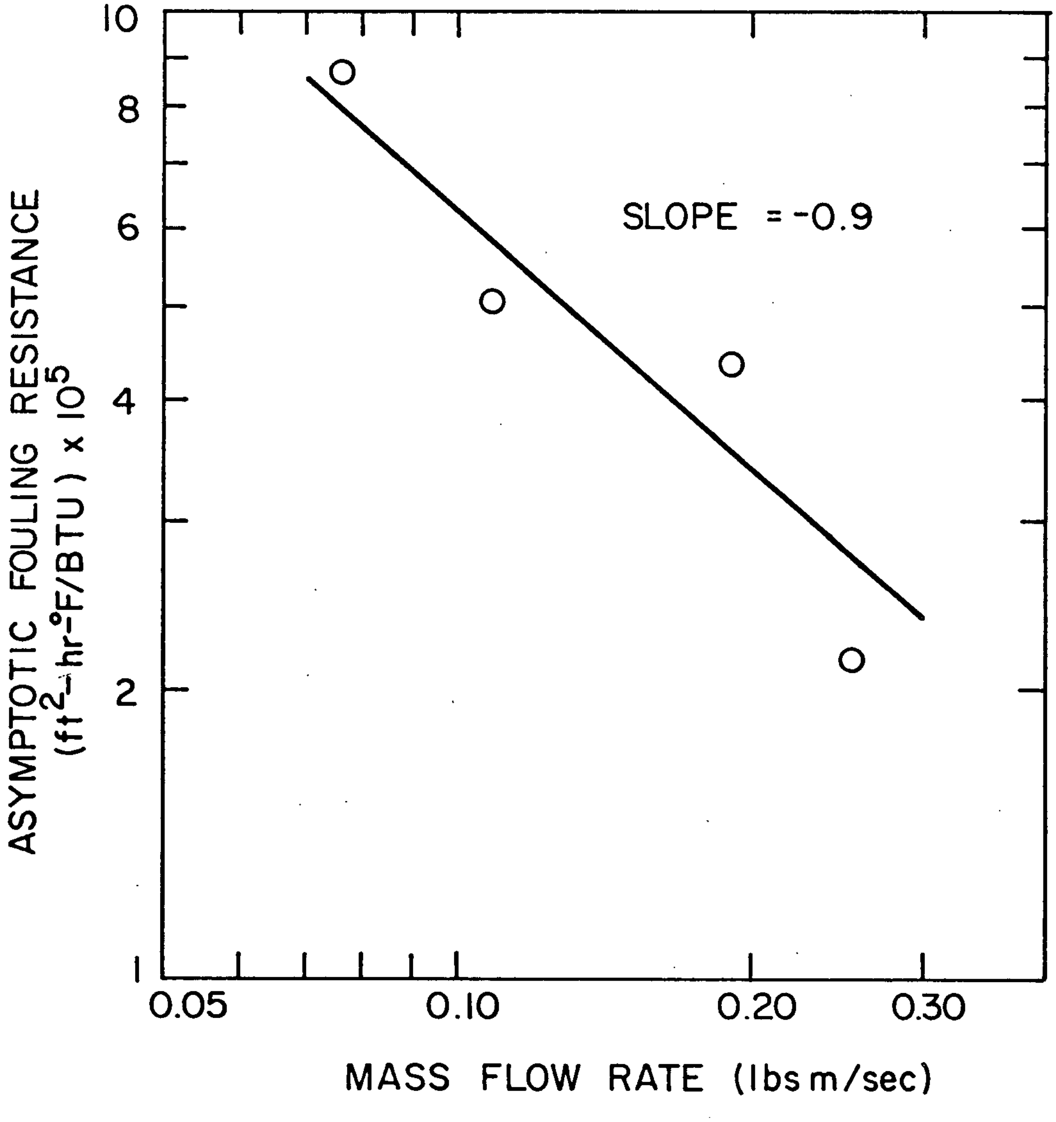


Figure 46. Dependence of Asymptotic Fouling Resistance on Mass Flow Rate for Runs 54,55,39 and 61. Mixed-Size Ferric Oxide Conc. 2130 ppm. Wall Temperature at Time Zero, 148°F ± 4.

as has already been shown, fouling behaviour appears to be temperature dependent, a proper test of the influence of mass flow rate on initial fouling rate and asymptotic fouling resistance requires that the wall temperature be constant. From Figure 45, it can be seen that the initial fouling rate increases with mass flow rate to the 0.3 power. The Kern-Seaton model predicts 1.0. It thus appears that the Kern-Seaton model does not correctly predict the dependence of initial fouling rate on mass velocity. The results of the log-log plot of asymptotic fouling resistance versus mass flow rate are more supportive of the Kern-Seaton model. The data show a dependence index on W of -0.9 while the Kern-Seaton model predicts -0.75 (or -1 for fully rough flow). However, because of the limited amount of data upon which this analysis is based, firm conclusions are not warranted.

Tests of models I and II as predictive methods for fouling behaviour have not been made because such tests, in order to be meaningful, would require a large amount of data, four constants being involved (K_1, K_2, h and E_{pm}/E_{pd}). Since, as already indicated, there are insufficient controlled data to test even the simpler Kern-Seaton model, it is felt that no quantitative test of models I and II can be meaningfully made with the present data. Nevertheless these models could serve as starting points towards the development of predictive equations for corrosion controlled fouling.

Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

An investigation was made of the fouling behaviour of aqueous suspensions of ferric oxide in 0.343 inch i.d. 304 type stainless steel tubes. Variables studied, using submicron to micron size particles, were ferric oxide concentration (15 - 3750 ppm), Reynolds number (10,090 - 37,590) and heat flux (0 - 92,460 BTU/ft^2-hr). Following selected runs, fouled tubes were sectioned and the chemical composition of the fouling deposit determined "in situ" in an electron microprobe.

Microprobe results showed the deposit to contain, in addition to iron and oxygen, significant amounts of nickel and chromium. Chemical composition-deposit distance profiles showed nickel and chromium concentration gradients, with levels highest at the tube wall, falling to zero at the deposit-fluid interface. A test section used for a series of fouling trials was found, when examined with an electron microscope, to have small, but distinct, pits.

During the fouling process, measurements were made of thermal resistance as a function of time. The resulting fouling curves fell into three distinct categories, depending upon the particle concentration and the mode of operation:

(1) At ferric oxide concentrations below 100 ppm, no thermal fouling could be detected over experimental periods of up to 14 days. Microprobe examination of such tubes showed spotty deposits.

(2) At ferric oxide concentrations of 750 ppm and higher, using mixed size particles, asymptotic type fouling behaviour occurred, similar to that reported by Kern and Seaton, and by Watkinson, for different fouling systems. This type of fouling occurs at a steadily decreasing rate. In the ferric oxide system studied here, the asymptotic condition occurred after approximately four hours of operation. Prolonged operation resulted in a sudden decrease in fouling resistance at localized positions on the test section, followed by refouling of the whole test section. The sudden decrease in thermal fouling resistance was taken to be indicative of release of material from the tube wall.

(3) If the suspension was circulated through the test section at zero heat flux for approximately eight

hours and then heating started, the tube commenced fouling at a constant rate considerably greater than the previous decreasing rates.

To explain the results, a hypothesis was developed which states that the fouling behaviour of water suspended ferric oxide on stainless steel is controlled by the rate at which crevice corrosion of the stainless steel occurs. The corrosion products produced serve to bind ferric oxide from the fluid to the wall or to the previous fouling deposit. In turn, the corrosion rate is controlled by the cathode reaction

$$O_2 + 2H_2O + 4\,\bar{e} \rightarrow 4(OH^-)$$

which occurs on unfouled areas of the tube wall.

Experiments designed to test this hypothesis, such as increasing the unfouled cathode area in an attempt to accelerate the corrosion rate, and removing oxygen with a scavenger in order to decrease the rate, gave results consistent with the hypothesis.

Two mathematical models of the fouling process have been developed in line with the corrosion hypothesis. A rigorous test of these models would require more controlled experiments.

The results of this study indicate that crevice corrosion plays an important role in the fouling of 304 stainless steel with ferric oxide. Further work with ferric oxide fouling should include a more detailed study of the linear fouling situation to determine how best to inhibit the fouling process. The results from such a study might well have practical benefits for fouling situations involving corrosion products of iron.

The techniques developed for examining fouling deposits 'in situ' should also be extended, since the possibility exists that many fouling situations could be eliminated or controlled by a judicious selection of materials of construction combined with selective removal of a troublesome foulant.

A wider variation, and more deliberate control, of wall temperature should be undertaken, as well as a more satisfactory study of particle size effects. In addition, the corrosion hypothesis should be further tested, for example by varying the pH of the circulating suspension.

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NOMENCLATURE

		Typical Units
a_1, a_2, A, A_1, A_1', A_2	constants	
A	heat transfer area	ft^2
b	parameter of equation (4.4)	hr^{-2}
C	ferric oxide concentration	ppm
C_i	constant	
C_1, C_2	constant	
C_0	coefficient inversely proportion to velocity	ft/sec^{-1}
C_0	particle concentration close to wall	ppm
C_r	function of fouling concentration	ppm
C_b	particle concentration in bulk fluid	ppm
C_w	particle concentration at wall	ppm
D	tube diameter	ft
D	Brownian diffusion coefficient	ft^2/sec
d	particle diameter	ft

		Typical Units
E_{pm}	energy of adhesion particle to metal	$lbs\text{-}ft^{-1}$
E_{pd}	energy of adhesion particle to deposit	$lbs\text{-}ft^{-1}$
e	base of natural logarithms	dimensionless
E	activation Energy	BTU/lb-mole
f	fanning friction factor	dimensionless
h	rate constant	hr^{-1}
h	pipe diameter	ft
h^{+}	dimensionless pipe diameter	dimensionless
h	heat transfer coefficient	BTU ft^{-2} hr^{-1} $°F^{-1}$
J	mass flux of particles	lbs ft^{-2} hr^{-1}
k_d	thermal conductivity deposit	BTU ft^{-2} hr^{-1} $°F^{-1}$
k_p	thermal conductivity particle	"
k_f	thermal conductivity fluid	"
K_1, K_2	constants	
K_D	deposition coefficient	ft^2 sec^{-1}
K_B	Boltzman constant 1.38×10^{-18}	gm/cm^2/molecule-$°K\text{-}sec^2$
k_c	mass transfer coefficient	ft sec^{-1}

		Typical Units
N	particle mass flux	lb ft^{-2} hr^{-1}
N_0	particle mass flux in wall region	"
N_w	particle mass flux depositing on wall	"
N_i	concentration of type i particles	ppm
N_T	total number of deposited particles per unit area	ft^{-2}
N_R	number of deposited particles per unit area held by physical forces	"
N_B	number of deposited particles per unit area held by chemical forces	"
p	sticking probability	dimensionless
P_{pm}	probability of particle deposition on unfouled tube	"
P_{pd}	probability of particle deposition on previous deposit	"
q'	heat flux	BTU ft^{-2} hr^{-1}
q	heat flow	BTU hr^{-1}
Q	liquid evaporated	lbs-hr^{-1}
R	total thermal resistance	ft^2 hr °F BTU^{-1}
R_0	total thermal resistance at time zero	"

		Typical Units
R_f	fouling resistance	ft^2 hr °F BTU^{-1}
R_f^*	asymptotic fouling resistance	"
r	exponent	dimensionless
R_g	universal gas constant	$BTU(lb\text{-}mole\text{-}°R)^{-1}$
R_b	bonding resistance of fouling deposit	lbs ft^{-2}
S	sticking probability	dimensionless
S_i	sticking probability of type i particle	"
S_0	total number of potential fouling sites per unit area	ft^{-2}
S	stopping distance	ft
S^+	dimensionless stopping distance	
t	time	hours
T_w	wall temperature	°F
T_b	fluid bulk temperature	°F
T_k	absolute temperature	°R
T	temperature	°F
ΔT	temperature difference	°F
T_{bo}	fluid temperature at time zero	°F

		Typical Units
T_{wo}	outer wall temperature at time zero	°F
T_s	heat transfer surface temperature	
U	overall heat transfer coefficient	$BTU\text{-}ft^{-2}\text{-}°F^{-1}\text{-}hr^{-1}$
U_i	velocity of a particle toward the surface in close proximity to the surface	
U_m	number of unfouled sites on tube surface	ft^{-2}
U_b	bulk velocity	$ft\text{-}sec^{-1}$
U^+	dimensionless velocity = $u/U_b\sqrt{f/2}$	
u	local fluid velocity	$ft\text{-}sec^{-1}$
V_{th}	thermophoretic velocity	ft/sec
W	mass flow rate	$lbm\text{-}hr^{-1}$
x	deposit thickness	ft
x	distance co-ordinate	ft
y	distance co-ordinate	ft
y^+	$y\,U_b\sqrt{f/2}/\nu$	dimensionless

DIMENSIONLESS GROUPS

Nu	Nusselt number	hd/k
Pr	Prandtl number	$C_p\mu/k$

		Typical Units
Re	Reynolds number	$d\ U_b \rho/\mu$
Sc	Schmidt number	ν/D

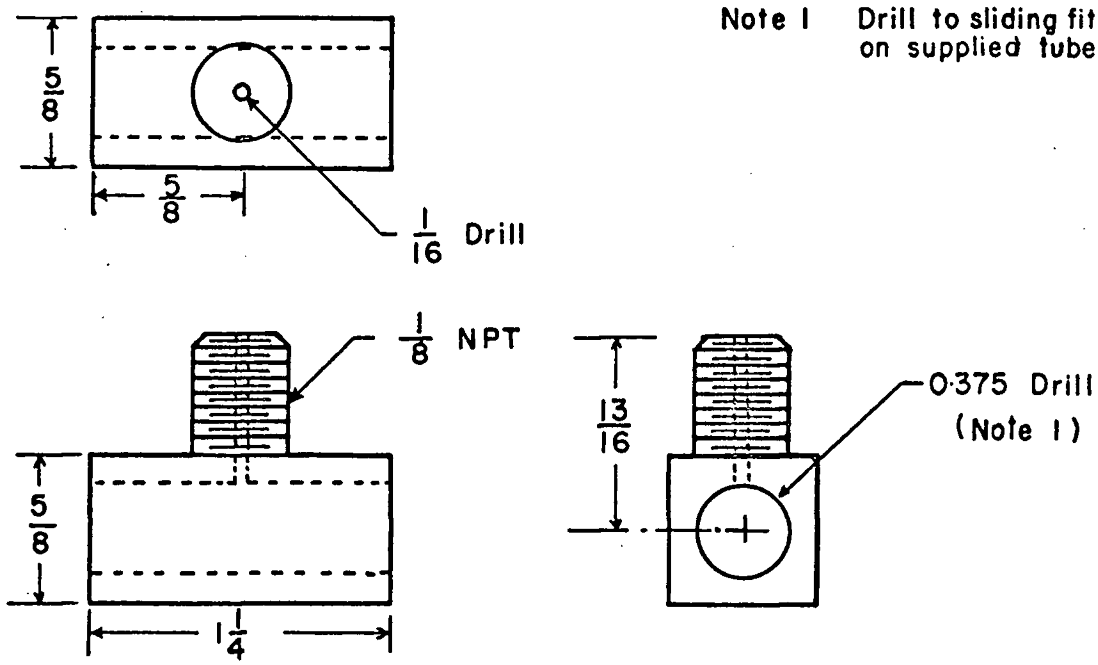
GREEK LETTERS

ε	eddy diffusivity of momentum	$ft^2\ sec^{-1}$
Δ	difference	
ϕ_D	deposition rate	ft^2-°F BTU^{-1}
ϕ_R	release rate	"
ρ	density	$lb\ ft^{-3}$
θ	time of induction	hrs
ν	kinematic viscosity	$ft^2\ hr^{-1}$
μ	viscosity	$lb\ ft^{-1}\ hr^{-1}$
τ	shear stress	$lb\ ft^{-1}\ hr^{-2}$

APPENDIX I

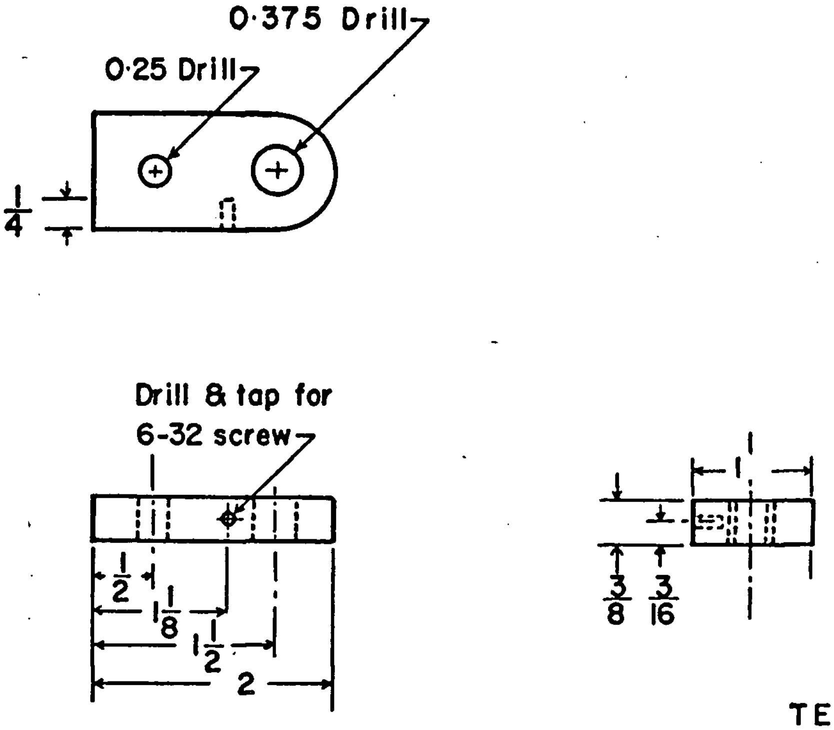
ELECTRICAL CONNECTIONS AND PRESSURE TAPS

(DRAWING FROM WATKINSON (7))



PRESSURE TAPS

Stainless steel
Dimensions - inches
Two required



TERMINAL BARS

Brass
Dimensions - inches
Two required

APPENDIX II

COMPUTER PROGRAMS

PROGRAM <u>PAR</u>


```
C      PROGRAM 'PAR' TO CALCULATE THE PARAMETERS OF A RUN
C      AND THE HEAT BALANCE
       DATA BETA/.602/,D2/.375/,C1/.8056/,C2/.97182/,CP/1.002/
1      READ(5,101,END=111)R,V,A
101    FORMAT(F3.0,1X,F5.1,1X,F5.1)
       WRITE(6,103)R
       WRITE(6,104)V,A
103    FORMAT(1H1,T7,7('*'),'RUN NO',F3.0,7('*'))
104    FORMAT(1H0,T7,'VOLTS:',F5.2,T25,'AMPS:'F5.0)
       READ(5,102)ZIN,ZOUT,DPOR
       DPOHG=-0.0761768+0.074429*DPOR+0.000467069*DPOR*DPOR
102    FORMAT(F4.2,1X,F4.2,1X,F5.2)
       TIN=26.8988+(51.355-1.76738*ZIN)*ZIN
       TOUT=24.7309+(53.2881-2.103*ZOUT)*ZOUT
       TBULK=(TIN+TOUT)/2.0
       TOR=TIN
       Q=3.413*V*A
       QF=Q/.1742
       WRITE(6,105)Q,QF
105    FORMAT(1H0,T7,'HEAT FLOW',F8.1,T27,'BTU/HR'/
      1T7,'HEAT FLUX',F9.0,T27,'BTU/SQFT-HR')
       CALL PROP(RHO,VISK,THK,TOR)
       ALPHA=1.0-BETA**4
       REORC=D2/12/VISK*RHO/6.7197/1E-4*SQRT(64.348*70.727*
      162.43*DPOHG*RHO/ALPHA)
       REORC=C1*REORC**C2
       W=D2*REORC*3.1416*VISK*6.7197/(12E4*RHO*4)
       WRITE(6,106)BETA,TOR,RHO,TOUT
106    FORMAT(1H0,T7,'BETA',F5.3,T25,'TOR=TINLET',F5.1,T43,
      1'DEG F',/T7,'DENSITY:',F5.3,T21,'GRAM/CC'/
      2T25,'T OUTLET',F5.1,T43,'DEG F')
       WRITE(6,107)W
107    FORMAT(1H0,T7,'FLOW RATE',F7.4,T25,'LBS.M/SEC')
       CALL PROP(RHO,VISK,THK,TBULK)
       UBULK=W/(RHO*62.43*6.425E-4)
       RE=UBULK*0.343*3600./(12.*VISK*0.03875)
       PR=2.42*CP*VISK*RHO/THK
       WRITE(6,108)TBULK,VISK
108    FORMAT(1H0,T7,'AVG TEMP:',F5.1,T25,'DEG F',
      1/T7,'KINEMATIC',/T7,'VISCOSITY:',F5.3,T25,'SQ.CM/SEC')
       WRITE(6,109)UBULK,RE,PR
109    FORMAT(1H0,T7,'FLUID VELOCITY',F6.3,T30,'FT/SEC',
      1/T7,'REYNOLDS NO',F9.1,/T7,'PRANDTL NO',F7.2)
       HTTR=W*3600.*(TOUT-TIN)*CP
       HLOSS=Q-HTTR
       PERL=HLOSS/Q*100.
       WRITE(6,110)Q,HTTR,HLOSS,PERL
110    FORMAT(1H0,T7,'HEAT SUPP ',F10.1,T30,'BTU/HR',/
      1T7,'HEAT TRANS',F10.1,T30,'BTU/HR',/
      2T7,'HEAT LOST ',F10.1,T30,'BTU/HR',/
      3T7,'PERCENT HEAT LOST',F8.2)
C      PREDICTED CLEAN WALL RESISTANCES FROM THE
C      SIEDER-TATE EQUATION
       XNU=0.023*(RE**0.8)*(PR**0.33)
       CALL PROP(RHO,VISK,THK,TBULK)
```

```
      XH=XNU*THK*12.0/0.343
      TWALL=QFLUX/XH+TBULK
      A=VISK
      C=THK
      CALL PROP(RHO,VISK,THK,TWALL)
      B=VISK
      XNU=XNU*((A/B)**0.14)
      RFILM=1000.0/(XNU*C*12.0/0.343)
      RWALL=(0.016/12.0/(8.45+0.00455*TWALL))*1000.
      RTOTAL=RFILM+RWALL
      XHTOT=1000.0/RTOTAL
      WRITE(6,120)XNU
120   FORMAT(//T7,'NUSSELT NO',F9.1)
      WRITE(6,121)RFILM,RWALL,RTOTAL
121   FORMAT(T7,'RFILM',F9.3,/T7,'RWALL',F9.3,/T7,'RTOTAL',
     1F9.3,T27,'SQ-FT-DEG F/BTU')
      GO TO 1
111   STOP
      END
      SUBROUTINE PROP(RHO,VISK,THK,T)
      RHO=0.988-(((T-32.)/1.8)-50.)*0.0006
      T=(T-32.)/1.8
      VISC=10.**((1.3272*(20.-T)-0.001053*(T-20.)**2)
     1/(T+105))
      VISK=VISC/RHO
      T=T*1.8+32.0
      THK=0.296938+0.834355E-3*T-0.180265E-5*T*T
      RETURN
      END
```

PROGRAM STOMV


```
C       THE FOLLOWING PROGRAM CONVERTS SOLARTRON READINGS TO
C       MILLIVOLTS,CHECKS FOR KEYPUNCHING ERRORS AND PLACES
C       INTO A STANDARD FORMAT FOR PROCESSING
C        CODED BY RMH 19 JAN 1971
        LL=0
        IUL=110000
3       RUNLAS=0.0
        TZERO=0.0
2       K=0
        DIMENSION IREAD(20),ZSTORE(20),Z(20),X(20)
        NLINE=0
1        READ(5,101,END=111)TIME,(IREAD(I),I=1,14)
        IFLAG=0
        Y=TIME
        MY=Y
        YY=MY
        TIME=YY+(Y-YY)*100.0/60.0
        IF(K.EQ.0)TZERO=TIME
        IF(TIME.GT.99.98)GO TO 3
        IF(TIME.LT.TZERO.AND.K.NE.0)TIME=TIME+24.00
        RUNTIM=TIME-TZERO
        IF(RUNTIM.LT.RUNLAS.AND.K.NE.0)RUNTIM=RUNTIM+24.00
        J=0
        RLTIME=TIME
        IF(RLTIME.GT.24.00)RLTIME=RLTIME-24.00
        RUNLAS=RUNTIM
        K=K+1
        NLINE=NLINE+1
        DO 623I=1,14
        IF(IREAD(I).GE.LL.AND.IREAD(I).LT.IUL)GO TO 632
        J=J+1
        IFLAG=I
        GO TO 623
632     ZSTORE(I)=IREAD(I)
623     CONTINUE
        DO 625I=1,20
625     Z(I)=ZSTORE(I)/2000.
C       THE FOLLOWING STATEMENTS PLACE DATA IN STD. FORMAT
C        CHECK NEXT 20 LINES BEFORE EACH NEW DATA SET
        X(1)=Y
        X(2)=RUNTIM
        X(3)=Z(1)
        X(4)=Z(2)
        X(5)=0.0
        X(6)=Z(3)
        X(7)=Z(4)
        X(8)=Z(5)
        X(9)=Z(6)
        X(10)=Z(7)
        X(11)=Z(8)
        X(12)=Z(10)
        X(13)=Z(11)
        X(14)=Z(12)
        X(15)=Z(13)
        X(16)=0.0
```

```
      X(17)=0.0
      X(18)=0.0
      X(19)=Z(9)
      X(20)=Z(14)
      IF(NLINE.EQ.57)NLINE=1
      IF(NLINE.NE.1)GO TO 150
      WRITE(6,103)
      WRITE(6,104)
150   WRITE(6,102)X,J,IFLAG
      WRITE(7,102)X,J,IFLAG
101   FORMAT(F5.3,14I5)
102   FORMAT(2X,F5.2,F6.2,3X,18F5.2,I3,2X,I3)
103   FORMAT('1',T3,'REAL',T11,'RUN',T19,'MV',T24,'MV',T28,
     1'MILLIVOLT READINGS OF THERMOCOUPLES ON WALL OF TEST SECTION
     2',T88,'COOL',T93,'INSL',T98,'AMB',T103,'DELT',T109,'FLAGS')
104   FORMAT(T3,'TIME',T11,'TIME',T18,'IN',T23,'OUT',T28,
     2'T215',T33,'T235',T38,'T255',T43,'T275',T48,'T295',
     3T53,'T315,'T58,'T335',T63,'T355',T68,'T375',T73,'T395',
     4T78,'T415',T83,'T428',T89,'MV',T94,'MV',T99,'MV',T104,'MV',
     5T108,'NO',T113,'LINE',/)
      GO TO 1
111   STOP
      END
```

PROGRAM <u>FOUL</u>


```
C      HEAT TRANSFER. FOULING
C      CODED BY O. MAYO 23-10-1970
C      UPDATED BY R.M. HOPKINS SEPT 1971
       DIMENSION Z(16),IREAD(16),M(16),T(12),TC(12),X(12),Y(12),T8(12),R
      1OT(700),TIM(700),TCON(12),COR(12),W(700),FCUL(700)
       DIMENSION TZERO(12),DT(12),RF(12)
C      PROGRAM 'PAR' TO CALCULATE THE PARAMETERS OF A RUN
C      AND THE HEAT BALANCE
       DATA BETA/.301/,D2/.1875/,C1/.8056/,C2/.97182/,CP/1.002/
1      READ(5,101,END=100)R,V,A
       READ(5,417)CONC
417    FORMAT(F6.0)
101    FORMAT(F3.0,1X,F5.1,1X,F5.1)
       WRITE(6,103)R
       WRITE(6,418)CONC
418    FORMAT(1H0,T7,'FERRIC OXIDE CONC (PPM)',F8.0)
       WRITE(6,104)V,A
103    FORMAT(1H1,T7,7('*'),'RUN NO',F3.0,7('*'))
104    FORMAT(1H0,T7,'VOLTS:',F5.2,T25,'AMPS:'F5.0)
       READ(5,102)ZIN,ZOUT,DPOR
       DPOHG=0.0761768+0.074429*DPOR+0.000467069*DPOR*DPOR
102    FORMAT(F4.2,1X,F4.2,1X,F5.2)
       TIN=26.8988+(51.355-1.76738*ZIN)*ZIN
       TOUT=24.7309+(53.2881-2.103*ZOUT)*ZOUT
       TBULK=(TIN+TOUT)/2.0
       TOR=TIN
       Q=3.413*V*A
       QF=Q/.1742
       WRITE(6,105)Q,QF
105    FORMAT(1H0,T7,'HEAT FLOW SUPPLIED',F8.1,T37,'BTU/HR'/
      1T7,'HEAT FLUX SUPPLIED',F9.0,T37,'BTU/SQFT-HR')
       CALL PROP(RHO,VISK,THK,TOR)
       ALPHA=1.0-BETA**4
       REORC=D2/12/VISK*RHO/6.7197/1E-4*SQRT(64.348*70.727*
      162.43*DPOHG*RHO/ALPHA)
       REORC=C1*REORC**C2
       WW=D2*REORC*3.1416*VISK*6.7197/(12E4*RHO*4)
       WRITE(6,106)BETA,TOR,RHO,TOUT
106    FORMAT(1H0,T7,'BETA',F5.3,T25,'TOR=TINLET',F5.1,T43,
      1'DEG F',/T7,'DENSITY:',F5.3,T21,'GRAM/CC'/
      2T25,'T OUTLET',F5.1,T43,'DEG F')
       WRITE(6,107)WW
107    FORMAT(1H0,T7,'FLOW RATE',F7.4,T25,'LBS.M/SEC')
       CALL PROP(RHO,VISK,THK,TBULK)
       UBULK=WW/(RHO*62.43*6.425E-4)
       RE=UBULK*0.343*3600./(12.*VISK*0.03875)
       PR=CP*VISK*RHO/THK*2.42
       WRITE(6,108)TBULK,VISK
108    FORMAT(1H0,T7,'AVG TEMP:',F5.1,T25,'DEG F',
      1/T7,'KINEMATIC',/T7,'VISCOSITY:',F5.3,T25,'SQ.CM/SEC')
       WRITE(6,109)UBULK,RE,PR
109    FORMAT(1H0,T7,'FLUID VELOCITY',F6.3,T30,'FT/SEC',
      1/T7,'REYNOLDS NO',F9.1,/T7,'PRANDTL NO',F7.2)
       HTTR=WW*3600.*(TOUT-TIN)*CP
       HLOSS=Q-HTTR
```

```
      PERL=HLOSS/Q*100.
      QFT=HTTR/.1742
      WRITE(6,110)Q,HTTR,HLOSS,PERL,QFT
110   FORMAT(1H0,T7,'HEAT SUPP ',F10.1,T30,'BTU/HR',/
     1T7,'HEAT TRANS',F10.1,T30,'BTU/HR',/
     2T7,'HEAT LOST ',F10.1,T30,'BTU/HR',/
     3T7,'PERCENT HEAT LOST',F8.2,/
     4T7,'HEAT FLUX TRANS. BTU/SQFT-HR',F9.0)
C     PREDICTED CLEAN WALL RESISTANCES FROM THE
C     SIEDER-TATE EQUATION
      XNU=0.023*(RE**0.8)*(PR**0.33)
      CALL PROP(RHO,VISK,THK,TBULK)
      XH=XNU*THK*12.0/0.343
      TWALL=QFT/XH+TBULK
      A=VISK
      C=THK
      CALL PROP(RHO,VISK,THK,TWALL)
      B=VISK
      XNU=XNU*((A/B)**0.14)
      RFILM=1000.0/(XNU*C*12.0/0.343)
      RWALL=(0.016/12.0/(8.45+0.00455*TWALL))*1000.
      RTOTAL=RFILM+RWALL
      XHTOT=1000.0/RTOTAL
      WRITE(6,120)XNU
120   FORMAT(//T7,'NUSSELT NO',F9.1)
      WRITE(6,121)RFILM,RWALL,RTOTAL
121   FORMAT(T7,'RFILM',F9.3,/T7,'RWALL',F9.3,/T7,'RTOTAL',
     1F9.3,T27,'SQFT-HR-DEG F/BTU')
      WRITE(6,150)
      WRITE(7,151)
      DO 830 I=1,12
      DT(I)=0.0
      RF(I)=0.0
      TZERO(I)=0.0
830   CONTINUE
C     DATA TRANSFORMATION AND LINES ELIMINATION
      NLINE=0
      READ(5,171)M
      JP=0
      ZERO=0.0
2     READ(4,112,END=10)RLTIM,(Z(I),I=1,16)
      JP=JP+1
      TIME=Z(1)
112   FORMAT(2X,F5.2,F6.2,3X,15F5.2)
      NLINE=NLINE+1
C     TEMPERATURE EVALUATIONS
      TIN=26.8988+(51.355-1.76738*Z(2))*Z(2)
      TOUT=24.7309+(53.2881-2.103*Z(3))*Z(3)
      CALL TEMP(Z,T)
      DELTA=TOUT-TIN
C  CORRECTION FOR DROP THROUGH TUBE WALL
      DO 5 I=1,12
      TCON(I)=8.45+0.00455*T(I)
      COR(I)=QDIS*0.0411755/(2.*3.1416*1.9488*TCON(I))
      TC(I)=T(I)-COR(I)
      IF(M(I+3).NE.0)TC(I)=0.
      IF(JP.EQ.1)TZERO(I)=T(I)
      DT(I)=T(I)-TZERO(I)
      IF(M(I+3).NE.0)DT(I)=0.0
      IF(DT(I).LE.0.0)GO TO 87
```

```
      RF(I)=DT(I)/QFT*100000.
      GO TO 5
87    RF(I)=0.0
5      CONTINUE
      M1=0
      X0=1.27
      DO 6 I=1,10
      X0=X0+5.08
      X(I)=X0
      TB(I)=DELTA/57.785*X(I)+TIN
      M1=M1+M(I+4)
      Y(I)=TC(I+1)-TB(I)
    6 CONTINUE
      TM=0
      SY=0.
      SX1=0.
      SX2=0.
      SX1Y=0.
      SX2Y=0.
      SX1X2=0.
      SSX1=0.
      SSX2=0.
      DO 7 I=1,10
      IF(M(I+4).NE.0) GO TO 7
      TM=TM+TC(I+1)
      SY=SY+Y(I)
      SX1=SX1+X(I)
      SSX1=SSX1+X(I)*X(I)
      SSX2=SSX2+X(I)**4
      SX1X2=SX1X2+X(I)**3
      SX1Y=SX1Y+X(I)*Y(I)
      SX2Y=SX2Y+X(I)*X(I)*Y(I)
    7 CONTINUE
      FN=10-M1
      TM=TM/FN
      IF(JP.EQ.1)ZERO=TM
      FOUL(NLINE)=(TM-ZERO)/QFT*100000.
      FOUX=FOUL(NLINE)
      SX2=SSX1
      B=SSX1-((SX1**2)/FN)
      C=SX1X2-SX1*SX2/FN
      D=SX1Y-SX1*SY/FN
      F=SSX2-(SX2**2)/FN
      G=SX2Y-SX2*SY/FN
      B2=(D*C-G*B)/(C*C-F*B)
      B1=(D-B2*C)/B
      B0=(SY-B1*SX1-B2*SX2)/FN
      AA=B2
      BB=B1
      CC=B0
      VV1=2*AA*52.07+BB
      VV2=2*AA*6.35+BB
      DISC=BB**2-4.*AA*CC
      IF(DISC.GT.0) GO TO 8
      RMDIS=SQRT(-1.*DISC)
      AREA1=2./RMDIS*(ATAN(VV1/RMDIS))
      AREA2=2./RMDIS*(ATAN(VV2/RMDIS))
      GO TO 9
    8 CONTINUE
      RDIS=SQRT(DISC)
```

```
      EXTERNAL AUX
      CALL DPLQF(X,Y,YF,W,E1,E2,P,0.0,N,M,NI,ND,EP,AUX)
      WRITE(6,100)
      WRITE(6,20)
   20 FORMAT(' ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE
     1RAMETER')
      WRITE(6,103)(E1(I),I=1,M)
      WRITE(6,30)
   30 FORMAT(' ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAME
     1RS')
      WRITE(6,103)(E2(I),I=1,M)
      A=EXP(P(1))*1000
      B=EXP(P(2))*1000
      C=EXP(P(3))
      WRITE(6,60)
   60 FORMAT( ' ESTIMATES OF PARAMETERS RO , RINF  AND  B')
      WRITE(6,103)A,B,C
      WRITE(6,40)
   40 FORMAT(T6,'TIME',T20,'CALC. RESISTANCE',T40,'FITTED VALUE',/T6,'H
     1URS',T25,'((SQFT-HR-DEGF/BTU)X1000)',/)
      DO 50 I=1,N
      Y(I)=Y(I)*1000
      YF(I)=YF(I)*1000
   50 WRITE(6,102)X(I),Y(I),YF(I)
      WRITE(6,100)
  100 FORMAT(1H1)
  102 FORMAT(F10.2,2(10X,F10.4))
  103 FORMAT(3(F10.5,10X))
      RETURN
      END
      FUNCTION AUX(P,D,X,L)
      DIMENSION P(3),D(3)
      D(1)=EXP(P(1))
      D(2)=-EXP(P(2))*EXP(-EXP(P(3))*X)
      D(3)=D(2)*(-EXP(P(3)))*X
      AUX=D(1)+D(2)
      RETURN
      END
      SUBROUTINE TEMP(Z,T)
      DIMENSION Z(16),T(12)
      DO 620I=1,12
      T(I)=-0.59362*Z(I+3)*Z(I+3)+43.551*Z(I+3)+36.5808
620   CONTINUE
      RETURN
      END
      SUBROUTINE PFIT(Y,X,N)
C  PROGRAM TO FIND THE BEST FIT OF AN EXPONENTIAL CURVE FOR THE
C     FOULING TOTAL RESISTANCE VS. TIME DATA
C  N=NUMBER OF POINTS,NI=NUMBER OF ITERATIONS,EP=ERROR PERMITED
C   THE EXPONENTIAL EQ. IS Y=  B( 1- EXP( -C*X ))
C   AB&C ARE SUBSTITUTED BY   B=EXP(P(1)), C=EXP(P(2))
      DIMENSION X(700),Y(700),YF(700),W(700),E1(2),E2(2),P(2)
      DATA M,NI,EP/2,20,0.001/
      P(1)=1.79
      P(2)=0.0
      EXTERNAL PAUX
      CALL DPLQF(X,Y,YF,W,E1,E2,P,0.0,N,M,NI,ND,EP,PAUX)
      WRITE(6,100)
      WRITE(6,20)
   20 FORMAT(' ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE P
```

```
     1RAMETER')
      WRITE(6,103)(E1(I),I=1,M)
      WRITE(6,30)
   30 FORMAT(' ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMET
     1RS')
      WRITE(6,103)(E2(I),I=1,M)
      A=0.0
      B=EXP(P(1))
      C=EXP(P(2))
      WRITE(6,60)
60    FORMAT( 'ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)')
      WRITE(6,103)A,B,C
      WRITE(6,40)
   40 FORMAT(T6,'TIME',T20,'CALC. RESISTANCE',T40,'FITTED VALUE',/T6,'H
     1URS',T22,'((SQFT-HR-DEGF/BTU)X100,000)',/)
      DO 50 I=1,N
   50 WRITE(6,102)X(I),Y(I),YF(I)
      WRITE(6,100)
  100 FORMAT(1H1)
  102 FORMAT(F10.2,2(10X,F10.2))
  103 FORMAT(2X,3(G10.5,10X))
      RETURN
      END
      FUNCTION PAUX(P,D,X,L)
      DIMENSION P(2),D(2)
      D(1)=EXP(P(1))*(1.0-EXP(-(EXP(P(2))*X)))
      D(2)=EXP(P(1))*EXP(P(2))*X*EXP(-EXP(P(2))*X)
      PAUX=D(1)
      RETURN
      END
```

```
      VV3=ABS((VV1-RDIS)/(VV1+RDIS))
      VV4=ABS((VV2-RDIS)/(VV2+RDIS))
      AREA1=1/RDIS*ALOG(VV3)
      AREA2=1/RDIS*ALOG(VV4)
    9 AREA=AREA1-AREA2
      QW=QFT*45.72/57.785
      DTM=57.785/AREA*(TB(10)-TB(1))/(DELTA)
      H=QW/DTM
      R=1000/H
      TIM(NLINE)=TIME
      IF(NLINE.EQ.1)W(NLINE)=1
      IF(NLINE.GT.1)W(NLINE)=(TIM(NLINE)-TIM(NLINE-1))/.6
      WRITE(6,113)(TC(I),I=1,12),TIN,TOUT,TM,DELTA,H,R,TIME
      WRITE(7,114)(RF(I),I=1,12),TIN, TOUT,FOUX,DELTA,H,R,TIME
      RTOT(NLINE)=1/H
      GO TO 2
10    WRITE(6,73)
73    FORMAT('1')
      CALL PFIT(FOUL,TIM,NLINE)
      CALL BFIT(RTOT,TIM,NLINE)
      GO TO 100
150   FORMAT('1',T3,'LOCALIZED WALL TEMPERATURES (DEG.F)'
     1,/T3,'T215',T10,'T235',T17,'T255',T24,'T275',
     2T31,'T295',T38,'T315',T45,'T335',T52,'T355',T59,'T375',T66,
     3'T395',T73,'T415',T80,'T428',T88,'TIN',T94,'TOUT',T102,
     2T88,'TIN',T94,'TOUT',T102,'TM',T108,'DELTA',T116,'H',
     3T123,'R',T128,'TIME',/16(2X,'DEG.F'),T121,'X1000',T128,'HOURS'
151   FORMAT('1',T3,'LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)
     1,T50,'X100,000',/T3,'T215',T10,'T235',T17,'T255',T24,'T275',
     2T31,'T295',T38,'T315',T45,'T335',T52,'T355',T59,'T375',T66,
     3'T395',T73,'T415',T80,'T428',T88,'TIN',T94,'TOUT',T102,
     4'RFM',T108,'DELTA',T116,'H',T120,'RTOT',T128,'TIME',/T85,
     5(2X,'DEG.F',2X,'DEG.F',9X,'DEG.F'),T120,'X1000',T128,'HOURS',/
  171 FORMAT(12I1)
  113 FORMAT(15F7.1,F6.1,F7.1,F7.4,F7.2)
114   FORMAT(12F7.2,2F7.1,F7.2,F6.1,F7.1,F7.4,F7.2)
  100 STOP
C
      END
      SUBROUTINE PROP(RHO,VISK,THK,T)
      RHO=0.988-(((T-32.)/1.8)-50.)*0.0006
      T=(T-32.)/1.8
      VISC=10.**((1.3272*(20.-T)-0.001053*(T-20.)**2)
     1/(T+105))
      VISK=VISC/RHO
      T=T*1.8+32.0
      THK=0.296938+0.834355E-3*T-0.180265E-5*T*T
      RETURN
      END
      SUBROUTINE BFIT(Y,X,N)
C  PROGRAM TO FIND THE BEST FIT OF AN EXPONENTIAL CURVE FOR THE
C     FOULING TOTAL RESISTANCE VS. TIME DATA
C  N=NUMBER OF POINTS,NI=NUMBER OF ITERATIONS,EP=ERROR PERMITED
C   THE EXPONENTIAL EQ. IS Y= A + B( 1- EXP( -C*X ))
C   AB&C ARE SUBSTITUTED BY  A=EXP(P(1)), B=EXP(P(2)), C=EXP(P(3))
      DIMENSION X(700),Y(700),YF(700),W(700),E1(3),E2(3),P(3)
      DATA M,NI,EP/3,20,0.001/
      P(1)=ALOG(Y(1))
      P(2)=0.0
      P(3)=0
```

PROGRAM MODEL

```
C      RUNGE KUTTA METHOD FOR FITTING FOULING EQUATIONS
       REAL K2T,KH,K1
       COMMON K2T,KH,K1,NT
       DIMENSION XHNT(240),Y(3),F(3),Q(3),XNT(240),T(240),XKSNT(240)
       DIMENSION XENT(240)
1      READ(5,101,END=111) PHID,K2T,KH,K1
       PHID=PHID/60.
       K2T=K2T/60.0
       XKSNT(1)=0.0
       XHNT(1)=PHID/K2T
       DO 801 J=2,240
       XHNT(J)=ALOG(K1*KH*(J-1)*60.+EXP(K1*PHID/K2T))/K1
801    XKSNT(J)=(1.-EXP(-K2T*(J-1)))*PHID/K2T
       J=0
       DO 802 J=1,240
802    T(J)=(J-1)/60.
101    FORMAT(F20.5)
       H=1.
       M=1
       N=3
       DO 11 NT=1,2
       Y(1)=0.0
       Y(2)=0.0
       Y(3)=PHID
       J=0
       DO 10 I=1,240
       CALL RK(Y,F,Q,H,N,M)
       J=J+1
       IF(NT.EQ.1)XNT(J)=Y(2)
       IF(NT.EQ.2)XENT(J)=Y(2)
10     CONTINUE
11     CONTINUE
       DO 623 J=1,240,10
623    WRITE(6,103)T(J),XKSNT(J),XNT(J),XENT(J),XHNT(J)
103    FORMAT(G13.3,4X,4G13.4)
       GO TO 1
111    STOP
       END
       SUBROUTINE AUXRK(Y,F)
       REAL K2T,KH,K1
       COMMON K2T,KH,K1,NT
       DIMENSION Y(3),F(3)
       F(2)=Y(3)
       IF(NT.EQ.2)F(3)=K2T*KH*EXP(-Y(2)*K1)-K2T*Y(3)
       IF(NT.EQ.1)F(3)=K2T*KH-K2T*Y(3)-K2T*KH*K1*Y(2)
       RETURN
       END
```

APPENDIX III

COMPUTATION OF THERMOPHORETIC VELOCITY FOR RUN 63

According to McNab (33), the thermophoretic velocity of a particle in a thermal gradient is independent of particle diameter and given by

$$V_{th} = -0.26 \frac{k_f}{2k_f + k_p} \cdot \frac{\mu}{\rho T_K} \nabla T \qquad (6.5)$$

where V_{th} = thermophoretic velocity

k_f = thermal conductivity of the fluid

k_p = thermal conductivity of the particle

μ = fluid viscosity

ρ = fluid density

T_K = absolute temperature

$\nabla T = \frac{dT}{dy}$ = temperature gradient

Assuming that the region of prime interest with respect to fouling is the viscous sublayer adjacent to the heat transfer surface, the temperature gradient can be found by noting that

$$q' = h(T_w - T_b) = k_f \left.\frac{dT}{dy}\right|_{wall} \qquad \text{(III.1)}$$

where q' = heat flux

h = heat transfer coefficient

T_w = wall temperature

T_b = bulk temperature

Hence

$$\left.\frac{dT}{dy}\right|_{wall} = \frac{h}{k_f}\,(T_w - T_b) \qquad \text{(III.2)}$$

Substituting equation (III.2) into equation (III.1) gives

$$V_{th} = -0.26\,\frac{k_f}{2k_f + k_p}\cdot\frac{\mu}{\rho T_K}\cdot\frac{h}{k_f}\,(T_w - T_b) \qquad \text{(III.3)}$$

Equation (III.3) can be made dimensionless by multiplying through by D/DU_b, which yields

$$\frac{V_{th}}{U_b} = +0.26 \frac{k_f}{2k_f + k_p} \cdot \left(\frac{\mu}{DU_b\rho}\right) \cdot \left(\frac{hD}{k_f}\right) \frac{(T_w - T_b)}{T_K} \qquad \text{(III.4)}$$

where U_b = bulk velocity

D = tube diameter

In terms of dimensionless groupings, equation (III.4) becomes

$$\frac{V_{th}}{U_b} = +0.26\left(\frac{k_f}{2k_f + k_p}\right) \cdot \left(\frac{N_u}{R_e}\right)\left(\frac{T_w - T_b}{T_K}\right) \qquad \text{(III.5)}$$

For Run 63, the heat flux used was 91,400 BTU/ft^2-hr and the maximum temperature rise was 2.6F°. If the deposit thickness is taken to be 100 microns, a typical figure based upon microscopic measurements, the thermal conductivity of the deposit k_d can be computed from the relationship

$$q' = -k_d \frac{dT}{dx} \qquad \text{(III.6)}$$

where $\frac{dT}{dx}$ = thermal gradient across the deposit

Therefore

$$k_d = \frac{q'}{\frac{dT}{dx}} = \frac{91,400}{\frac{2.6}{100} \times 10^4 \times 2.54 \times 12} = 11.5 \text{ BTU/hr-ft-°F} \cong k_p$$

which somewhat exceeds the estimate of 7.2 on page 75.

From program PAR, the remaining variables in equation (III.) are as follows:

k_f = 0.388 BTU/hr-ft-°F

N_u = 121

R_e = 26490

T_w = 181 °F

T_b = 138 °F

T_K = 640 °R

U_b = 4.79 ft/sec

Substituting these values into equation (III.5) gives

$$V_{th} = \frac{0.26 \times 0.388 \times 121 \times (181 - 138)}{(2 \times 0.388 + 11.5) \times 26{,}490 \times 640}$$

$$= 2.58 \times 10^{-6}$$

The thermophoretic velocity is therefore

$$V_{th} = 2.58 \times 10^{-6} \times U_b$$

$$= 2.58 \times 10^{-6} \times 4.79 \times 12 \times 2.54 \times 10^{4}$$

$$= 3.7 \text{ microns/second}$$

That is, under the operating conditions of Run 63, a particle in close proximity to the wall will tend to migrate away from the wall at a velocity of 3.7 microns/second.

It has been pointed out by Keng and Orr (40) that use of an equation such as (6.6) to compute thermophoretic velocities leads to low results when the thermal conductivity of the particle is more than ten times the thermal conductivity of the fluid. For the example used here, this ratio is approximately thirty. The estimate of thermophoretic velocity computed for Run 63 is therefore considered to be conservative.

APPENDIX IV

EXPERIMENTAL DATA

*******RUN NO33.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.33 AMPS: 254.

HEAT FLOW SUPPLIED 8098.2 BTU/HR
HEAT FLUX SUPPLIED 45430. BTU/SQFT-HR

BETA0.301 TCR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4 DEG F
KINEMATIC
VISCOSITY:0.496 SQ.CM/SEC

FLUID VELOCITY 3.655 FT/SEC
REYNOLDS NO. 19550.0
PRANDTL NO 3.15

HEAT SUPP 8088.2 BTU/HR
HEAT TRANS 7727.9 BTU/HR
HEAT LOST 360.3 BTU/HR
PERCENT HEAT LOST 4.45
HEAT FLUX TRANS. BTU/SQFT-HR 44362.
NUSSELT NO 94.6
RFILM 0.803
RWALL 0.144
RTOTAL 0.947 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.41682E-01 .19634
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.14264 .67193
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 8.5010 .26422

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
2.53	5.52	4.14
4.92	5.72	6.18
5.08	5.82	6.28
6.96	6.72	7.16
23.08	10.72	8.48
27.50	11.02	8.50
32.50	11.72	8.50
35.08	9.62	8.50
47.08	10.72	8.50
47.75	11.02	8.50
24.33	2.51	8.49
46.75	1.00	8.50

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	154.3	153.9	159.1	159.1	160.7	157.5	156.3	0.0	162.3	165.9	0.0	127.0	141.8	158.8	14.9	1434.5	0.6971	0.0
0.0	157.1	156.3	161.9	161.5	163.1	159.5	158.7	0.0	164.3	168.7	0.0	127.4	142.2	161.2	14.8	1328.1	0.7530	2.53
0.0	156.7	156.3	161.5	161.5	163.1	159.9	158.7	0.0	164.7	169.5	0.0	126.5	141.8	161.3	15.3	1290.5	0.7749	4.92
0.0	157.5	156.3	162.3	161.5	163.5	159.9	157.1	0.0	165.1	169.1	0.0	127.0	142.2	161.4	15.3	1313.9	0.7611	5.08
0.0	157.1	156.3	162.3	162.3	163.9	160.3	159.1	0.0	165.1	169.5	0.0	127.0	142.2	161.8	15.3	1288.4	0.7762	6.98
0.0	158.7	157.5	163.5	164.3	165.1	161.9	161.1	0.0	166.7	171.1	0.0	127.0	142.2	163.5	15.3	1211.2	0.8256	23.08
0.0	159.1	158.3	164.3	164.3	165.1	162.7	161.5	0.0	167.1	170.7	0.0	126.5	141.4	163.7	14.9	1176.7	0.8498	27.50
0.0	160.7	159.5	163.1	164.3	165.5	162.3	161.5	0.0	167.9	171.1	0.0	127.8	142.7	164.0	14.8	1223.4	0.8174	32.50
0.0	159.9	158.7	163.9	163.1	163.9	160.7	159.9	0.0	166.7	170.7	0.0	126.5	141.8	163.0	15.3	1221.7	0.8185	35.08
0.0	159.9	158.7	163.5	164.3	165.1	162.3	161.1	0.0	167.1	169.9	0.0	127.4	142.2	163.5	14.8	1221.0	0.8190	47.08
0.0	159.5	158.7	163.9	163.5	166.3	161.5	161.9	0.0	165.9	171.9	0.0	127.4	142.2	163.7	14.8	1215.1	0.8230	47.75
0.0	157.1	154.7	159.9	159.5	161.1	158.7	157.9	0.0	163.1	167.1	0.0	126.5	141.8	159.9	15.3	1367 4	0.7313	24.33
0.0	154.3	153.9	159.5	159.1	161.1	158.3	157.5	0.0	162.7	166.7	0.0	127.0	141.8	159.2	14.9	1405.1	0.7117	46.75

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	141.8	0.0	14.9	1434.5	0.6971	0.0
0.0	6.34	5.44	6.32	5.41	5.41	4.52	5.43	0.0	4.50	6.28	0.0	127.4	142.2	5.52	14.8	1328.1	0.7530	2.53
0.0	5.43	5.44	5.41	5.41	5.41	5.42	5.43	0.0	5.40	8.08	0.0	126.5	141.8	5.72	15.3	1290.5	0.7749	4.92
0.0	7.24	5.44	7.22	5.41	6.31	5.42	1.81	0.0	6.30	7.18	0.0	127.0	142.2	5.82	15.3	1313.9	0.7611	5.09
0.0	6.34	5.44	7.22	7.22	7.21	6.32	6.33	0.0	6.30	8.08	0.0	127.0	142.2	6.72	15.3	1288.4	0.7762	6.98
0.0	9.96	12.67	9.92	11.72	9.91	9.93	10.84	0.0	7.90	11.66	0.0	127.0	142.2	10.72	15.3	1211.2	0.8256	23.08
0.0	10.86	9.96	11.72	11.72	9.91	11.73	11.74	0.0	10.79	10.77	0.0	126.5	141.4	11.02	14.9	1176.7	0.8498	27.50
0.0	14.47	12.67	9.02	11.72	10.81	10.83	11.74	0.0	12.59	11.66	0.0	127.8	142.7	11.72	14.8	1223.4	0.8174	32.50
0.0	12.66	10.86	10.82	9.02	7.21	7.23	8.14	0.0	7.70	10.77	0.0	126.5	141.8	9.62	15.3	1221.7	0.8185	35.08
0.0	12.66	10.86	9.92	11.72	9.91	10.83	10.84	0.0	10.79	8.97	0.0	127.4	142.2	10.72	14.8	1221.0	0.8190	47.08
0.0	11.76	10.86	10.82	9.92	12.60	9.03	12.65	0.0	8.10	13.45	0.0	127.4	142.2	11.02	14.8	1215.1	0.8230	47.75
0.0	6.34	1.81	1.81	0.90	0.90	2.71	3.62	0.0	1.80	2.70	0.0	126.5	141.8	2.51	15.3	1367.4	0.7313	24.33
0.0	0.0	0.0	0.90	0.0	0.90	1.81	2.71	0.0	0.90	1.80	0.0	127.0	141.8	1.00	14.9	1405.1	0.7117	46.75

```
*******RUN NO34.*******

FERRIC OXIDE CONC (PPM)    2130.

VOLTS: 9.35        AMPS: 253.

HEAT FLOW SUPPLIED  8073.6    BTU/HR
HEAT FLUX SUPPLIED   46347.   BTU/SQFT-HR

BETAO.301          TOR=TINLET127.0   DEG F
DENSITY:0.986 GRAM/CC
                   T OUTLET141.8     DEG F

FLOW RATE 0.1442  LBS.M/SEC

AVG TEMP:134.4     DEG F
KINEMATIC
VISCOSITY:0.496    SQ.CM/SEC

FLUID VELOCITY 3.655   FT/SEC
REYNOLDS NO  19550.0
PRANDTL NO   3.15

HEAT SUPP       8073.6   BTU/HR
HEAT TRANS      7727.9   BTU/HR
HEAT LOST        345.7   BTU/HR
PERCENT HEAT LOST     4.28
HEAT FLUX TRANS. BTU/SQFT-HR    44362.
NUSSELT NO        94.6
RFILM     0.803
RWALL     0.144
RTOTAL     0.947      SQFT-HR-DEG F/BTU
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ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
 .20350              .46327
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
 .13583              .30921
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
 .0                  5.6774              1.2677
```

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.08	1.30	0.55
0.13	0.30	0.66
0.17	1.20	1.10
0.28	0.70	1.70
0.38	1.60	2.17
0.52	2.91	2.74
0.58	4.21	2.96
1.30	3.91	4.58
1.45	5.11	4.77
1.67	5.21	4.99
2.10	5.11	5.28

Only data for first 2.1 hours are processed here.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	154.7	154.3	159.9	159.9	161.1	158.7	157.9	0.0	162.7	166.7	0.0	126.5	141.8	159.5	15.3	1376.4	0.7266	0.0
0.0	155.1	155.1	160.3	160.3	161.9	159.1	157.9	0.0	163.5	167.9	0.0	126.5	141.8	160.1	15.3	1347.0	0.7424	0.08
0.0	155.1	154.7	159.9	159.9	161.5	158.7	157.5	0.0	162.7	167.1	0.0	126.5	141.4	159.7	14.9	1359.8	0.7354	0.13
0.0	155.5	155.1	160.3	160.3	161.9	159.1	157.9	0.0	163.5	167.1	0.0	126.5	141.4	160.1	14.9	1338.6	0.7471	0.17
0.0	155.1	154.7	160.3	159.9	161.5	158.7	157.9	0.0	163.5	167.1	0.0	126.5	141.4	159.8	14.9	1349.6	0.7410	0.28
0.0	155.5	155.1	160.7	160.3	161.9	159.1	158.3	0.0	163.5	167.9	0.0	126.5	141.4	160.2	14.9	1329.6	0.7521	0.38
0.0	155.9	155.5	161.1	161.1	162.7	159.9	158.7	0.0	163.9	168.7	0.0	127.0	141.4	160.8	14.4	1310.2	0.7632	0.52
0.0	156.7	156.3	161.9	161.9	163.1	160.3	159.1	0.0	164.3	169.1	0.0	127.0	141.8	161.4	14.9	1294.7	0.7724	0.58
0.0	156.3	155.9	161.5	161.5	163.1	160.3	159.1	0.0	164.7	169.1	0.0	127.0	141.8	161.3	14.9	1299.3	0.7696	1.30
0.0	156.7	156.7	162.3	161.9	163.5	160.7	159.9	0.0	165.1	169.5	0.0	127.0	141.8	161.8	14.9	1274.2	0.7848	1.45
0.0	157.1	156.7	162.3	162.3	163.9	160.7	159.5	0.0	165.1	169.1	0.0	126.5	141.8	161.8	15.3	1263.2	0.7917	1.67
0.0	156.7	157.1	162.3	162.3	163.9	160.7	159.5	0.0	164.7	169.1	0.0	127.0	141.8	161.8	14.9	1274.4	0.7847	2.10

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	141.8	0.0	15.3	1376.4	0.7266	0.0
0.0	0.91	1.81	0.90	0.90	1.60	0.90	0.0	0.0	1.80	2.69	0.0	126.5	141.8	1.30	15.3	1347.0	0.7424	0.08
0.0	0.91	0.91	0.0	0.0	0.90	0.0	0.0	0.0	0.0	0.90	0.0	126.5	141.4	0.30	14.9	1359.8	0.7354	0.13
0.0	1.81	1.81	0.90	0.90	1.60	0.90	0.0	0.0	1.80	0.90	0.0	126.5	141.4	1.20	14.9	1338.6	0.7471	0.17
0.0	0.91	0.91	0.90	0.0	0.90	0.0	0.0	0.0	1.80	0.90	0.0	126.5	141.4	0.70	14.9	1349.6	0.7410	0.28
0.0	1.81	1.61	1.80	0.90	1.60	0.90	0.90	0.0	1.80	2.69	0.0	126.5	141.4	1.60	14.9	1329.6	0.7521	0.38
0.0	2.72	2.72	2.71	2.71	3.61	2.71	1.81	0.0	2.70	4.49	0.0	127.0	141.4	2.91	14.4	1310.2	0.7632	0.52
0.0	4.53	4.53	4.51	4.51	4.51	3.61	2.71	0.0	3.60	5.38	0.0	127.0	141.8	4.21	14.9	1294.7	0.7724	0.58
0.0	3.62	3.62	3.61	3.61	4.51	3.61	2.71	0.0	4.50	5.38	0.0	127.0	141.8	3.91	14.9	1299.3	0.7696	1.30
0.0	4.53	5.43	5.41	4.51	5.41	4.51	4.52	0.0	5.40	6.29	0.0	127.0	141.8	5.11	14.9	1274.2	0.7848	1.45
0.0	5.43	5.43	5.41	5.41	6.31	4.51	3.61	0.0	5.40	5.38	0.0	126.5	141.8	5.21	15.3	1263.2	0.7917	1.67
0.0	4.53	6.34	5.41	5.41	6.31	4.51	3.61	0.0	4.50	5.38	0.0	127.0	141.8	5.11	14.9	1274.4	0.7847	2.10

*******RUN NO34.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4 DEG F
KINEMATIC
VISCOSITY:0.496 SQ.CM/SEC

FLUID VELOCITY 3.655 FT/SEC
REYNOLDS NO 19550.0
PRANDTL NO 3.15

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7727.9 BTU/HR
HEAT LOST 345.7 BTU/HR
PERCENT HEAT LOST 4.28
HEAT FLUX TRANS. BTU/SQFT-HR 44362.
NUSSELT NO 94.6
RFILM 0.803
RWALL 0.144
RTOTAL 0.947 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAM
.66787E-01 .29820
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.77697E-01 .34691
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 4.6395 1.8926

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.08	1.30	0.65
0.13	0.30	1.01
0.17	1.20	1.28
0.28	0.70	1.91
0.38	1.60	2.38
0.52	2.91	2.91
0.58	4.21	3.09
1.30	3.91	4.24
1.45	5.11	4.34
1.67	5.21	4.44
2.10	5.11	4.55
2.40	6.11	4.59
2.67	6.41	4.61
3.43	3.41	4.63
3.52	3.51	4.63
3.60	2.91	4.63
4.20	4.51	4.64
4.67	3.91	4.64
6.50	2.71	4.64
23.68	6.71	4.64

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	XI
0.0	154.7	154.3	159.9	159.9	161.1	158.7	157.9	0.0	162.7	166.7	0.0	126.5	141.8	159.5	15.3	1376.4	0.7
0.0	155.1	155.1	160.3	160.3	161.9	159.1	157.9	0.0	163.5	167.9	0.0	126.5	141.8	160.1	15.3	1347.0	0.7
0.0	155.1	154.7	159.9	159.9	161.5	158.7	157.5	0.0	162.7	167.1	0.0	126.5	141.4	159.7	14.9	1359.8	0.7
0.0	155.5	155.1	160.3	160.3	161.9	159.1	157.9	0.0	163.5	167.1	0.0	126.5	141.4	160.1	14.9	1338.6	0.7
0.0	155.1	154.7	160.3	159.9	161.5	158.7	157.9	0.0	163.5	167.1	0.0	126.5	141.4	159.8	14.9	1349.6	0.7
0.0	155.5	155.1	160.7	160.3	161.9	159.1	158.3	0.0	163.5	167.9	0.0	126.5	141.4	160.2	14.9	1329.6	0.7
0.0	155.9	155.5	161.1	161.1	162.7	159.9	158.7	0.0	163.9	168.7	0.0	127.0	141.4	160.8	14.4	1310.2	0.7
0.0	156.7	156.3	161.9	161.9	163.1	160.3	159.1	0.0	164.3	169.1	0.0	127.0	141.8	161.4	14.9	1294.7	0.7
0.0	156.3	155.9	161.5	161.5	163.1	160.3	159.1	0.0	164.7	169.1	0.0	127.0	141.8	161.3	14.9	1299.3	0.7
0.0	156.7	156.7	162.3	161.9	163.5	160.7	159.9	0.0	165.1	169.5	0.0	127.0	141.8	161.8	14.9	1274.2	0.7
0.0	157.1	156.7	162.3	162.3	163.9	160.7	159.5	0.0	165.1	169.1	0.0	126.5	141.8	161.8	15.3	1263.[illegible]	0.7
0.0	156.7	157.1	162.3	162.3	163.9	160.7	159.5	0.0	164.7	169.1	0.0	127.0	141.8	161.8	14.9	1274.[illegible]	0.78
0.0	157.1	157.1	163.1	162.7	164.3	161.1	159.9	0.0	165.5	169.5	0.0	126.5	141.8	162.2	15.3	1244.2	0.80
0.0	157.1	157.1	163.1	163.1	164.3	161.5	159.9	0.0	165.5	169.9	0.0	127.0	141.8	162.4	14.9	1247.0	0.80
0.0	157.1	156.7	161.9	161.5	162.7	159.9	158.7	0.0	163.5	167.5	0.0	127.0	141.8	161.0	14.9	1315.6	0.76
0.0	157.1	156.7	161.9	161.5	162.7	159.9	158.7	0.0	163.5	167.9	0.0	127.0	141.8	161.1	14.9	1313.6	0.76
0.0	157.1	157.1	161.9	161.5	162.3	159.5	157.9	0.0	163.1	157.1	0.0	127.0	141.8	160.8	14.9	1330.3	0.75
0.0	157.5	157.5	162.7	162.3	163.1	159.9	158.7	0.0	163.9	168.3	0.0	126.5	141.8	161.5	15.3	1284.1	0.77
0.0	157.1	156.7	162.3	161.9	163.1	159.9	158.7	0.0	163.9	167.9	0.0	127.0	141.8	161.3	14.9	1304.0	0.76
0.0	157.1	156.3	161.1	160.7	162.3	159.5	158.3	0.0	163.5	167.9	0.0	127.0	141.8	160.7	14.9	1332.9	0.75
0.0	157.1	156.7	163.1	162.7	164.7	161.9	160.7	0.0	165.9	169.9	0.0	127.0	141.8	162.5	14.9	1238.7	0.807

*******RUN NO35.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 254.

HEAT FLOW SUPPLIED 8105.5 BTU/HR
HEAT FLUX SUPPLIED 46530. BTU/SQFT-HR

BETAO.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4 DEG F
KINEMATIC
VISCOSITY:0.496 SQ.CM/SEC

FLUID VELOCITY 3.655 FT/SEC
REYNOLDS NO 19550.0
PRANDTL NO 3.15

HEAT SUPP 8105.5 BTU/HR
HEAT TRANS 7727.9 BTU/HR
HEAT LOST 377.6 BTU/HR
PERCENT HEAT LOST 4.66
HEAT FLUX TRANS. BTU/SQFT-HR 44362.
NUSSELT NO 94.6
RFILM 0.803
RWALL 0.144
RTOTAL 0.947 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.20331 .68319
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.17012 .41024
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 3.2942 .61053

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.18	-0.20	0.34
0.48	0.90	0.84
0.70	-0.20	1.15
0.78	0.70	1.25
1.32	2.41	1.82
1.58	2.21	2.04
1.65	3.01	2.09
2.33	2.71	2.50
3.65	2.81	2.94
4.05	3.11	3.02
4.12	2.51	3.03
4.28	3.11	3.05

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	154.3	153.9	159.5	159.5	160.7	157.9	156.7	0.0	162.3	167.5	0.0	127.0	141.8	159.1	14.9	1413.6	0.7074	0.0
0.0	154.3	153.9	159.1	159.1	160.3	157.9	156.7	0.0	162.7	167.5	0.0	126.5	141.8	159.0	15.3	1407.4	0.7105	0.18
0.0	154.7	154.3	159.9	159.9	161.1	158.3	157.1	0.0	162.7	167.9	0.0	127.0	141.8	159.5	14.9	1391.1	0.7188	0.48
0.0	154.3	153.9	159.5	159.1	160.3	157.9	156.7	0.0	162.3	167.5	0.0	127.0	141.8	159.0	14.9	1419.7	0.7044	0.70
0.0	154.7	154.3	159.9	159.5	160.7	158.3	157.1	0.0	162.7	167.9	0.0	127.0	141.8	159.4	14.9	1397.1	0.7158	0.78
0.0	155.5	155.1	160.7	160.3	161.5	158.7	157.9	0.0	163.5	168.7	0.0	127.0	142.2	160.2	15.3	1368.7	0.7306	1.32
0.0	155.5	155.1	160.7	160.3	161.5	158.7	157.5	0.0	163.5	168.3	0.0	127.0	141.8	160.1	14.9	1362.0	0.7342	1.58
0.0	155.5	155.5	161.1	160.7	161.9	159.1	157.9	0.0	163.9	168.7	0.0	127.0	142.2	160.5	15.3	1353.5	0.7388	1.65
0.0	155.5	155.1	160.7	160.7	161.9	159.1	157.9	0.0	163.5	168.7	0.0	127.0	142.2	160.3	15.3	1359.9	0.7353	2.33
0.0	155.5	155.1	160.7	160.7	161.9	159.5	157.9	0.0	163.5	168.7	0.0	126.5	141.8	160.4	15.3	1334.4	0.7494	3.65
0.0	155.5	155.1	161.1	161.1	161.9	159.5	158.3	0.0	163.5	168.7	0.0	126.5	141.4	160.5	14.9	1315.7	0.7600	4.05
0.0	155.5	155.1	160.7	160.7	161.9	159.1	157.9	0.0	163.1	168.3	0.0	126.5	141.8	160.2	15.3	1341.8	0.7453	4.12
0.0	155.5	155.1	161.5	161.1	161.9	159.5	157.9	0.0	163.5	168.7	0.0	126.5	141.8	160.5	15.3	1327.5	0.7533	4.28

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	141.8	0.0	14.9	1413.6	0.7074	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.90	0.0	0.0	126.5	141.8	-0.20	15.3	1407.4	0.7105	0.18
0.0	0.91	0.91	0.90	0.90	0.90	0.90	0.90	0.0	0.90	0.90	0.0	127.0	141.8	0.90	14.9	1391.1	0.7188	0.48
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	141.8	-0.20	14.9	1419.7	0.7044	0.70
0.0	0.91	0.91	0.90	0.0	0.0	0.90	0.90	0.0	0.90	0.90	0.0	127.0	141.8	0.70	14.9	1397.1	0.7158	0.78
0.0	2.72	2.72	2.71	1.81	1.80	1.81	2.71	0.0	2.70	2.69	0.0	127.0	142.2	2.41	15.3	1368.7	0.7306	1.32
0.0	2.72	2.72	2.71	1.81	1.80	1.81	1.81	0.0	2.70	1.79	0.0	127.0	141.8	2.21	14.9	1362.0	0.7342	1.58
0.0	2.72	3.62	3.61	2.71	2.71	2.71	2.71	0.0	3.60	2.69	0.0	127.0	142.2	3.01	15.3	1353.5	0.7388	1.65
0.0	2.72	2.72	2.71	2.71	2.71	2.71	2.71	0.0	2.70	2.69	0.0	127.0	142.2	2.71	15.3	1359.9	0.7353	2.33
0.0	2.72	2.72	2.71	2.71	2.71	3.61	2.71	0.0	2.70	2.69	0.0	126.5	141.8	2.81	15.3	1334.4	0.7494	3.65
0.0	2.72	2.72	3.61	3.61	2.71	3.61	3.62	0.0	2.70	2.69	0.0	126.5	141.4	3.11	14.9	1315.7	0.7600	4.05
0.0	2.72	2.72	2.71	2.71	2.71	2.71	2.71	0.0	1.80	1.79	0.0	126.5	141.8	2.51	15.3	1341.8	0.7453	4.12
0.0	2.72	2.72	4.51	3.61	2.71	3.61	2.71	0.0	2.70	2.69	0.0	126.5	141.8	3.11	15.3	1327.5	0.7533	4.28

********RUN NO36.********

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 254.

HEAT FLOW SUPPLIED 8105.5 BTU/HR
HEAT FLUX SUPPLIED 46530. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4 DEG F
KINEMATIC
VISCOSITY:0.496 SQ.CM/SEC

FLUID VELOCITY 3.655 FT/SEC
REYNOLDS NO 19550.0
PRANDTL NO 3.15

HEAT SUPP 8105.5 BTU/HR
HEAT TRANS 7727.9 BTU/HR
HEAT LOST 377.6 BTU/HR
PERCENT HEAT LOST 4.66
HEAT FLUX TRANS. BTU/SQFT-HR 44362.
NUSSELT NO 94.6
RFILM 0.803
RWALL 0.144
RTOTAL 0.947 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.40053E-01 .18652
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.42811E-01 .19936
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 7.2248 .33106

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.10	1.41	0.24
0.35	0.81	0.79
0.63	1.41	1.36
0.88	3.31	1.83
1.03	1.71	2.09
1.67	3.91	3.07
1.75	3.41	3.18
2.17	3.01	3.70
2.45	3.01	4.01
22.07	5.61	7.22
22.25	5.91	7.22
22.75	5.51	7.22
25.92	7.42	7.22
26.25	7.12	7.22
27.42	7.22	7.22
28.92	8.12	7.22
29.92	6.92	7.22
45.98	9.42	7.22
46.22	9.12	7.22
24.25	7.62	7.22
25.72	6.82	7.22

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	154.7	154.7	160.3	159.9	161.1	157.9	155.7	0.0	162.7	167.5	0.0	126.5	141.8	159.5	15.3	1383.9	0.7226	0.0
0.0	155.5	155.5	161.1	160.7	161.5	158.7	157.5	0.0	163.1	167.5	0.0	126.5	141.8	160.1	15.3	1350.9	0.7402	0.10
0.0	156.3	155.9	161.1	160.7	161.1	158.3	156.7	0.0	162.3	166.3	0.0	126.5	141.4	159.8	14.9	1359.6	0.7355	0.35
0.0	156.7	155.9	161.1	160.7	161.5	158.7	157.1	0.0	162.7	166.7	0.0	126.5	141.4	160.1	14.9	1345.0	0.7435	0.63
0.0	157.9	156.7	161.9	161.5	162.3	159.1	157.9	0.0	163.5	167.9	0.0	127.0	142.2	161.0	15.3	1338.1	0.7473	0.88
0.0	156.7	156.3	161.5	160.7	161.5	158.3	157.5	0.0	162.7	167.1	0.0	126.5	141.8	160.2	15.3	1351.0	0.7402	1.03
0.0	157.1	156.7	161.9	161.5	162.7	159.9	158.7	0.0	164.3	168.3	0.0	127.0	141.8	161.2	14.9	1306.8	0.7652	1.67
0.0	156.3	156.3	161.5	161.5	162.7	159.9	158.7	0.0	163.9	168.3	0.0	127.0	141.8	161.0	14.9	1314.5	0.7608	1.75
0.0	156.7	155.9	161.9	161.5	162.3	159.5	158.3	C.0	163.5	167.9	0.0	126.5	141.4	160.8	14.9	1304.5	0.7666	2.17
0.0	157.1	156.3	161.5	161.1	162.3	159.5	158.3	0.0	163.5	167.9	0.0	127.0	141.8	160.8	14.9	1328.3	0.7529	2.45
0.0	157.5	157.1	162.7	162.3	163.5	160.7	159.5	0.0	165.1	169.5	0.0	127.0	141.8	162.0	14.9	1269.4	0.7878	22.07
0.0	157.5	157.1	162.3	161.9	163.9	161.1	159.9	0.0	165.5	169.9	0.0	127.0	141.8	162.1	14.9	1261.9	0.7924	22.25
0.0	157.5	157.1	162.3	162.3	163.5	160.7	159.5	0.0	165.1	169.5	0.0	127.0	141.4	161.9	14.4	1261.2	0.7929	22.75
0.0	158.7	157.9	163.5	162.7	164.3	161.5	160.3	0.0	166.3	169.9	0.0	127.0	141.8	162.8	14.9	1234.8	0.8099	25.92
0.0	158.3	158.3	163.1	163.1	164.3	161.5	159.9	0.0	165.5	169.9	0.0	126.5	141.8	162.6	15.3	1231.4	0.8121	26.25
0.0	157.9	157.9	163.1	163.5	164.3	161.1	160.3	0.0	165.9	170.3	0.0	127.0	141.8	162.7	14.9	1236.7	0.8086	27.42
0.0	159.1	158.3	163.9	163.5	164.3	161.9	160.3	0.0	166.3	170.3	0.0	127.0	141.8	163.1	14.9	1222.4	0.8181	28.92
0.0	158.7	158.3	163.1	163.5	163.5	161.1	159.9	0.0	165.5	169.5	0.0	127.0	141.8	162.6	14.9	1246.8	0.8020	29.92
0.0	159.9	159.1	164.7	163.9	164.7	162.7	161.5	0.0	166.3	170.3	0.0	127.0	141.8	163.7	14.9	1198.3	0.8345	45.98
0.0	159.5	158.7	164.7	163.9	165.1	162.3	161.1	0.0	166.3	170.3	0.0	127.0	141.8	163.5	14.9	1202.8	0.8314	46.22
0.0	159.1	158.3	163.9	163.5	164.7	161.5	160.3	0.0	165.1	169.5	0.0	127.0	141.8	162.9	14.9	1232.2	0.8116	24.25
0.0	157.5	157.5	163.9	163.5	164.3	161.1	160.3	0.0	165.1	169.5	0.0	126.5	141.4	162.5	14.9	1223.9	0.8171	25.72

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	141.8	0.0	15.3	1383.9	0.7226	0.0
0.0	1.81	1.81	1.60	1.80	0.90	1.81	1.81	0.0	0.90	0.0	0.0	126.5	141.8	1.41	15.3	1350.9	0.7402	0.10
0.0	3.62	2.72	1.80	1.80	0.0	0.90	0.0	0.0	0.0	0.0	0.0	126.5	141.4	0.81	14.9	1359.6	0.7355	0.35
0.0	4.53	2.72	1.80	1.80	0.90	1.81	0.90	0.0	0.0	0.0	0.0	126.5	141.4	1.41	14.9	1345.0	0.7435	0.63
0.0	7.24	4.53	3.61	3.61	2.70	2.71	2.71	0.0	1.80	0.90	0.0	127.0	142.2	3.31	15.3	1338.1	0.7473	0.88
0.0	4.53	3.62	2.71	1.80	0.90	0.90	1.81	0.0	0.0	0.0	0.0	126.5	141.8	1.71	15.3	1351.0	0.7402	1.03
0.0	5.43	4.53	3.61	3.61	3.61	4.52	4.52	0.0	3.60	1.79	0.0	127.0	141.8	3.91	14.9	1306.8	0.7652	1.67
0.0	3.62	3.62	2.71	3.61	3.61	4.52	4.52	0.0	2.70	1.79	0.0	127.0	141.8	3.41	14.9	1314.5	0.7608	1.75
0.0	4.53	2.72	3.61	3.61	2.70	3.61	3.62	0.0	1.80	0.90	0.0	126.5	141.4	3.01	14.9	1304.5	0.7666	2.17
0.0	5.43	3.62	2.71	2.71	2.70	3.61	3.62	0.0	1.80	0.90	0.0	127.0	141.8	3.01	14.9	1328.3	0.7529	2.45
0.0	6.34	5.43	5.41	5.41	5.41	6.32	6.33	0.0	5.40	4.49	0.0	127.0	141.8	5.61	14.9	1269.4	0.7878	22.07
0.0	6.34	5.43	4.51	4.51	6.31	7.22	7.23	0.0	6.30	5.38	0.0	127.0	141.8	5.91	14.9	1261.9	0.7924	22.25
0.0	6.34	5.43	4.51	5.41	5.41	6.32	6.33	0.0	5.40	4.49	0.0	127.0	141.4	5.51	14.4	1261.2	0.7929	22.75
0.0	9.05	7.24	7.21	6.31	7.21	8.13	8.13	0.0	8.10	5.38	0.0	127.0	141.8	7.42	14.9	1234.8	0.8099	25.92
0.0	8.15	8.15	6.31	7.21	7.21	8.13	7.23	0.0	6.30	5.38	0.0	126.5	141.8	7.12	15.3	1231.4	0.8121	26.25
0.0	7.24	7.24	6.31	8.11	7.21	7.22	8.13	0.0	7.20	6.28	0.0	127.0	141.8	7.22	14.9	1236.7	0.8086	27.42
0.0	9.95	8.15	8.11	8.11	7.21	9.03	8.13	0.0	8.10	6.28	0.0	127.0	141.8	8.12	14.9	1222.4	0.8181	28.92
0.0	9.05	8.15	6.31	8.11	5.41	7.22	7.23	0.0	6.30	4.49	0.0	127.0	141.8	6.92	14.9	1246.8	0.8020	29.92
0.0	11.76	9.95	9.91	9.01	8.11	10.83	10.84	0.0	8.10	6.28	0.0	127.0	141.8	9.42	14.9	1198.3	0.8345	45.98
0.0	10.86	9.05	9.91	9.01	9.01	9.91	9.94	0.0	8.10	6.28	0.0	127.0	141.8	9.12	14.9	1202.8	0.8314	46.22
0.0	9.95	8.15	8.11	8.11	8.11	8.13	8.13	0.0	5.40	4.49	0.0	127.0	141.8	7.62	14.9	1232.2	0.8116	24.25
0.0	6.34	6.34	8.11	8.11	7.21	7.22	8.13	0.0	5.40	4.49	0.0	126.5	141.4	6.82	14.9	1223.9	0.8171	25.72

*******RUN NO38.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

EETA0.301 TCR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4 DEG F
KINEMATIC
VISCOSITY:0.496 SQ.CM/SEC

FLUID VELOCITY 3.655 FT/SEC
REYNOLDS NO 19550.0
PRANDTL NO 3.15

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7727.9 BTU/HR
HEAT LOST 345.7 BTU/HR
PERCENT HEAT LOST 4.28
HEAT FLUX TRANS. BTU/SQFT-HR 44362.
NUSSELT NO 94.6
RFILM 0.803
RWALL 0.144
RTOTAL 0.947 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.10359 .52789
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.73209E-01 .21050
ESTIMATE OF RO,RINF,AND B IN KF=RINF*(1.-EXP(-B*TIME))
.0 3.5178 .92273

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.23	0.86	0.67
0.40	0.87	1.09
0.50	1.35	1.30
0.75	1.44	1.76
1.07	1.92	2.21
1.38	2.59	2.53
1.77	3.17	2.83
2.12	3.07	3.02
2.37	3.94	3.12
2.65	3.27	3.21
3.18	2.50	3.33
4.32	3.17	3.45
4.53	3.75	3.46

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	153.9	153.9	159.5	159.5	160.7	158.3	157.1	0.0	162.7	166.7	0.0	127.0	141.8	159.1	14.9	1781.6	0.5613	0.0
0.0	154.3	154.3	159.9	159.9	161.1	158.3	157.5	0.0	163.1	167.5	0.0	127.0	141.8	159.5	14.9	1754.8	0.5699	0.23
0.0	154.7	154.3	159.9	159.9	161.1	158.7	157.5	0.0	162.7	167.1	0.0	127.0	141.8	159.5	14.9	1755.4	0.5697	0.40
0.0	155.1	154.7	160.3	159.9	161.5	158.7	157.5	0.0	163.1	167.1	0.0	127.0	141.8	159.8	14.9	1741.9	0.5741	0.50
0.0	155.1	154.7	159.5	160.3	161.5	159.1	157.9	0.0	163.1	167.1	0.0	127.0	141.8	159.8	14.9	1736.4	0.5759	0.75
0.0	155.1	155.1	160.7	160.7	161.5	159.1	157.9	0.0	163.1	167.1	0.0	127.0	141.8	160.0	14.9	1722.3	0.5806	1.07
0.0	155.9	155.5	161.1	160.7	161.9	159.1	157.9	0.0	163.5	167.5	0.0	127.0	141.8	160.3	14.9	1705.6	0.5863	1.38
0.0	156.7	155.9	161.5	161.1	161.9	159.1	157.9	0.0	163.5	167.9	0.0	127.0	142.2	160.6	15.3	1707.6	0.5856	1.77
0.0	156.3	155.9	161.1	160.7	162.3	159.5	158.3	0.0	163.5	167.5	0.0	127.0	141.8	160.6	14.9	1691.3	0.5913	2.12
0.0	156.7	156.3	161.5	161.9	162.7	159.9	158.3	0.0	163.5	167.9	0.0	127.0	141.8	161.0	14.9	1666.3	0.6001	2.37
0.0	156.3	156.3	161.5	161.1	161.9	159.5	157.9	0.0	163.5	167.9	0.0	126.5	141.8	160.6	15.3	1674.8	0.5971	2.65
0.0	156.3	155.5	161.1	160.7	161.9	159.1	157.9	0.0	163.1	167.1	0.0	127.0	141.8	160.3	14.9	1710.	0.5847	3.18
0.0	156.3	155.9	161.9	161.1	161.9	159.5	157.9	0.0	163.5	167.5	0.0	126.5	141.8	160.6	15.3	1676.6	0.5964	4.32
0.0	156.3	156.3	161.9	161.5	162.3	159.5	158.3	0.0	163.9	167.9	0.0	127.0	141.8	160.9	14.9	1671.9	0.5981	4.53

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	141.8	0.0	14.9	1781.6	0.5613	0.0
0.0	0.91	0.91	0.90	0.90	0.90	0.0	0.90	0.0	0.90	1.80	0.0	127.0	141.8	0.86	14.9	1754.8	0.5699	0.23
0.0	1.81	0.91	0.90	0.90	0.90	0.90	0.90	0.0	0.0	0.90	0.0	127.0	141.8	0.87	14.9	1755.4	0.5697	0.40
0.0	2.72	1.81	1.81	0.90	1.80	0.90	0.90	0.0	0.90	0.90	0.0	127.0	141.8	1.35	14.9	1741.9	0.5741	0.50
0.0	2.72	1.81	0.0	1.81	1.80	1.81	1.81	0.0	0.90	0.90	0.0	127.0	141.8	1.44	14.9	1736.4	0.5759	0.75
0.0	2.72	2.72	2.71	2.71	1.80	1.81	1.81	0.0	0.90	0.90	0.0	127.0	141.8	1.92	14.9	1722.3	0.5806	1.07
0.0	4.53	3.62	3.61	2.71	2.71	1.81	1.81	0.0	1.80	1.80	0.0	127.0	141.8	2.59	14.9	1705.6	0.5863	1.38
0.0	6.34	4.53	4.51	3.61	2.71	1.81	1.81	0.0	1.80	2.69	0.0	127.0	142.2	3.17	15.3	1707.6	0.5856	1.77
0.0	5.44	4.53	3.61	2.71	3.61	2.71	2.71	0.0	1.80	1.80	0.0	127.0	141.8	3.07	14.9	1691.3	0.5913	2.12
0.0	6.34	5.44	4.51	5.41	4.51	3.61	2.71	0.0	1.80	2.69	0.0	127.0	141.8	3.94	14.9	1666.3	0.6001	2.37
0.0	5.44	5.44	4.51	3.61	2.71	2.71	1.81	0.0	1.80	2.69	0.0	126.5	141.8	3.27	15.3	1674.8	0.5971	2.65
0.0	5.44	3.62	3.61	2.71	2.71	1.81	1.81	0.0	0.90	0.90	0.0	127.0	141.8	2.50	14.9	1710.3	0.5847	3.18
0.0	5.44	4.53	5.41	3.61	2.71	2.71	1.81	0.0	1.80	1.80	0.0	126.5	141.8	3.17	15.3	1676.6	0.5964	4.32
0.0	5.44	5.44	5.41	4.51	3.61	2.71	2.71	0.0	2.70	2.69	0.0	127.0	141.8	3.75	14.9	1671.9	0.5981	4.53

*******RUN NO39.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3 DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6 DEG F
KINEMATIC
VISCOSITY:0.504 SQ.CM/SEC

FLUID VELOCITY 4.817 FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO 3.20

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7817.1 BTU/HR
HEAT LOST 256.5 BTU/HR
PERCENT HEAT LOST 3.18
HEAT FLUX TRANS. BTU/SQFT-HR 44874.
NUSSELT NO 116.5
RFILM 0.653
RWALL 0.145
RTOTAL 0.798 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.13462 .49466
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.57654E-01 .21184
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 4.2464 2.6390

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.25	1.79	2.05
0.42	2.91	2.84
0.62	3.59	3.42
0.82	4.03	3.76
1.12	3.59	4.03
1.58	4.26	4.18
2.08	4.93	4.23
2.25	3.59	4.24

Data processed for top half of tube only.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	150.6	149.8	0.0	154.7	158.3	0.0	127.0	138.3	153.4	11.4	1677.4	0.5962	0.0
0.0	0.0	0.0	0.0	0.0	0.0	151.5	150.6	0.0	155.1	159.5	0.0	127.0	138.3	154.2	11.4	1576.1	0.6345	0.25
0.0	0.0	0.0	0.0	0.0	0.0	151.9	151.1	0.0	155.9	159.9	0.0	127.0	138.3	154.7	11.4	1561.4	0.6404	0.42
0.0	0.0	0.0	0.0	0.0	0.0	152.3	151.5	0.0	156.3	159.9	0.0	127.0	138.3	155.0	11.4	15[illegible].1	0.6447	0.62
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.5	0.0	156.3	160.3	0.0	127.0	138.3	155.2	11.4	1499.2	0.6670	0.82
0.0	0.0	0.0	0.0	0.0	0.0	152.3	151.5	0.0	156.3	159.9	0.0	127.0	138.3	155.0	11.4	1551.1	0.6447	1.12
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.9	0.0	156.3	160.3	0.0	127.0	139.3	155.3	11.4	1506.0	0.6640	1.56
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.9	0.0	157.1	160.7	0.0	127.0	138.3	155.6	11.4	1521.6	0.6572	2.08
0.0	0.0	0.0	0.0	0.0	0.0	152.3	151.5	0.0	156.3	159.9	0.0	126.5	138.3	155.0	11.8	1538.3	0.6501	2.25

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	0.0	11.4	1677.4	0.5962	0.0
0.0	0.0	0.0	0.0	0.0	0.0	1.80	1.80	0.0	0.90	2.68	0.0	127.0	138.3	1.79	11.4	1576.1	0.6345	0.25
0.0	0.0	0.0	0.0	0.0	0.0	2.69	2.70	0.0	2.69	3.57	0.0	127.0	138.3	2.91	11.4	1561.4	0.6404	0.42
0.0	0.0	0.0	0.0	0.0	0.0	3.59	3.59	0.0	3.58	3.57	0.0	127.0	138.3	3.59	11.4	1551.1	0.6447	0.62
0.0	0.0	0.0	0.0	0.0	0.0	4.49	3.59	0.0	3.58	4.46	0.0	127.0	138.3	4.03	11.4	1499.2	0.6670	0.82
0.0	0.0	0.0	0.0	0.0	0.0	3.59	3.59	0.0	3.58	3.57	0.0	127.0	138.3	3.59	11.4	1551.1	0.6447	1.12
0.0	0.0	0.0	0.0	0.0	0.0	4.49	4.47	0.0	3.58	4.46	0.0	127.0	138.3	4.26	11.4	1506.0	0.6640	1.58
0.0	0.0	0.0	0.0	0.0	0.0	4.47	4.49	0.0	5.37	5.36	0.0	127.0	138.3	4.93	11.4	1521.6	0.6572	2.08
0.0	0.0	0.0	0.0	0.0	0.0	3.59	3.59	0.0	3.58	3.57	0.0	126.5	138.3	3.59	11.8	1538.3	0.6501	2.25

*******RUN NO39.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3 DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6 DEG F
KINEMATIC
VISCOSITY:0.504 SQ.CM/SEC

FLUID VELOCITY 4.817 FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO 3.20

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7817.1 BTU/HR
HEAT LOST 256.5 BTU/HR
PERCENT HEAT LOST 3.18
HEAT FLUX TRANS. BTU/SQFT-HR 44874.
NUSSELT NO 116.5
RFILM 0.653
RWALL 0.145
RTOTAL 0.798 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.14899 .47751
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.72210E-01 .23143
ESTIMATE OF RO,RINF,AND B IN RF=RINF(1.-EXP(-B*TIME)
.0 4.4392 2.0696

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.25	1.26	1.79
0.42	2.15	2.58
0.62	3.95	3.21
0.82	3.95	3.63
1.12	3.95	4.00
1.58	3.95	4.27
2.08	4.85	4.38
2.25	3.95	4.40

Data processed for bottom half of tube only.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	148.6	147.8	152.7	152.7	153.1	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	151.0	11.4	1808.7	0.5529	0.0
0.0	149.0	148.2	153.5	153.1	153.9	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	151.5	11.4	1737.9	0.5754	0.25
0.0	149.4	148.6	153.9	153.5	154.3	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	151.9	11.4	1704.1	0.5868	0.42
0.0	150.2	149.4	154.7	154.3	155.1	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	152.7	11.4	1640.4	0.6096	0.62
0.0	150.2	149.4	154.7	154.3	155.1	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	152.7	11.4	1640.4	0.6096	0.82
0.0	150.2	149.4	154.7	154.3	155.1	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	152.7	11.4	1640.4	0.6096	1.12
0.0	150.2	149.4	154.7	154.3	155.1	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	152.7	11.4	1640.4	0.6096	1.58
0.0	150.6	149.8	155.1	154.7	155.5	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	153.1	11.4	1610.3	0.6210	2.08
0.0	150.2	149.6	154.7	153.9	155.1	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	152.7	11.8	1642.3	0.6089	2.25

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	0.0	11.4	1808.7	0.5529	0.0
0.0	0.90	0.90	1.79	0.90	1.79	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	1.26	11.4	1737.9	0.5754	0.25
0.0	1.80	1.80	2.69	1.79	2.69	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	2.15	11.4	1704.1	0.5868	0.42
0.0	3.60	3.60	4.48	3.59	4.48	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	3.95	11.4	1640.4	0.6096	0.62
0.0	3.60	3.60	4.48	3.59	4.48	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	3.95	11.4	1640.4	0.6096	0.82
0.0	3.60	3.60	4.48	3.59	4.48	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	3.95	11.4	1640.4	0.6096	1.12
0.0	3.60	3.60	4.48	3.59	4.48	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	3.95	11.4	1640.4	0.6096	1.58
0.0	4.50	4.50	5.38	4.48	5.38	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	4.85	11.4	1610.3	0.6210	2.08
0.0	3.60	4.50	4.48	2.69	4.48	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	3.95	11.8	1642.3	0.6089	2.25

*******RUN NO39.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TDR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3 DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6 DEG F
KINEMATIC
VISCOSITY:0.504 SQ.CM/SEC

FLUID VELOCITY 4.817 FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO 3.20

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7817.1 BTU/HR
HEAT LOST 256.5 BTU/HR
PERCENT HEAT LOST 3.18
HEAT FLUX TRANS. BTU/SQFT-HR 44874.
NUSSELT NO 116.5
RFILM 0.653
RWALL 0.145
RTOTAL 0.798 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.14226 .48191
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.59295E-01 .20086
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 4.3522 2.2882

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.25	1.49	1.90
0.42	2.49	2.69
0.62	3.79	3.30
0.82	3.99	3.69
1.12	3.79	4.02
1.58	4.09	4.24
2.08	4.88	4.31
2.25	3.79	4.33

Data processed for whole tube.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	148.6	147.8	152.7	152.7	153.1	150.6	149.8	0.0	154.7	158.3	0.0	127.0	138.3	152.0	11.4	1829.4	0.5466	0.0
0.0	149.0	148.2	153.5	153.1	153.9	151.5	150.6	0.0	155.1	159.5	0.0	127.0	138.3	152.7	11.4	1766.2	0.5662	0.25
0.0	149.4	148.6	153.9	153.5	154.3	151.9	151.1	0.0	155.9	159.9	0.0	127.0	138.3	153.2	11.4	1727.5	0.5789	0.42
0.0	150.2	149.4	154.7	154.3	155.1	152.3	151.5	0.0	156.3	159.9	0.0	127.0	138.3	153.7	11.4	1681.2	0.5948	0.62
0.0	150.2	149.4	154.7	154.3	155.1	152.7	151.5	0.0	156.3	160.3	0.0	127.0	138.3	153.8	11.4	1673.5	0.5975	0.82
0.0	150.2	149.4	154.7	154.3	155.1	152.3	151.5	0.0	156.3	159.9	0.0	127.0	138.3	153.7	11.4	1681.2	0.5948	1.12
0.0	150.2	149.4	154.7	154.3	155.1	152.7	151.9	0.0	156.3	160.3	0.0	127.0	138.3	153.9	11.4	1669.0	0.5992	1.58
0.0	150.6	149.8	155.1	154.7	155.5	152.7	151.9	0.0	157.1	160.7	0.0	127.0	138.3	154.2	11.4	1643.3	0.6085	2.08
0.0	150.2	149.8	154.7	153.9	155.1	152.3	151.5	0.0	156.3	159.9	0.0	126.5	138.3	153.7	11.8	1666.0	0.6002	2.25

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	139.3	0.0	11.4	1829.4	0.5466	0.0
0.0	0.90	0.90	1.79	0.90	1.79	1.80	1.80	0.0	0.90	2.68	0.0	127.0	138.3	1.49	11.4	1766.2	0.5662	0.25
0.0	1.80	1.80	2.69	1.79	2.69	2.69	2.70	0.0	2.69	3.57	0.0	127.0	138.3	2.49	11.4	1727.5	0.5789	0.42
0.0	3.60	3.60	4.48	3.59	4.48	3.59	3.59	0.0	3.58	3.57	0.0	127.0	138.3	3.79	11.4	1681.2	0.5948	0.62
0.0	3.60	3.60	4.48	3.59	4.48	4.49	3.59	0.0	3.58	4.46	0.0	127.0	138.3	3.99	11.4	1673.5	0.5975	0.82
0.0	3.60	3.60	4.48	3.59	4.48	3.59	3.59	0.0	3.58	3.57	0.0	127.0	138.3	3.79	11.4	1681.2	0.5948	1.12
0.0	3.60	3.60	4.48	3.59	4.48	4.49	4.49	0.0	3.58	4.46	0.0	127.0	138.3	4.09	11.4	1669.0	0.5992	1.58
0.0	4.50	4.50	5.38	4.48	5.38	4.49	4.49	0.0	5.37	5.36	0.0	127.0	138.3	4.88	11.4	1643.3	0.6085	2.08
0.0	3.60	4.50	4.48	2.69	4.48	3.59	3.59	0.0	3.58	3.57	0.0	126.5	138.3	3.79	11.8	1666.0	0.6002	2.25

********RUN NO40.********

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

DELTA0.301 TCR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3 DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6 DEG F
KINEMATIC
VISCOSITY:0.504 SQ.CM/SEC

FLUID VELOCITY 4.817 FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO 3.20

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7817.1 BTU/HR
HEAT LOST 256.5 BTU/HR
PERCENT HEAT LOST 3.18
HEAT FLUX TRANS. BTU/SQFT-HR 44874.
NUSSELT NO 116.5
RFILM 0.653
RWALL 0.145
RTOTAL 0.798 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.78043E-01 .21988
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.67714E-01 .19078
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 8.7549 1.4373

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.18	1.26	2.00
0.28	1.52	2.90
0.45	2.87	4.17
0.62	5.39	5.16
0.88	7.18	6.28
0.95	7.18	6.52
1.13	8.43	7.03
1.47	8.08	7.70
1.65	7.36	7.94
2.08	8.08	8.31
2.47	7.72	8.50
2.85	8.61	8.61

Data processed for bottom half of tube only.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	148.2	147.4	153.1	152.7	153.5	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	151.0	11.4	1791.7	0.5581	0.0
0.0	149.0	148.2	153.5	153.1	153.9	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	151.5	11.4	1737.9	0.5754	0.18
0.0	149.0	148.2	153.5	153.5	154.3	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	151.7	11.4	1668.1	0.5995	0.28
0.0	149.4	149.0	154.3	153.9	154.7	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	152.3	11.4	1724.4	0.5799	0.45
0.0	150.6	149.8	155.5	155.1	155.9	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	153.4	11.4	1595.8	0.6266	0.62
0.0	151.5	150.6	156.3	155.9	156.7	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	154.2	11.4	1539.9	0.6494	0.88
0.0	151.5	150.6	156.3	155.9	156.7	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	154.2	11.4	1539.9	0.6494	0.95
0.0	152.3	151.5	156.7	156.3	157.1	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	154.8	11.8	1487.4	0.6723	1.13
0.0	152.3	151.5	156.7	155.9	156.7	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	154.6	11.4	1559.8	0.6411	1.47
0.0	151.9	151.1	156.3	155.5	156.7	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	154.3	11.4	1515.1	0.6600	1.65
0.0	151.9	151.5	156.7	156.3	156.7	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	154.6	11.4	1627.3	0.6145	2.08
0.0	151.9	151.5	156.3	155.9	156.7	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	154.4	11.4	1554.7	0.6432	2.47
0.0	152.3	151.9	157.1	155.9	157.1	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	154.8	11.8	1549.9	0.6452	2.85

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	0.0	11.4	1791.7	0.5581	0.0
0.0	1.80	1.80	0.90	0.90	0.90	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	1.26	11.4	1737.9	0.5754	0.18
0.0	1.80	1.80	0.90	1.79	1.79	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	1.62	11.4	1668.1	0.5995	0.28
0.0	2.70	3.60	2.69	2.69	2.69	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	2.87	11.4	1724.4	0.5799	0.45
0.0	5.40	5.40	5.38	5.38	5.38	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	5.39	11.4	1595.8	0.6266	0.62
0.0	7.19	7.20	7.17	7.17	7.17	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	7.18	11.4	1539.9	0.6494	0.88
0.0	7.19	7.20	7.17	7.17	7.17	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	7.18	11.4	1539.9	0.6494	0.95
0.0	8.99	8.99	8.06	8.06	8.06	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	8.43	11.8	1487.4	0.6723	1.13
0.0	8.99	8.99	8.06	7.17	7.17	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	8.08	11.4	1559.8	0.6411	1.47
0.0	8.09	8.10	7.17	6.27	7.17	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	7.36	11.4	1515.1	0.6600	1.65
0.0	8.09	8.99	8.06	8.06	7.17	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	8.08	11.4	1627.3	0.6145	2.08
0.0	8.09	8.99	7.17	7.17	7.17	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	7.72	11.4	1554.7	0.6432	2.47
0.0	8.99	9.89	8.96	7.17	8.06	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	8.61	11.8	1549.9	0.6452	2.85

********RUN NO40.********

FERRIC OXIDE CONC (PPM)   2130.

VOLTS: 9.35   AMPS: 253.

HEAT FLOW SUPPLIED 8073.6   BTU/HR
HEAT FLUX SUPPLIED 46347.   BTU/SQFT-HR

BETA0.301   TOR=TINLET127.0   DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3   DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6   DEG F
KINEMATIC
VISCOSITY:0.504   SQ.CM/SEC

FLUID VELOCITY 4.817   FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO   3.20

HEAT SUPP   8073.6   BTU/HR
HEAT TRANS   7817.1   BTU/HR
HEAT LOST   256.5   BTU/HR
PERCENT HEAT LOST   3.18
HEAT FLUX TRANS. BTU/SQFT-HR   44874.
NUSSELT NO   116.5
RFILM   0.653
RWALL   0.145
RTOTAL   0.798   SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.97787E-01   .36630
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.42380E-01   .15875
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0   4.8267   2.3710

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.18	1.57	1.68
0.28	2.24	2.34
0.45	3.14	3.17
0.62	4.03	3.72
0.88	4.48	4.23
0.95	4.48	4.32
1.13	4.26	4.50
1.47	4.26	4.68
1.65	4.03	4.73
2.08	4.93	4.79
2.47	4.48	4.81
2.85	5.82	4.62

Data processed for top half of tube only.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	150.6	149.4	0.0	154.7	158.7	0.0	127.0	138.3	153.4	11.4	1649.5	0.6062	0.0
0.0	0.0	0.0	0.0	0.0	0.0	151.5	150.2	0.0	155.5	159.1	0.0	127.0	138.3	154.1	11.4	1603.1	0.6238	0.18
0.0	0.0	0.0	0.0	0.0	0.0	151.9	150.6	0.0	155.5	159.5	0.0	127.0	138.3	154.4	11.4	1556.9	0.6423	0.28
0.0	0.0	0.0	0.0	0.0	0.0	152.3	151.1	0.0	155.9	159.9	0.0	127.0	138.3	154.8	11.4	1527.5	0.6547	0.45
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.5	0.0	155.9	160.7	0.0	127.0	138.3	155.2	11.4	1472.0	0.6793	0.62
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.5	0.0	156.3	161.1	0.0	127.0	138.3	155.4	11.4	1468.9	0.6808	0.88
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.5	0.0	156.3	161.1	0.0	127.0	138.3	155.4	11.4	1468.9	0.6808	0.95
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.5	0.0	156.3	160.7	0.0	126.5	138.3	155.3	11.8	1471.9	0.6794	1.13
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.5	0.0	156.3	160.7	0.0	127.0	138.3	155.3	11.4	1483.6	0.6741	1.47
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.5	0.0	156.3	160.3	0.0	127.0	138.3	155.2	11.4	1499.2	0.6670	1.65
0.0	0.0	0.0	0.0	0.0	0.0	153.1	151.9	0.0	156.7	160.7	0.0	127.0	138.3	155.6	11.4	1472.1	0.6793	2.08
0.0	0.0	0.0	0.0	0.0	0.0	153.1	151.9	0.0	156.3	160.3	0.0	127.0	138.3	155.4	11.4	1474.5	0.6782	2.47
0.0	0.0	0.0	0.0	0.0	0.0	153.5	152.3	0.0	157.1	161.1	0.0	126.5	138.3	156.0	11.8	1434.9	0.6969	2.85

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	0.0	11.4	1649.5	0.6062	0.0
0.0	0.0	0.0	0.0	0.0	0.0	1.80	1.80	0.0	1.79	0.89	0.0	127.0	138.3	1.57	11.4	1603.1	0.6238	0.18
0.0	0.0	0.0	0.0	0.0	0.0	2.69	2.70	0.0	1.79	1.79	0.0	127.0	138.3	2.24	11.4	1556.9	0.6423	0.28
0.0	0.0	0.0	0.0	0.0	0.0	3.59	3.60	0.0	2.69	2.68	0.0	127.0	138.3	3.14	11.4	1527.5	0.6547	0.45
0.0	0.0	0.0	0.0	0.0	0.0	4.49	4.49	0.0	2.69	4.46	0.0	127.0	138.3	4.03	11.4	1472.0	0.6793	0.62
0.0	0.0	0.0	0.0	0.0	0.0	4.49	4.49	0.0	3.58	5.35	0.0	127.0	138.3	4.48	11.4	1468.9	0.6808	0.88
0.0	0.0	0.0	0.0	0.0	0.0	4.49	4.49	0.0	3.58	5.35	0.0	127.0	138.3	4.48	11.4	1468.9	0.6808	0.95
0.0	0.0	0.0	0.0	0.0	0.0	4.49	4.49	0.0	3.58	4.46	0.0	126.5	138.3	4.26	11.8	1471.9	0.6794	1.13
0.0	0.0	0.0	0.0	0.0	0.0	4.49	4.49	0.0	3.58	4.46	0.0	127.0	138.3	4.26	11.4	1483.6	0.6741	1.47
0.0	0.0	0.0	0.0	0.0	0.0	4.49	4.49	0.0	3.58	3.57	0.0	127.0	138.3	4.03	11.4	1499.2	0.6670	1.65
0.0	0.0	0.0	0.0	0.0	0.0	5.39	5.39	0.0	4.48	4.46	0.0	127.0	139.3	4.93	11.4	1472.1	0.6793	2.08
0.0	0.0	0.0	0.0	0.0	0.0	5.39	5.37	0.0	3.58	3.57	0.0	127.0	138.3	4.48	11.4	1474.5	0.6782	2.47
0.0	0.0	0.0	0.0	0.0	0.0	6.28	6.29	0.0	5.37	5.35	0.0	126.5	138.3	5.82	11.8	1434.9	0.6969	2.85

******RUN NO40.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3 DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6 DEG F
KINEMATIC
VISCOSITY:0.504 SQ.CM/SEC

FLUID VELOCITY 4.817 FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO 3.20

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7817.1 BTU/HR
HEAT LOST 256.5 BTU/HR
PERCENT HEAT LOST 3.18
HEAT FLUX TRANS. BTU/SQFT-HR 44874.
NUSSELT NO 116.5
RFILM 0.653
RWALL 0.145
RTOTAL 0.798 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.86945E-01 .26354
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.46906E-01 .14218
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 7.0171 1.6332

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.18	1.40	1.79
0.28	1.89	2.58
0.45	2.99	3.65
0.62	4.78	4.47
0.88	5.98	5.35
0.95	5.98	5.53
1.13	6.58	5.91
1.47	6.38	6.38
1.65	5.88	6.54
2.08	6.68	6.78
2.47	6.28	6.89
2.85	7.37	6.95

Data processed for whole tube.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	148.2	147.4	153.1	152.7	153.5	150.6	149.4	0.0	154.7	158.7	0.0	127.0	138.3	152.0	11.4	1826.6	0.5475	0.0
0.0	149.0	148.2	153.5	153.1	153.9	151.5	150.2	0.0	155.5	159.1	0.0	127.0	138.3	152.7	11.4	1770.4	0.5648	0.18
0.0	149.0	148.2	153.5	153.5	154.3	151.9	150.6	0.0	155.5	159.5	0.0	127.0	138.3	152.9	11.4	1747.6	0.5722	0.28
0.0	149.4	149.0	154.3	153.9	154.7	152.3	151.1	0.0	155.9	159.9	0.0	127.0	138.3	153.4	11.4	1707.4	0.5857	0.45
0.0	150.6	149.8	155.5	155.1	155.9	152.7	151.5	0.0	155.9	160.7	0.0	127.0	138.3	154.2	11.4	1647.1	0.6071	0.62
0.0	151.5	150.6	156.3	155.9	156.7	152.7	151.5	0.0	156.3	161.1	0.0	127.0	138.3	154.7	11.4	1611.1	0.6207	0.88
0.0	151.5	150.6	156.3	155.9	156.7	152.7	151.5	0.0	156.3	161.1	0.0	127.0	138.3	154.7	11.4	1611.1	0.6207	0.95
0.0	152.3	151.5	156.7	156.3	157.1	152.7	151.5	0.0	156.3	160.7	0.0	126.5	138.3	155.0	11.8	1581.9	0.6321	1.13
0.0	152.3	151.5	156.7	155.9	156.7	152.7	151.5	0.0	156.3	160.7	0.0	127.0	138.3	154.9	11.4	1604.4	0.6233	1.47
0.0	151.9	151.1	156.3	155.5	156.7	152.7	151.5	0.0	156.3	160.3	0.0	127.0	138.3	154.7	11.4	1617.3	0.6183	1.65
0.0	151.9	151.5	156.7	156.3	156.7	153.1	151.9	0.0	156.7	160.7	0.0	127.0	138.3	155.0	11.4	1589.7	0.6291	2.08
0.0	151.9	151.5	156.3	155.9	156.7	153.1	151.9	0.0	156.3	160.3	0.0	127.0	138.3	154.8	11.4	1602.8	0.6239	2.47
0.0	152.3	151.9	157.1	155.9	157.1	153.5	152.3	0.0	157.1	161.1	0.0	126.5	138.3	155.3	11.8	1554.2	0.6434	2.85

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	139.3	0.0	11.4	1826.6	0.5475	0.0
0.0	1.80	1.80	0.90	0.90	0.90	1.80	1.80	0.0	1.79	0.89	0.0	127.0	138.3	1.40	11.4	1770.4	0.5648	0.18
0.0	1.80	1.80	0.90	1.79	1.79	2.69	2.70	0.0	1.79	1.79	0.0	127.0	138.3	1.89	11.4	1747.6	0.5722	0.28
0.0	2.70	3.60	2.69	2.69	2.69	3.59	3.60	0.0	2.69	2.68	0.0	127.0	138.3	2.99	11.4	1707.4	0.5857	0.45
0.0	5.40	5.40	5.38	5.38	5.38	4.49	4.49	0.0	2.69	4.46	0.0	127.0	138.3	4.78	11.4	1647.1	0.6071	0.62
0.0	7.19	7.20	7.17	7.17	7.17	4.49	4.49	0.0	3.58	5.35	0.0	127.0	138.3	5.98	11.4	1611.1	0.6207	0.88
0.0	7.19	7.20	7.17	7.17	7.17	4.49	4.49	0.0	3.58	5.35	0.0	127.0	138.3	5.98	11.4	1611.1	0.6207	0.95
0.0	8.99	8.99	8.06	8.06	8.06	4.49	4.49	0.0	3.58	4.46	0.0	126.5	138.3	6.58	11.8	1581.9	0.6321	1.13
0.0	8.99	8.99	8.06	7.17	7.17	4.49	4.49	0.0	3.58	4.46	0.0	127.0	138.3	6.38	11.4	1604.4	0.6233	1.47
0.0	8.09	8.10	7.17	6.27	7.17	4.49	4.49	0.0	3.58	3.57	0.0	127.0	138.3	5.88	11.4	1617.3	0.6183	1.65
0.0	8.09	8.99	8.06	8.06	7.17	5.39	5.39	0.0	4.48	4.46	0.0	127.0	138.3	6.68	11.4	1589.7	0.6291	2.08
0.0	8.09	8.99	7.17	7.17	7.17	5.39	5.39	0.0	3.58	3.57	0.0	127.0	138.3	6.28	11.4	1602.8	0.6239	2.47
0.0	8.99	9.89	8.96	7.17	8.06	6.28	6.29	0.0	5.37	5.35	0.0	126.5	138.3	7.37	11.8	1554.2	0.6434	2.85

*******RUN NO41.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TOK=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3 DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6 DEG F
KINEMATIC
VISCOSITY:0.504 SQ.CM/SEC

FLUID VELOCITY 4.817 FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO 3.20

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7817.1 BTU/HR
HEAT LOST 256.5 BTU/HR
PERCENT HEAT LOST 3.18
HEAT FLUX TRANS. BTU/SQFT-HR 44874.
NUSSELT NO 116.5
RFILM 0.653
RWALL 0.145
RTOTAL 0.798 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.17814 .42147
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.98651E-01 .23340
ESTIMATE OF RO,RINF,AND B IN RF=RINF(1.-EXP(-B*TIME)
.0 7.3342 1.6519

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.18	1.12	1.89
0.42	3.58	3.67
0.57	4.48	4.47
0.87	6.49	5.59
1.20	6.05	6.32
1.77	6.72	6.94

Data processed for top half of tube only.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	151.1	150.2	0.0	155.5	159.1	0.0	127.0	138.3	154.0	11.4	1642.3	0.6089	0.0
0.0	0.0	0.0	0.0	0.0	0.0	151.9	150.6	0.0	155.9	159.5	0.0	126.5	138.3	154.5	11.8	1558.9	0.6415	0.18
0.0	0.0	0.0	0.0	0.0	0.0	152.7	151.9	0.0	157.1	160.7	0.0	127.0	138.3	155.6	11.4	1521.6	0.6572	0.42
0.0	0.0	0.0	0.0	0.0	0.0	153.1	152.3	C.0	157.5	161.1	0.0	127.0	138.3	156.0	11.4	1494.2	0.6693	0.57
0.0	0.0	0.0	0.0	0.0	0.0	154.3	153.5	0.0	157.9	161.9	0.0	127.0	138.3	156.9	11.4	1403.3	0.7126	0.87
0.0	0.0	0.0	0.0	0.0	0.0	154.3	153.5	0.0	157.5	161.5	0.0	127.0	138.3	156.7	11.4	1404.8	0.7119	1.20
0.0	0.0	0.0	0.0	0.0	0.0	154.3	153.5	0.0	158.3	161.9	0.0	126.5	138.3	157.0	11.8	1407.9	0.7103	1.77

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	0.0	11.4	1642.3	0.6089	0.0
0.0	0.0	0.0	0.0	0.0	0.0	1.80	0.90	0.0	0.90	0.87	0.0	126.5	138.3	1.12	11.8	1558.9	0.6415	0.18
0.0	0.0	0.0	0.0	0.0	0.0	3.59	3.59	0.0	3.58	3.57	0.0	127.0	138.3	3.58	11.4	1521.6	0.6572	0.42
0.0	0.0	0.0	0.0	0.0	0.0	4.49	4.49	0.0	4.47	4.46	0.0	127.0	138.3	4.48	11.4	1494.2	0.6693	0.57
0.0	0.0	0.0	0.0	0.0	0.0	7.18	7.18	0.0	5.37	6.24	0.0	127.0	138.3	6.49	11.4	1403.3	0.7126	0.87
0.0	0.0	0.0	0.0	0.0	0.0	7.18	7.18	0.0	4.47	5.35	0.0	127.0	138.3	6.05	11.4	1404.8	0.7119	1.20
0.0	0.0	0.0	0.0	0.0	0.0	7.18	7.18	0.0	6.26	6.24	0.0	126.5	138.3	6.72	11.8	1407.9	0.7103	1.77

*******RUN NO41.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3 DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6 DEG F
KINEMATIC
VISCOSITY:0.504 SQ.CM/SEC

FLUID VELOCITY 4.817 FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO 3.20

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7817.1 BTU/HR
HEAT LOST 256.5 BTU/HR
PERCENT HEAT LOST 3.18
HEAT FLUX TRANS. BTU/SQFT-HR 44874.
NUSSELT NO 116.5
RFILM 0.653
RWALL 0.145
RTOTAL 0.798 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.22543 .44819
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.12887 .25621
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 8.9096 1.1941

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.18	1.30	1.72
0.42	3.09	3.51
0.57	4.08	4.40
0.87	6.77	5.76
1.20	6.87	6.78
1.77	7.47	7.83

Data processed for whole tube.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	148.6	148.2	153.5	153.1	153.5	151.1	150.2	0.0	155.5	159.1	0.0	127.0	138.3	152.5	11.4	1782.3	0.5611	0.0
0.0	149.4	148.6	154.3	153.5	154.3	151.9	150.6	0.0	155.9	159.5	0.0	126.5	138.3	153.1	11.8	1714.1	0.5834	0.18
0.0	149.8	149.4	154.3	154.3	155.1	152.7	151.9	0.0	157.1	160.7	0.0	127.0	138.3	153.9	11.4	1663.7	0.6011	0.42
0.0	150.2	149.8	155.1	154.7	155.5	153.1	152.3	0.0	157.5	161.1	0.0	127.0	138.3	154.4	11.4	1629.6	0.6136	0.57
0.0	151.9	151.1	156.7	155.9	157.1	154.3	153.5	0.0	157.9	161.9	0.0	127.0	138.3	155.6	11.4	1544.9	0.6473	0.87
0.0	152.3	151.9	156.7	156.3	156.7	154.3	153.5	0.0	157.5	161.5	0.0	127.0	138.3	155.6	11.4	154[illegible].6	0.6470	1.20
0.0	152.7	151.9	157.1	156.3	157.1	154.3	153.5	0.0	158.3	161.9	0.0	126.5	138.3	155.9	11.8	1515.1	0.6600	1.77

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	0.0	11.4	1782.3	0.5611	0.0
0.0	1.80	0.90	1.79	0.90	1.79	1.80	0.90	0.0	0.90	0.89	0.0	126.5	138.3	1.30	11.8	1714.1	0.5834	0.18
0.0	2.70	2.70	1.79	2.69	3.58	3.59	3.59	0.0	3.58	3.57	0.0	127.0	138.3	3.09	11.4	1663.7	0.6011	0.42
0.0	3.60	3.60	3.58	3.59	4.48	4.49	4.49	0.0	4.47	4.46	0.0	127.0	138.3	4.08	11.4	1629.6	0.6136	0.57
0.0	7.19	6.29	7.17	6.27	8.06	7.18	7.18	0.0	5.37	6.24	0.0	127.0	138.3	6.77	11.4	1544.9	0.6473	0.87
0.0	8.09	8.09	7.17	7.17	7.17	7.18	7.18	0.0	4.47	5.35	0.0	127.0	138.3	6.87	11.4	1545.6	0.6470	1.20
0.0	8.99	8.09	8.06	7.17	8.06	7.18	7.18	0.0	6.26	6.24	0.0	126.5	138.3	7.47	11.8	1515.1	0.6600	1.77

*******RUN NO41.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 T0R=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET138.3 DEG F

FLOW RATE 0.1902 LBS.M/SEC

AVG TEMP:132.6 DEG F
KINEMATIC
VISCOSITY:0.504 SQ.CM/SEC

FLUID VELOCITY 4.817 FT/SEC
REYNOLDS NO 25394.5
PRANDTL NO 3.20

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7817.1 BTU/HR
HEAT LOST 256.5 BTU/HR
PERCENT HEAT LOST 3.18
HEAT FLUX TRANS. BTU/SQFT-HR 44874.
NUSSELT NO 116.5
RFILM 0.653
RWALL 0.145
RTOTAL 0.798 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.28110 .49271
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.20172 .35356
ESTIMATE OF RO,RINF,AND B IN RF=RINF(1.-EXP(-B*TIME)
.0 10.651 .92106

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.18	1.44	1.63
0.42	2.69	3.42
0.57	3.77	4.35
0.87	7.00	5.87
1.20	7.54	7.12
1.77	8.07	8.56

Data processed for bottom half of tube only.

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	148.6	148.2	153.5	153.1	153.5	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	151.4	11.4	1920.9	0.5206	0.0
0.0	149.4	148.6	154.3	153.5	154.3	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	152.0	11.8	1749.1	0.5717	0.18
0.0	149.8	149.4	154.3	154.3	155.1	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	152.6	11.4	1635.9	0.6113	0.42
0.0	150.2	149.8	155.1	154.7	155.5	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	153.1	11.4	1658.7	0.6029	0.57
0.0	151.9	151.1	156.7	155.9	157.1	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	154.5	11.4	1501.8	0.6659	0.87
0.0	152.3	151.9	156.7	156.3	156.7	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	154.8	11.4	1609.9	0.6212	1.20
0.0	152.7	151.9	157.1	156.3	157.1	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	155.0	11.8	1519.2	0.6582	1.77

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	0.0	11.4	1920.9	0.5206	0.0
0.0	1.80	0.90	1.79	0.90	1.79	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	1.44	11.8	1749.1	0.5717	0.18
0.0	2.70	2.70	1.79	2.69	3.58	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	2.69	11.4	1635.9	0.6113	0.42
0.0	3.60	3.60	3.58	3.59	4.48	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	3.77	11.4	1658.7	0.6029	0.57
0.0	7.19	6.29	7.17	6.27	8.06	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	7.00	11.4	1501.8	0.6659	0.87
0.0	8.09	8.09	7.17	7.17	7.17	0.0	0.0	0.0	0.0	0.0	0.0	127.0	138.3	7.54	11.4	1609.9	0.6212	1.20
0.0	8.99	8.09	8.06	7.17	8.06	0.0	0.0	0.0	0.0	0.0	0.0	126.5	138.3	8.07	11.8	1519.2	0.6582	1.77

*******RUN NO42.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

BETA0.301 TCR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.9 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:138.4 DEG F
KINEMATIC
VISCOSITY:0.480 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26486.8
PRANDTL NO 3.03

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15633.8 BTU/HR
HEAT LOST 723.0 BTU/HR
PERCENT HEAT LOST 4.42
HEAT FLUX TRANS. BTU/SQFT-HR 89746.
NUSSELT NO 121.3
RFILM 0.624
RWALL 0.143
RTOTAL 0.766 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
2.8492 3.4941
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
1.2836 1.5742
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 7.4646 .35431

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.18	1.17	0.46
0.35	1.41	0.87
0.55	1.27	1.32
0.70	1.07	1.64
0.83	1.46	1.90
1.08	2.68	2.37
1.30	2.87	2.76
1.47	3.02	3.03

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	175.0	174.6	182.1	182.5	184.1	180.6	179.8	0.0	187.6	193.5	0.0	127.0	149.9	182.2	23.0	1616.3	0.6187	0.0
0.0	175.8	175.8	183.7	183.7	185.3	181.3	180.9	0.0	188.4	194.3	0.0	127.0	149.9	183.3	23.0	1578.1	0.6337	0.18
0.0	176.2	176.2	183.7	183.3	185.3	181.7	181.3	0.0	188.8	194.7	0.0	127.0	1 0.3	183.5	23.4	1578.8	0.6334	0.35
0.0	176.2	175.8	183.7	183.7	185.3	181.3	180.9	0.0	188.8	194.3	0.0	127.0	1 0.3	183.3	23.4	1583.5	0.6315	0.55
0.0	176.6	175.8	183.3	183.7	184.9	181.7	180.6	0.0	188.0	193.9	0.0	127.0	1[illegible].9	183.2	23.0	1583.2	0.6316	0.70
0.0	177.0	176.6	183.7	183.7	185.3	181.7	181.3	0.0	188.4	193.9	0.0	127.0	149.9	183.5	23.0	1571.4	0.6364	0.83
0.0	177.8	177.4	184.9	185.3	186.5	182.9	182.1	0.0	189.2	195.5	0.0	127.0	149.9	184.6	23.0	1533.5	0.6521	1.08
0.0	177.8	177.8	185.7	184.9	186.5	182.9	182.1	0.0	190.0	195.5	0.0	127.0	149.9	184.8	23.0	1528.3	0.6543	1.30
0.0	178.2	177.8	186.1	185.3	186.8	183.3	182.1	0.0	189.6	195.1	0.0	127.0	150.3	184.9	23.4	1531.1	0.6531	1.47

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1616.3	0.6187	0.0
0.0	0.88	1.32	1.75	1.32	1.31	0.88	1.32	0.0	0.87	0.87	0.0	127.0	149.9	1.17	23.0	1578.1	0.6337	0.18
0.0	1.32	1.76	1.75	0.88	1.31	1.32	1.76	0.0	1.31	1.30	0.0	127.0	150.3	1.41	23.4	1578.8	0.6334	0.35
0.0	1.32	1.32	1.75	1.32	1.31	0.88	1.32	0.0	1.31	0.87	0.0	127.0	150.3	1.27	23.4	1583.5	0.6315	0.55
0.0	1.76	1.32	1.32	1.32	0.88	1.32	0.88	0.0	0.44	0.43	0.0	127.0	149.9	1.07	23.0	1583.2	0.6316	0.70
0.0	2.20	2.21	1.75	1.32	1.31	1.32	1.76	0.0	0.87	0.43	0.0	127.0	149.9	1.46	23.0	1571.4	0.6364	0.83
0.0	3.09	3.09	3.07	3.07	2.63	2.63	2.64	0.0	1.75	2.17	0.0	127.0	149.9	2.68	23.0	1533.5	0.6521	1.08
0.0	3.09	3.53	3.94	2.63	2.63	2.63	2.64	0.0	2.62	2.17	0.0	127.0	149.9	2.87	23.0	1528.3	0.6543	1.30
0.0	3.53	3.53	4.38	3.07	3.06	3.07	2.64	0.0	2.18	1.74	0.0	127.0	150.3	3.02	23.4	1531.1	0.6531	1.47

*******RUN NO43.*******

FERRIC OXIDE CONC (PPM)   2130.

VOLTS: 9.35   AMPS: 253.

HEAT FLOW SUPPLIED 8073.6   BTU/HR
HEAT FLUX SUPPLIED 46347.   BTU/SQFT-HR

BETA0.301   TOR=TINLET127.0   DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8   DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4   DEG F
KINEMATIC
VISCOSITY:0.496   SQ.CM/SEC

FLUID VELOCITY 3.655   FT/SEC
REYNOLDS NO 19550.0
PRANDTL NO   3.15

HEAT SUPP   8073.6   BTU/HR
HEAT TRANS   7727.9   BTU/HR
HEAT LOST   345.7   BTU/HR
PERCENT HEAT LOST   4.28
HEAT FLUX TRANS. BTU/SQFT-HR   44362.
NUSSELT NO   94.6
RFILM   0.803
RWALL   0.144
RTOTAL   0.947   SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.70252E-01   .28279
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.13059   .52568
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0   5.9149   4.8757

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.07	1.40	1.71
0.12	2.41	2.62
0.17	2.81	3.33
0.27	4.61	4.33
0.45	6.92	5.26
0.83	4.32	5.81
1.17	3.21	5.90
1.27	3.91	5.90
1.45	5.72	5.91
1.58	6.92	5.91
1.78	10.02	5.91

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	154.7	153.9	159.9	159.5	160.7	157.1	156.3	0.0	161.9	167.1	0.0	127.0	141.8	159.0	14.9	1425.1	0.7017	0.0
0.0	154.7	154.3	160.3	159.9	161.1	157.9	157.1	0.0	163.1	168.3	0.0	127.0	141.4	159.6	14.4	1375.4	0.7271	0.07
0.0	155.5	155.1	160.7	160.3	161.5	158.3	157.5	0.0	163.5	168.3	0.0	127.0	141.8	160.1	14.9	1365.1	0.7326	0.12
0.0	155.9	155.1	161.1	160.7	161.9	158.7	157.5	0.0	163.5	167.9	0.0	126.5	141.8	160.2	15.3	1344.2	0.7437	0.17
0.0	156.3	155.5	161.9	161.5	162.7	159.5	158.7	0.0	164.3	169.1	0.0	127.0	141.8	161.0	14.9	1312.2	0.7621	0.27
0.0	157.1	156.7	163.1	162.7	163.9	160.3	159.5	0.0	165.5	169.9	0.0	127.0	141.8	162.1	14.9	1263.6	0.7914	0.45
0.0	156.7	156.7	161.9	161.1	161.9	158.7	157.9	0.0	163.5	167.9	0.0	127.0	141.8	160.9	14.9	1333.6	0.7498	0.83
0.0	157.1	155.5	161.5	161.1	161.5	158.7	157.9	0.0	163.1	167.5	0.0	126.5	141.4	160.4	14.9	1328.4	0.7528	1.17
0.0	157.1	155.9	161.9	161.1	161.9	159.1	158.3	0.0	163.5	167.9	0.0	127.0	141.4	160.7	14.4	1322.2	0.7563	1.27
0.0	157.5	156.7	162.7	161.9	162.7	159.9	159.1	0.0	164.3	169.1	0.0	126.5	141.4	161.5	14.9	1272.6	0.7858	1.45
0.0	157.9	157.1	162.7	162.7	163.5	160.3	159.5	0.0	165.1	169.9	0.0	127.0	141.4	162.1	14.4	1257.1	0.7955	1.58
0.0	159.1	158.3	164.7	163.9	165.1	161.5	160.7	0.0	166.7	171.1	0.0	127.0	141.8	163.4	14.9	1206.7	0.8287	1.78

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	141.8	0.0	14.9	1425.1	0.7017	0.0
0.0	0.0	0.91	0.90	0.90	0.90	1.81	1.81	0.0	2.70	2.69	0.0	127.0	141.4	1.40	14.4	1375.4	0.7271	0.07
0.0	1.81	2.72	1.80	1.81	1.80	2.71	2.71	0.0	3.60	2.69	0.0	127.0	141.8	2.41	14.9	1365.1	0.7326	0.12
0.0	2.72	2.72	2.71	2.71	2.71	3.62	2.71	0.0	3.60	1.80	0.0	126.5	141.8	2.81	15.3	1344.2	0.7439	0.17
0.0	3.62	3.62	4.51	4.51	4.51	5.42	5.43	0.0	5.40	4.49	0.0	127.0	141.8	4.61	14.9	1312.2	0.7621	0.27
0.0	5.43	6.34	7.21	7.22	7.21	7.23	7.23	0.0	8.10	6.28	0.0	127.0	141.8	6.92	14.9	1263.6	0.7914	0.45
0.0	9.05	6.34	4.51	3.61	2.71	3.62	3.62	0.0	3.60	1.80	0.0	127.0	141.8	4.32	14.9	1333.6	0.7498	0.83
0.0	5.43	3.62	3.61	3.61	1.80	3.62	3.62	0.0	2.70	0.90	0.0	126.5	141.4	3.21	14.9	1328.4	0.7528	1.17
0.0	5.43	4.53	4.51	3.61	2.71	4.52	4.52	0.0	3.60	1.80	0.0	127.0	141.4	3.91	14.4	1322.2	0.7563	1.27
0.0	6.34	6.34	6.31	5.41	4.51	6.33	6.33	0.0	5.40	4.49	0.0	126.5	141.4	5.72	14.9	1272.6	0.7858	1.45
0.0	7.24	7.25	6.31	7.22	6.31	7.23	7.23	0.0	7.20	6.28	0.0	127.0	141.4	6.92	14.4	1257.1	0.7955	1.58
0.0	9.95	9.96	10.81	9.92	9.91	9.93	9.94	0.0	10.80	8.97	0.0	127.0	141.8	10.02	14.9	1206.7	0.8287	1.78

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*******RUN NO44.*******

FERRIC OXIDE CONC (PPM)   2130.

VOLTS:13.49        AMPS: 356.

HEAT FLOW SUPPLIED 16390.7     BTU/HR
HEAT FLUX SUPPLIED   94691.    BTU/SQFT-HR

BETAO.301           TOR=TINLET127.0    DEG F
DENSITY:0.986 GRAM/CC
                    T OUTLET142.7      DEG F

FLOW RATE 0.2763   LBS.M/SEC

AVG TEMP:134.8      DEG F
KINEMATIC
VISCOSITY:0.495    SQ.CM/SEC

FLUID VELOCITY 7.002    FT/SEC
REYNOLDS NO  37585.9
PRANDTL NO    3.13

HEAT SUPP      16390.7    BTU/HR
HEAT TRANS     15659.8    BTU/HR
HEAT LOST        730.9    BTU/HR
PERCENT HEAT LOST      4.46
HEAT FLUX TRANS. BTU/SQFT-HR     89896.
NUSSELT NO      160.4
RFILM      0.473
RWALL      0.144
RTOTAL     0.617       SQFT-HR-DEG F/BTU
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ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.24877              .87951
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.26192E-01          .92598E-01
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0                      2.1977                   2.8763
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TIME HOURS	CALC. RESISTANCE (SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.13	0.59	0.69
0.22	1.08	1.03
0.33	1.52	1.35
0.55	1.57	1.75
0.77	1.97	1.96
0.92	1.92	2.04
1.00	2.16	2.07
1.42	2.21	2.16
1.78	2.16	2.18
2.08	2.21	2.19

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	162.7	161.9	167.9	167.9	168.7	165.9	165.5	0.0	171.5	175.8	0.0	127.0	142.7	167.5	15.7	2169.5	0.4609	0.0
0.0	163.1	163.1	168.7	168.3	169.5	166.3	165.9	0.0	171.5	176.2	0.0	126.5	142.7	168.0	16.2	2122.5	0.4711	0.13
0.0	163.9	163.1	169.1	169.1	169.9	166.7	166.3	0.0	171.9	176.6	0.0	126.5	142.7	168.5	16.2	2095.3	0.4773	0.22
0.0	163.9	163.5	169.5	169.1	170.3	167.1	166.7	0.0	172.6	177.4	0.0	126.5	142.7	168.9	16.2	2070.0	0.4831	0.33
0.0	164.3	163.5	169.5	169.5	170.3	167.1	166.7	0.0	172.6	177.0	0.0	126.5	142.7	168.9	16.2	2068.2	0.4835	0.55
0.0	164.3	163.9	169.9	169.5	170.7	167.5	167.1	0.0	173.4	177.4	0.0	126.5	142.7	169.3	16.2	2045.8	0.4898	0.77
0.0	164.7	163.9	169.5	169.5	170.7	167.5	167.1	0.0	173.0	177.4	0.0	126.5	142.7	169.2	16.2	2050.0	0.4878	0.92
0.0	164.7	163.9	170.3	169.9	170.7	167.9	167.1	0.0	173.0	177.8	0.0	126.5	142.7	169.5	16.2	2036.4	0.4911	1.00
0.0	164.7	163.9	170.3	169.9	170.7	167.9	167.5	0.0	173.0	177.8	0.0	126.5	142.7	169.5	16.2	2033.1	0.4919	1.42
0.0	164.7	163.9	170.3	169.9	170.7	167.9	167.1	0.0	173.0	177.8	0.0	126.5	142.7	169.5	16.2	2036.4	0.4911	1.78
0.0	164.7	163.9	169.9	170.3	171.1	167.9	167.5	0.0	173.0	177.4	0.0	126.5	142.7	169.5	16.2	2031.6	0.4922	2.08

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	142.7	0.0	15.7	2169.5	0.4609	0.0
0.0	0.44	1.33	0.89	0.44	0.88	0.44	0.44	0.0	0.0	0.44	0.0	126.5	142.7	0.59	16.2	2122.5	0.4711	0.13
0.0	1.33	1.33	1.33	1.33	1.33	0.89	0.89	0.0	0.44	0.88	0.0	126.5	142.7	1.08	16.2	2095.3	0.4773	0.22
0.0	1.33	1.78	1.77	1.33	1.77	1.33	1.33	0.0	1.32	1.76	0.0	126.5	142.7	1.52	16.2	2070.0	0.4831	0.33
0.0	1.78	1.78	1.77	1.77	1.77	1.33	1.33	0.0	1.32	1.32	0.0	126.5	142.7	1.57	16.2	2068.2	0.4835	0.55
0.0	1.78	2.22	2.21	1.77	2.21	1.77	1.77	0.0	2.21	1.76	0.0	126.5	142.7	1.97	16.2	2045.8	0.4888	0.77
0.0	2.22	2.22	1.77	1.77	2.21	1.77	1.77	0.0	1.77	1.76	0.0	126.5	142.7	1.92	16.2	2050.0	0.4878	0.92
0.0	2.22	2.22	2.65	2.21	2.21	2.22	1.77	0.0	1.77	2.20	0.0	126.5	142.7	2.16	16.2	2036.4	0.4911	1.00
0.0	2.22	2.22	2.65	2.21	2.21	2.22	2.22	0.0	1.77	2.20	0.0	126.5	142.7	2.21	16.2	2033.1	0.4919	1.42
0.0	2.22	2.22	2.65	2.21	2.21	2.22	1.77	0.0	1.77	2.20	0.0	126.5	142.7	2.16	16.2	2036.4	0.4911	1.78
0.0	2.22	2.22	2.21	2.65	2.65	2.22	2.22	0.0	1.77	1.76	0.0	126.5	142.7	2.21	16.2	2031.6	0.4922	2.08

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*******RUN NO45.*******

FERRIC OXIDE CONC (PPM)     250.

VOLTS' 3.50        AMPS: 355.

HEAT   W SUPPLIED 16356.8       BTU/HR
HEAT   JX SUPPLIED   93897.     BTU/SQFT-HR

BETA0.301          TOR=TINLET127.0    DEG F
DENSITY:0.986 GRAM/CC
                   T OUTLET149.9      DEG F

FLOW RATE 0.1888   LBS.M/SEC

AVG TEMP:138.4     DEG F
KINEMATIC
VISCOSITY:0.480    SQ.CM/SEC

FLUID VELOCITY 4.790    FT/SEC
REYNOLDS NO  26466.8
PRANDTL NO    3.03

HEAT SUPP      16356.8    BTU/HR
HEAT TRANS     15633.8    BTU/HR
HEAT LOST        723.0    BTU/HR
PERCENT HEAT LOST     4.42
HEAT FLUX TRANS. BTU/SQFT-HR     89746.
NUSSELT NO     121.3
RFILM     0.624
RWALL     0.143
RTOTAL     0.766        SQFT-HR-DEG F/BTU
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ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
 1.0661             5.9943
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
 .15249             .85735
ESTIMATE OF RO,RINF,AND B IN RF=RINF(1.-EXP(-B*TIME)
 .0                 .52974              2.2537
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TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.17	0.15	0.17
1.00	0.39	0.47
1.10	0.44	0.49
1.27	0.63	0.50
1.67	0.68	0.52
1.95	0.59	0.52
2.17	0.58	0.53
2.42	0.24	0.53

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	175.0	175.0	182.5	182.5	184.1	180.2	179.8	0.0	187.2	193.5	0.0	127.0	149.9	182.2	23.0	1617.4	0.6183	0.0
0.0	175.0	175.0	182.5	182.9	184.1	180.6	179.8	0.0	187.6	193.5	0.0	127.0	149.9	182.3	23.0	1611.8	0.6204	0.17
0.0	175.4	175.4	182.5	182.9	184.1	180.6	180.2	0.0	188.0	193.9	0.0	127.0	149.9	182.6	23.0	1604.9	0.6231	1.00
0.0	175.4	175.8	183.3	182.9	184.1	180.6	180.2	0.0	187.6	193.5	0.0	127.0	149.9	182.6	23.0	1603.8	0.6235	1.10
0.0	175.8	175.4	182.9	182.9	184.5	180.9	180.6	0.0	188.0	193.9	0.0	127.0	149.9	182.8	23.0	1596.6	0.6263	1.27
0.0	175.8	175.4	182.9	182.9	184.5	180.9	180.6	0.0	188.4	193.9	0.0	127.0	150.3	182.8	23.4	1602.8	0.6239	1.67
0.0	175.4	175.4	182.9	182.9	184.5	180.9	180.6	0.0	188.0	193.9	0.0	127.4	150.3	182.7	22.9	1612.9	0.6200	1.95
0.0	175.4	175.0	182.9	183.3	184.5	180.9	180.6	0.0	188.0	193.9	0.0	127.0	150.3	182.7	23.4	1604.5	0.6232	2.17
0.0	175.0	175.0	182.5	182.5	184.1	180.6	180.2	0.0	188.0	193.9	0.0	127.0	149.9	182.4	23.0	1608.5	0.6217	2.42

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1617.4	0.6183	0.0
0.0	0.0	0.0	0.0	0.44	0.0	0.44	0.0	0.0	0.44	0.0	0.0	127.0	149.9	0.15	23.0	1611.8	0.6204	0.17
0.0	0.44	0.44	0.0	0.44	0.0	0.44	0.44	0.0	0.87	0.43	0.0	127.0	149.9	0.39	23.0	1604.9	0.6231	1.00
0.0	0.44	0.88	0.88	0.44	0.0	0.44	0.44	0.0	0.44	0.0	0.0	127.0	149.9	0.44	23.0	1603.8	0.6235	1.10
0.0	0.88	0.44	0.44	0.44	0.44	0.88	0.88	0.0	0.87	0.43	0.0	127.0	149.9	0.63	23.0	1596.6	0.6263	1.27
0.0	0.88	0.44	0.44	0.44	0.44	0.88	0.88	0.0	1.31	0.43	0.0	127.0	150.3	0.68	23.4	1602.8	0.6239	1.67
0.0	0.44	0.44	0.44	0.44	0.44	0.88	0.88	0.0	0.87	0.43	0.0	127.4	150.3	0.59	22.9	1612.9	0.6200	1.95
0.0	0.44	0.0	0.44	0.88	0.44	0.88	0.88	0.0	0.87	0.43	0.0	127.0	150.3	0.58	23.4	1604.5	0.6232	2.17
0.0	0.0	0.0	0.0	0.0	0.0	0.44	0.44	0.0	0.87	0.43	0.0	127.0	149.9	0.24	23.0	1608.5	0.6217	2.42

*******RUN NO46.*******

FERRIC OXIDE CONC (PPM) 750.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.9 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:138.4 DEG F
KINEMATIC
VISCOSITY:0.480 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26486.8
PRANDTL NO 3.03

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15633.8 BTU/HR
HEAT LOST 723.0 BTU/HR
PERCENT HEAT LOST 4.42
HEAT FLUX TRANS. BTU/SQFT-HR 89746.
NUSSELT NO 121.3
RFILM 0.624
RWALL 0.143
RTOTAL 0.766 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
1.6950 3.5752
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.47800 .90279
ESTIMATE OF R0,RINF,AND B IN RF=RINF*((1.-EXP(-B*TIME)
.0 .67021 .52437

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.05	0.20	0.02
0.08	-0.39	0.03
0.18	-0.05	0.06
0.23	0.10	0.08
0.33	0.10	0.11
0.52	0.34	0.16
0.90	0.63	0.25
1.05	0.00	0.28
1.38	-0.10	0.35
1.43	0.19	0.35
1.78	0.54	0.41
2.17	0.59	0.46
2.40	0.44	0.48
2.60	0.73	0.50
3.27	0.98	0.55
3.43	0.34	0.56
4.32	0.34	0.60
4.73	0.64	0.61

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	174.6	174.6	182.1	182.1	183.7	180.2	179.4	0.0	187.2	192.7	0.0	127.0	149.5	181.9	22.5	1621.5	0.6167	0.0
0.0	175.0	175.0	182.5	182.1	184.1	180.2	179.4	0.0	186.8	193.1	0.0	127.0	149.9	182.0	23.0	1624.5	0.6156	0.05
0.0	174.6	174.2	181.3	181.7	183.3	179.8	179.4	0.0	186.8	192.3	0.0	127.0	149.5	181.5	22.5	1635.0	0.6116	0.08
0.0	175.0	174.6	182.1	182.1	183.7	180.2	179.4	0.0	186.5	192.7	0.0	127.0	149.9	181.8	23.0	1632.5	0.6126	0.18
0.0	174.6	174.6	182.1	182.5	183.7	180.2	179.8	0.0	186.8	193.1	0.0	127.0	149.9	181.9	23.0	1626.0	0.6150	0.23
0.0	174.6	174.6	182.1	182.1	183.7	180.2	179.8	0.0	187.2	193.1	0.0	127.0	149.9	181.9	23.0	1626.1	0.6150	0.33
0.0	175.0	175.0	182.1	182.5	184.1	180.6	179.8	0.0	187.2	193.1	0.0	127.0	149.9	182.2	23.0	1618.3	0.6179	0.52
0.0	175.0	175.4	182.5	182.9	184.1	180.6	180.2	0.0	187.6	193.5	0.0	127.0	149.9	182.4	23.0	1608.6	0.6217	0.90
0.0	174.6	174.6	182.1	182.1	183.7	180.2	179.8	0.0	186.8	192.7	0.0	127.0	149.5	181.9	22.5	1621.1	0.6169	1.05
0.0	174.6	174.6	182.1	182.5	182.9	179.8	179.8	0.0	187.2	192.3	0.0	127.0	149.5	181.8	22.5	1625.1	0.6153	1.38
0.0	175.0	174.6	182.1	182.1	184.1	180.2	179.8	0.0	187.2	193.1	0.0	127.0	149.9	182.0	23.0	1623.4	0.6160	1.43
0.0	175.0	175.4	182.5	182.5	183.7	180.6	180.2	0.0	187.6	193.5	0.0	127.0	149.9	182.3	23.0	1[illegible]2.4	0.6202	1.78
0.0	175.4	175.4	182.5	182.9	184.1	180.9	179.8	0.0	187.2	193.1	0.0	127.0	149.9	182.4	23.0	1611.0	0.6207	2.17
0.0	175.0	175.0	182.5	182.5	184.1	180.6	180.2	0.0	187.2	193.1	0.0	127.0	149.9	182.3	23.0	1614.6	0.6193	2.40
0.0	175.4	175.4	182.5	182.9	184.5	180.9	180.2	0.0	187.6	193.1	0.0	127.0	149.9	182.5	23.0	1605.2	0.6230	2.60
0.0	175.8	175.4	182.5	182.9	184.5	180.9	180.6	0.0	188.0	193.9	0.0	127.0	149.9	182.7	23.0	1598.1	0.6257	3.27
0.0	175.0	175.0	182.1	182.1	184.1	180.6	180.2	0.0	187.2	193.1	0.0	127.0	149.9	182.2	23.0	1618.0	0.6180	3.43
0.0	175.0	175.0	182.1	182.1	183.7	180.2	180.2	0.0	187.6	193.5	0.0	127.0	149.9	182.2	23.0	1619.1	0.6176	4.32
0.0	175.4	175.4	182.9	182.9	184.1	180.9	180.2	0.0	187.2	192.7	0.0	127.0	149.9	182.4	23.0	1608.8	0.6216	4.73

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.5	0.0	22.5	1621.5	0.6167	0.0
0.0	0.44	0.44	0.44	0.0	0.44	0.0	0.0	0.0	0.0	0.44	0.0	127.0	149.9	0.20	23.0	1624.5	0.6156	0.05
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.5	-0.39	22.5	1635.0	0.6116	0.08
0.0	0.44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-0.05	23.0	1632.5	0.6126	0.18
0.0	0.0	0.0	0.0	0.44	0.0	0.0	0.44	0.0	0.0	0.44	0.0	127.0	149.9	0.10	23.0	1626.0	0.6150	0.23
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.44	0.0	0.0	0.44	0.0	127.0	149.9	0.10	23.0	1626.1	0.6150	0.33
0.0	0.44	0.44	0.0	0.44	0.44	0.44	0.44	0.0	0.0	0.44	0.0	127.0	149.9	0.34	23.0	1618.3	0.6179	0.52
0.0	0.44	0.88	0.44	0.88	0.44	0.44	0.88	0.0	0.44	0.87	0.0	127.0	149.9	0.63	23.0	1608.6	0.6217	0.90
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.44	0.0	0.0	0.0	0.0	127.0	149.5	0.00	22.5	1621.1	0.6169	1.05
0.0	0.0	0.0	0.0	0.44	0.0	0.0	0.44	0.0	0.0	0.0	0.0	127.0	149.5	-0.10	22.5	1625.1	0.6153	1.38
0.0	0.44	0.0	0.0	0.0	0.44	0.0	0.44	0.0	0.0	0.44	0.0	127.0	149.9	0.19	23.0	1623.4	0.6160	1.43
0.0	0.44	0.88	0.44	0.44	0.0	0.44	0.88	0.0	0.44	0.87	0.0	127.0	149.9	0.54	23.0	1612.4	0.6202	1.78
0.0	0.88	0.88	0.44	0.88	0.44	0.88	0.44	0.0	0.0	0.44	0.0	127.0	149.9	0.59	23.0	1611.0	0.6207	2.17
0.0	0.44	0.44	0.44	0.44	0.44	0.44	0.88	0.0	0.0	0.44	0.0	127.0	149.9	0.44	23.0	1614.6	0.6193	2.40
0.0	0.88	0.88	0.44	0.88	0.88	0.88	0.88	0.0	0.44	0.44	0.0	127.0	149.9	0.73	23.0	1605.2	0.6230	2.60
0.0	1.32	0.88	0.44	0.88	0.88	0.88	1.32	0.0	0.87	1.31	0.0	127.0	149.9	0.98	23.0	1598.1	0.6257	3.27
0.0	0.44	0.44	0.0	0.0	0.44	0.44	0.88	0.0	0.0	0.44	0.0	127.0	149.9	0.34	23.0	1618.0	0.6180	3.43
0.0	0.44	0.44	0.0	0.0	0.0	0.0	0.88	0.0	0.44	0.87	0.0	127.0	149.9	0.34	23.0	1619.1	0.6176	4.32
0.0	0.88	0.88	0.88	0.88	0.44	0.88	0.88	0.0	0.0	0.0	0.0	127.0	149.9	0.64	23.0	1608.8	0.6216	4.73

*******RUN NO47.*******

FERRIC OXIDE CONC (PPM) 1500.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

PETAO.301 FOR*TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.9 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:136.4 DEG F
KINEMATIC
VISCOSITY:0.480 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26486.8
PRANDTL NO 3.03

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15633.8 BTU/HR
HEAT LOST 723.0 BTU/HR
PERCENT HEAT LOST 4.42
HEAT FLUX TRANS. BTU/SQFT-HR 89746.
NUSSELT NO 121.3
RFILM 0.624
RWALL 0.143
RTOTAL 0.766 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.22616 1.4401
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.76211E-01 .48531
ESTIMATE OF RO,RINF,AND B IN R=RINF(1.-EXP(-B*TIME))
.0 1.0764 3.6802

TIME HOURS	CALC. RESISTANCE (SQFT-HR-DEGF/BTU)X100,000	FITTED VALUE
0.0	0.0	-0.0
0.10	0.34	0.33
0.15	0.63	0.46
0.23	0.78	0.61
0.43	0.53	0.86
0.63	0.73	0.97
0.85	1.21	1.03
0.92	1.26	1.04
1.30	0.83	1.07
1.47	1.17	1.07
1.78	1.12	1.07
2.03	0.88	1.08
2.22	0.63	1.08
2.40	1.41	1.08
2.52	1.22	1.08
2.75	1.12	1.08
2.90	1.22	1.08
3.00	1.61	1.08
3.02	1.56	1.08
3.22	1.61	1.08
3.42	0.93	1.08
4.33	0.64	1.08
4.83	0.25	1.08
4.93	0.93	1.08

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	173.8	174.6	182.1	181.7	184.1	178.2	180.2	0.0	186.5	192.7	0.0	127.0	150.8	181.6	23.8	1657.6	0.6033	0.0
0.0	173.4	174.6	182.5	182.1	184.5	178.6	180.6	0.0	186.8	193.5	0.0	127.0	150.8	181.9	23.8	1643.6	0.6084	0.10
0.0	173.4	174.6	182.9	182.1	184.5	178.6	180.9	0.0	187.2	194.7	0.0	127.0	150.8	182.1	23.8	1633.8	0.6121	0.15
-0.0	173.8	175.0	183.3	182.1	184.9	179.0	180.9	0.0	187.2	193.9	0.0	126.5	150.8	182.2	24.2	1621.1	0.6169	0.23
0.0	173.4	174.6	182.5	182.1	184.9	178.2	180.6	0.0	186.8	195.1	0.0	127.0	151.2	182.0	24.2	1646.3	0.6074	0.43
0.0	174.2	174.2	182.5	182.1	185.3	177.8	180.9	0.0	187.2	195.5	0.0	127.0	150.8	182.2	23.8	1632.7	0.6125	0.63
0.0	174.6	174.2	182.1	182.9	186.1	177.8	180.9	0.0	188.8	196.2	0.0	126.5	151.2	182.6	24.7	1616.4	0.6187	0.85
0.0	174.6	173.8	182.1	183.3	186.1	178.2	181.3	0.0	188.8	195.8	0.0	127.0	151.6	182.7	24.6	1628.8	0.6140	0.92
0.0	175.0	173.0	182.1	183.7	185.3	178.6	180.6	0.0	188.0	194.3	0.0	127.4	151.6	182.3	24.2	1652.0	0.6053	1.30
0.0	175.4	173.0	182.5	183.7	185.3	179.4	180.9	0.0	188.4	194.7	0.0	127.4	151.6	182.6	24.2	1640.0	0.6098	1.47
0.0	175.4	173.0	182.5	183.7	185.3	180.2	180.9	0.0	188.0	193.9	0.0	127.0	150.8	182.6	23.8	1616.1	0.6188	1.78
0.0	175.4	173.4	182.5	183.3	184.5	180.2	180.6	0.0	187.6	193.5	0.0	127.0	149.9	182.3	23.0	1609.9	0.6212	2.03
0.0	175.4	174.2	182.1	182.5	184.1	180.2	180.2	0.0	187.2	193.1	0.0	127.0	149.9	182.1	23.0	1619.9	0.6173	2.22
0.0	176.2	174.6	182.5	183.3	184.9	180.9	180.9	0.0	188.0	193.9	0.0	127.0	150.3	182.8	23.4	1601.8	0.6243	2.40
0.0	175.8	174.6	182.9	183.3	184.9	180.6	180.6	0.0	187.6	193.5	0.0	127.0	150.3	182.6	23.4	1608.2	0.6218	2.52
0.0	175.8	174.6	182.9	182.9	184.5	180.6	180.6	0.0	187.6	193.5	0.0	127.4	149.9	182.6	22.5	1611.7	0.6205	2.75
0.0	176.2	175.4	182.5	182.9	184.5	180.6	180.2	0.0	188.0	193.5	0.0	127.0	149.9	182.6	23.0	1603.0	0.6238	2.90
0.0	177.0	175.4	183.3	183.3	184.5	180.9	180.6	0.0	188.0	193.9	0.0	127.0	149.9	183.0	23.0	1591.5	0.6283	3.00
0.0	176.2	175.0	183.3	183.3	184.5	180.9	180.9	0.0	188.0	194.3	0.0	127.0	149.9	183.0	23.0	1590.5	0.6287	3.02
0.0	176.2	175.8	183.3	182.9	184.5	180.9	180.9	0.0	188.4	193.9	0.0	127.0	150.3	183.0	23.4	1597.5	0.6260	3.22
0.0	175.4	175.0	182.5	182.9	184.5	180.9	179.8	0.0	187.2	193.1	0.0	127.0	149.9	182.4	23.0	1610.2	0.6211	3.42
0.0	175.4	175.0	182.5	182.1	184.1	180.2	179.8	0.0	187.2	192.7	0.0	127.4	149.9	182.1	22.5	1629.3	0.6138	4.33
0.0	175.0	174.6	182.1	182.5	183.7	179.8	179.4	0.0	186.5	192.3	0.0	127.0	149.9	181.8	23.0	1634.2	0.6119	4.83
0.0	175.4	175.4	182.9	182.5	184.1	180.6	180.2	0.0	187.2	193.1	0.0	127.0	149.9	182.4	23.0	1611.3	0.6206	4.93

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	150.8	0.0	23.8	1657.6	0.6033	0.0
0.0	0.0	0.0	0.44	0.44	0.44	0.44	0.44	0.0	0.44	0.87	0.0	127.0	150.8	0.34	23.8	1643.6	0.6084	0.10
0.0	0.0	0.0	0.88	0.44	0.44	0.44	0.88	0.0	0.87	2.17	0.0	127.0	150.8	0.63	23.8	1633.8	0.6121	0.15
0.0	0.0	0.44	1.32	0.44	0.88	0.88	0.88	0.0	0.87	1.31	0.0	126.5	150.8	0.78	24.2	1621.1	0.6169	0.23
0.0	0.0	0.0	0.44	0.44	0.88	0.0	0.44	0.0	0.44	2.61	0.0	127.0	151.2	0.53	24.2	1646.3	0.6074	0.43
0.0	0.44	0.0	0.44	0.44	1.31	0.0	0.88	0.0	0.87	3.04	0.0	127.0	150.8	0.73	23.8	1632.7	0.6125	0.63
0.0	0.88	0.0	0.0	1.32	2.19	0.0	0.88	0.0	2.62	3.91	0.0	126.5	151.2	1.21	24.7	1616.4	0.6187	0.85
0.0	0.88	0.0	0.0	1.75	2.19	0.0	1.32	0.0	2.62	3.48	0.0	127.0	151.6	1.26	24.6	1628.8	0.6140	0.92
0.0	1.32	0.0	0.0	2.19	1.31	0.44	0.44	0.0	1.75	1.74	0.0	127.4	151.6	0.83	24.2	1652.0	0.6053	1.30
0.0	1.77	0.0	0.44	2.19	1.31	1.32	0.88	0.0	2.19	2.17	0.0	127.4	151.6	1.17	24.2	1640.0	0.6098	1.47
0.0	1.77	0.0	0.44	2.19	1.31	2.20	0.88	0.0	1.75	1.31	0.0	127.0	150.8	1.12	23.8	1616.1	0.6188	1.78
0.0	1.77	0.0	0.44	1.75	0.44	2.20	0.44	0.0	1.31	0.87	0.0	127.0	149.9	0.88	23.0	1609.9	0.6212	2.03
0.0	1.77	0.0	0.0	0.88	0.0	2.20	0.0	0.0	0.87	0.44	0.0	127.0	149.9	0.63	23.0	1619.9	0.6173	2.22
0.0	2.65	0.0	0.44	1.75	0.88	3.08	0.88	0.0	1.75	1.31	0.0	127.0	150.3	1.41	23.4	1601.8	0.6243	2.40
0.0	2.21	0.0	0.88	1.75	0.88	2.64	0.44	0.0	1.31	0.87	0.0	127.0	150.3	1.22	23.4	1608.2	0.6218	2.52
0.0	2.21	0.0	0.88	1.32	0.44	2.64	0.44	0.0	1.31	0.87	0.0	127.4	149.9	1.12	22.5	1611.7	0.6205	2.75
0.0	2.65	0.88	0.44	1.32	0.44	2.64	0.0	0.0	1.75	0.87	0.0	127.0	149.9	1.22	23.0	1603.0	0.6238	2.90
0.0	3.53	0.88	1.32	1.75	0.44	3.08	0.44	0.0	1.75	1.31	0.0	127.0	149.9	1.61	23.0	1591.5	0.6283	3.00
0.0	2.65	0.44	1.32	1.75	0.44	3.08	0.88	0.0	1.75	1.74	0.0	127.0	149.9	1.56	23.0	1590.5	0.6287	3.02
0.0	2.65	1.32	1.32	1.32	0.44	3.08	0.88	0.0	2.19	1.31	0.0	127.0	150.3	1.61	23.4	1597.5	0.6260	3.22
0.0	1.77	0.44	0.44	1.32	0.44	3.08	0.0	0.0	0.87	0.44	0.0	127.0	149.9	0.93	23.0	1610.2	0.6211	3.42
0.0	1.77	0.44	0.44	0.44	0.0	2.20	0.0	0.0	0.87	0.0	0.0	127.4	149.9	0.64	22.5	1629.3	0.6138	4.33
0.0	1.32	0.00	0.0	0.88	0.0	1.76	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.25	23.0	1634.2	0.6119	4.83
0.0	1.77	0.88	0.88	0.88	0.0	2.64	0.0	0.0	0.87	0.44	0.0	127.0	149.9	0.93	23.0	1611.3	0.6206	4.93

*******RUN NO48.*******

FERRIC OXIDE CONC (PPM) 1750.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.9 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:138.4 DEG F
KINEMATIC
VISCOSITY:0.480 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26486.8
PRANDTL NO 3.03

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15633.8 BTU/HR
HEAT LOST 723.0 BTU/HR
PERCENT HEAT LOST 4.42
HEAT FLUX TRANS. BTU/SQFT-HR 89746.
NUSSELT NO 121.3
RFILM 0.624
RWALL 0.143
RTOTAL 0.766 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
1.2607 4.1779
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.19861 .65818
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 .43220 3.3676

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.03	0.24	0.04
0.07	-0.24	0.09
0.08	-0.10	0.10
0.17	0.34	0.19
0.27	0.24	0.26
0.45	0.49	0.34
0.62	0.39	0.38
0.80	0.34	0.40
1.62	0.49	0.43
1.75	0.39	0.43
1.95	0.39	0.43

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	175.0	175.0	182.5	182.1	183.7	180.2	179.8	0.0	187.6	192.7	0.0	127.0	149.9	182.1	23.0	1622.4	0.6164	0.0
0.0	175.0	174.6	182.9	182.5	184.1	180.2	179.8	0.0	187.6	193.9	0.0	127.0	149.9	182.3	23.0	1614.0	0.6196	0.03
0.0	175.4	174.6	182.1	182.1	183.3	179.6	179.4	0.0	187.2	192.7	0.0	127.0	149.9	181.9	23.0	1632.5	0.6126	0.07
0.0	175.0	175.0	182.1	182.1	183.7	180.2	179.8	0.0	187.2	192.7	0.0	127.0	149.9	182.0	23.0	1625.7	0.6151	0.08
0.0	175.4	175.0	182.5	182.5	184.1	180.6	180.2	0.0	187.6	193.5	0.0	126.5	149.9	182.4	23.4	1603.2	0.6233	0.17
0.0	175.0	175.0	182.1	182.5	184.1	180.6	180.2	0.0	187.6	193.5	0.0	126.5	149.9	182.3	23.4	1605.3	0.6229	0.27
0.0	175.0	174.6	182.1	186.5	183.7	180.2	179.8	0.0	187.6	193.1	0.0	127.0	149.9	182.5	23.0	1603.7	0.6236	0.45
0.0	175.0	175.0	182.5	182.9	184.5	180.6	180.2	0.0	188.0	193.1	0.0	127.0	149.9	182.4	23.0	1607.4	0.6221	0.62
0.0	175.0	175.4	182.5	182.5	184.1	180.6	180.7	0.0	187.6	193.5	0.0	127.0	149.9	182.4	23.0	1610.4	0.6210	0.80
0.0	175.4	175.0	182.5	182.5	184.5	180.6	180.6	0.0	188.0	193.5	0.0	127.0	149.9	182.5	23.0	1605.1	0.6230	1.62
0.0	175.4	175.4	182.5	182.5	184.1	180.6	180.2	0.0	187.6	193.5	0.0	127.0	149.9	182.4	23.0	1609.7	0.6212	1.75
0.0	175.4	175.0	182.5	182.5	184.1	180.6	180.2	0.0	188.0	193.5	0.0	127.0	149.9	182.4	23.0	1609.2	0.6214	1.95

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1622.4	0.6164	0.0
0.0	0.0	0.0	0.44	0.44	0.44	0.0	0.0	0.0	0.0	1.31	0.0	127.0	149.9	0.24	23.0	1614.0	0.6196	0.03
0.0	0.44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-0.24	23.0	1632.5	0.6126	0.07
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-0.10	23.0	1625.7	0.6151	0.08
0.0	0.44	0.0	0.0	0.44	0.44	0.44	0.44	0.0	0.0	0.87	0.0	126.5	149.9	0.34	23.4	1603.2	0.6238	0.17
0.0	0.0	0.0	0.0	0.44	0.44	0.44	0.44	0.0	0.0	0.87	0.0	126.5	149.9	0.24	23.4	1605.3	0.6229	0.27
0.0	0.0	0.0	0.0	4.82	0.0	0.0	0.0	0.0	0.0	0.44	0.0	127.0	149.9	0.49	23.0	1603.7	0.6236	0.45
0.0	0.0	0.0	0.0	0.88	0.88	0.44	0.44	0.0	0.44	0.44	0.0	127.0	149.9	0.39	23.0	1607.4	0.6221	0.62
0.0	0.0	0.44	0.0	0.44	0.44	0.44	0.44	0.0	0.0	0.87	0.0	127.0	149.9	0.34	23.0	1610.4	0.6210	0.80
0.0	0.44	0.0	0.0	0.44	0.88	0.44	0.88	0.0	0.44	0.87	0.0	127.0	149.9	0.49	23.0	1605.1	0.6230	1.62
0.0	0.44	0.44	0.0	0.44	0.44	0.44	0.44	0.0	0.0	0.87	0.0	127.0	149.9	0.39	23.0	1609.7	0.6212	1.75
0.0	0.44	0.0	0.0	0.44	0.44	0.44	0.44	0.0	0.44	0.87	0.0	127.0	149.9	0.39	23.0	1609.2	0.6214	1.95

*******RUN NO49.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

BETA0.301 TCR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.9 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:138.4 DEG F
KINEMATIC
VISCOSITY:0.460 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26486.8
PRANDTL NO 3.03

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15633.8 BTU/HR
HEAT LOST 723.0 BTU/HR
PERCENT HEAT LOST 4.42
HEAT FLUX TRANS. BTU/SQFT-HR 89746.
NUSSELT NO 121.3
RFILM 0.624
RWALL 0.143
RTOTAL 0.766 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.12740 .78465
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.64190E-01 .39535
ESTIMATE OF RO,RINF,AND B IN RF=RINF*(1.-EXP(-B*TIME))
.0 2.0657 5.3409

TIME HOURS	CALC. RESISTANCE (SQFT-HR-DEGF/BTU)X100,000	FITTED VALUE
0.0	0.0	-0.0
0.02	1.02	0.21
0.15	1.41	1.14
0.20	1.46	1.36
0.23	1.22	1.45
0.53	1.56	1.94
0.63	1.51	1.99
0.80	1.95	2.04
0.97	1.85	2.05
1.25	2.20	2.06
1.43	2.00	2.06
1.55	1.90	2.07
1.75	2.34	2.07
2.13	2.54	2.07
2.47	2.10	2.07
3.00	1.61	2.07
3.12	1.56	2.07
3.25	1.71	2.07
3.38	1.51	2.07
3.63	3.22	2.07
3.87	3.07	2.07

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	174.6	174.2	182.5	182.5	183.3	178.6	178.6	0.0	186.5	192.7	0.0	127.0	149.9	181.5	23.0	1645.9	0.6076	0.0
0.0	175.4	175.0	182.5	182.5	184.1	180.6	180.2	0.0	188.0	193.5	0.0	127.0	149.9	182.4	23.0	1609.2	0.6214	0.02
0.0	175.8	175.8	182.9	182.9	184.5	180.6	180.6	C.0	188.4	193.5	0.0	126.5	149.9	182.8	23.4	1589.6	0.6291	0.15
0.0	175.8	175.8	182.9	183.3	184.5	180.9	180.6	0.0	188.0	193.5	0.0	126.5	149.9	182.8	23.4	1587.5	0.6299	0.20
0.0	175.8	175.4	182.5	182.9	184.1	180.6	180.6	0.0	187.6	193.9	0.0	126.5	149.9	182.6	23.4	1596.2	0.6265	0.23
0.0	175.8	175.8	182.9	182.9	184.5	180.9	180.9	0.0	188.4	193.9	0.0	126.5	149.9	182.9	23.4	1584.3	0.6312	0.53
0.0	176.2	175.8	182.9	183.3	184.5	180.9	180.6	C.0	188.0	193.5	0.0	126.5	149.9	182.9	23.4	1586.9	0.6302	0.63
0.0	177.0	176.2	183.3	183.3	184.9	181.3	180.9	0.0	188.4	193.9	0.0	126.5	149.9	183.3	23.4	1574.2	0.6352	0.80
0.0	177.0	176.2	182.9	182.9	184.9	180.9	180.9	0.0	188.4	194.3	0.0	126.5	149.9	183.2	23.4	1578.1	0.6337	0.97
0.0	177.0	176.6	183.7	183.7	184.9	181.7	181.3	C.0	188.4	193.9	0.0	126.5	149.9	183.5	23.4	1566.0	0.6386	1.25
0.0	177.4	177.0	183.7	183.7	184.9	180.9	180.6	0.0	188.0	193.5	0.0	126.5	149.5	183.3	23.0	1567.6	0.6379	1.43
0.0	176.6	176.2	183.3	183.7	184.9	180.9	180.9	0.0	188.0	194.3	0.0	126.5	149.9	183.2	23.4	1575.4	0.6348	1.55
0.0	177.4	177.0	183.7	184.1	185.3	181.3	180.9	0.0	188.4	194.3	0.0	127.0	149.9	183.6	23.0	1570.7	0.6367	1.75
0.0	177.4	177.4	184.5	184.1	185.3	181.7	180.9	C.0	188.4	194.3	0.0	126.5	149.5	183.8	23.0	1550.0	0.6452	2.13
0.0	177.8	176.6	183.7	183.7	184.9	180.9	180.9	0.0	188.0	193.9	0.0	127.0	149.9	183.4	23.0	1579.8	0.6330	2.47
0.0	175.8	175.8	183.3	183.3	184.9	180.9	180.6	0.0	188.0	193.9	0.0	127.0	149.9	183.0	23.0	1590.3	C.6268	3.CC
0.0	175.8	176.2	182.9	183.3	184.5	180.9	180.6	C.0	188.0	193.9	0.0	127.0	149.9	182.9	23.0	1592.6	0.6279	3.12
0.0	176.2	175.8	183.7	183.3	184.9	180.9	180.6	0.0	188.4	193.5	0.0	127.0	149.9	183.0	23.0	1587.8	0.6298	3.25
0.0	176.2	175.8	183.3	183.3	184.5	180.9	180.6	0.0	187.6	193.5	0.0	127.0	149.9	182.9	23.0	1594.6	C.6271	3.38
0.0	172.2	177.8	184.9	184.9	186.1	182.1	181.7	C.0	189.2	194.7	0.0	127.0	149.9	184.4	23.0	1543.7	0.6478	3.63
0.0	178.6	177.8	184.9	184.5	186.1	182.1	181.7	0.0	188.4	194.3	0.0	127.0	149.9	184.3	23.0	1549.3	0.6454	3.87

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1645.9	0.6076	0.0
0.0	0.88	0.88	0.0	0.0	0.88	2.20	1.76	0.0	1.75	0.87	0.0	127.0	149.9	1.02	23.0	1609.2	0.6214	0.02
0.0	1.32	1.76	0.44	0.44	1.31	2.20	2.20	0.0	2.19	0.87	0.0	126.5	149.9	1.41	23.4	1589.6	0.6291	0.15
0.0	1.32	1.76	0.44	0.88	1.31	2.64	2.20	0.0	1.75	0.87	0.0	126.5	149.9	1.46	23.4	1587.5	C.6299	0.20
0.0	1.32	1.32	0.0	0.44	0.88	2.20	2.20	0.0	1.31	1.31	0.0	126.5	149.9	1.22	23.4	1596.2	0.6265	0.23
0.0	1.32	1.76	0.44	0.44	1.31	2.64	2.64	0.0	2.19	1.31	0.0	126.5	149.9	1.56	23.4	1584.3	0.6312	0.53
0.0	1.76	1.76	0.44	0.88	1.31	2.64	2.70	0.0	1.75	0.87	0.0	126.5	149.9	1.51	23.4	1586.9	0.6302	0.63
0.0	2.65	2.21	0.88	0.88	1.75	3.08	2.64	0.0	2.19	1.31	0.0	126.5	149.9	1.95	23.4	1574.2	0.6352	0.80
0.0	2.65	2.21	0.44	0.44	1.75	2.64	2.64	0.0	2.19	1.74	0.0	126.5	149.9	1.85	23.4	1578.1	0.6337	0.97
0.0	2.65	2.65	1.32	1.32	1.75	3.52	3.08	0.0	2.19	1.31	0.0	126.5	149.9	2.20	23.4	1566.0	0.6386	1.25
0.0	3.09	3.09	1.32	1.32	1.75	2.64	2.70	0.0	1.75	0.87	0.0	126.5	149.5	2.00	23.0	1567.6	0.6379	1.43
0.0	2.21	2.21	0.88	1.32	1.75	2.64	2.64	0.0	1.75	1.74	0.0	126.5	149.9	1.90	23.4	1575.4	0.6348	1.55
0.0	3.09	3.09	1.32	1.75	2.19	3.08	2.64	0.0	2.19	1.74	0.0	127.0	149.9	2.34	23.0	1570.7	0.6367	1.75
0.0	3.09	3.53	2.19	1.75	2.19	3.52	2.64	0.0	2.19	1.74	0.0	126.5	149.5	2.54	23.0	1550.0	0.6452	2.13
0.0	3.53	2.65	1.32	1.32	1.75	2.64	2.64	0.0	1.75	1.31	0.0	127.0	149.9	2.10	23.0	1579.8	0.6330	2.47
0.0	1.32	1.76	0.88	0.88	1.75	2.64	2.70	0.0	1.75	1.31	0.0	127.0	149.9	1.61	23.0	1590.3	0.6268	3.00
0.0	1.32	2.21	0.44	0.88	1.31	2.64	2.70	0.0	1.75	1.31	0.0	127.0	149.9	1.56	23.0	1592.6	0.6279	3.12
0.0	1.76	1.76	1.32	0.88	1.75	2.64	2.20	0.0	2.19	0.87	0.0	127.0	149.9	1.71	23.0	1587.8	0.6298	3.25
0.0	1.76	1.76	0.88	0.88	1.31	2.64	2.20	0.0	1.31	0.87	0.0	127.0	149.9	1.51	23.0	1594.6	0.6271	3.38
0.0	3.97	3.97	2.63	2.63	3.07	3.95	3.52	0.0	1.05	2.17	0.0	127.0	149.9	3.22	23.0	1543.7	0.6478	3.63
0.0	4.41	3.97	2.63	2.19	3.07	3.95	3.52	0.0	2.19	1.74	0.0	127.0	149.9	3.07	23.0	1549.3	0.6454	3.87

*******RUN NO50.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 43897. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.966 GRAM/CC
T OUTLET149.9 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:138.4 DEG F
KINEMATIC
VISCOSITY:0.480 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26486.8
PRANDTL NO 3.03

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15633.8 BTU/HR
HEAT LOST 723.0 BTU/HR
PERCENT HEAT LOST 4.42
HEAT FLUX TRANS. BTU/SQFT-HR 89746.
NUSSELT NO 121.3
RFILM 0.624
RWALL 0.143
RTOTAL 0.766 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.14037 .60704
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.43249E-01 .18704
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 3.0913 3.6707

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.07	0.73	0.70
0.15	1.51	1.31
0.30	1.51	2.06
0.43	3.07	2.45
0.67	2.92	2.83
0.73	2.39	2.88
0.97	2.92	3.00
1.17	3.02	3.05
1.28	3.22	3.06
1.40	3.26	3.07
1.57	3.02	3.08
1.72	3.07	3.09

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	175.4	175.8	183.3	182.9	164.1	180.2	179.8	0.0	188.0	193.5	0.0	127.4	149.9	182.6	22.5	1613.9	0.6196	0.0
0.0	176.6	176.2	183.7	183.3	184.9	180.9	180.6	0.0	188.4	194.3	0.0	127.0	149.5	183.2	22.5	1575.7	0.6346	0.07
0.0	177.0	177.0	184.5	184.1	165.7	181.7	181.3	0.0	189.2	194.7	0.0	127.0	149.5	183.9	22.5	1550.5	0.6449	0.15
0.0	178.2	177.8	164.5	183.7	185.7	181.3	181.3	0.0	188.4	194.3	0.0	127.0	149.5	183.9	22.5	1554.9	0.6431	0.30
0.0	179.0	179.0	165.7	185.3	186.8	182.9	182.9	0.0	190.0	196.2	0.0	126.5	149.5	185.3	23.0	1500.2	0.6666	0.43
0.0	179.0	179.0	185.7	185.3	186.5	182.9	182.5	0.0	190.0	195.8	0.0	126.5	149.5	185.2	23.0	1505.0	0.6645	0.67
0.0	178.2	178.6	185.3	184.9	186.5	182.5	182.1	0.0	189.6	194.7	0.0	126.5	149.5	184.7	23.0	1518.9	0.6584	0.73
0.0	179.0	178.6	186.1	185.3	186.8	182.9	182.5	0.0	190.0	195.5	0.0	126.5	149.9	185.2	23.4	1511.2	0.6617	0.97
0.0	179.0	178.6	186.1	185.7	187.2	182.9	182.5	0.0	190.0	195.5	0.0	126.5	149.9	185.3	23.4	1507.8	0.6632	1.17
0.0	179.0	179.0	185.7	185.7	187.6	183.3	182.9	0.0	190.0	195.8	0.0	126.5	149.9	185.4	23.4	1501.6	0.6660	1.28
0.0	179.0	178.6	186.1	185.7	187.2	183.3	182.9	0.0	190.8	195.8	0.0	127.0	149.9	185.5	23.0	1506.7	0.6637	1.40
0.0	179.4	178.6	185.7	185.7	186.8	182.9	182.9	0.0	190.0	195.5	0.0	127.0	149.9	185.3	23.0	1515.3	0.6599	1.57
0.0	179.0	178.6	185.7	186.1	187.2	182.9	182.5	0.0	190.0	195.8	0.0	126.5	149.9	185.3	23.4	1506.3	0.6639	1.72

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.4	149.9	0.0	22.5	1613.9	0.6196	0.0
0.0	1.32	0.44	0.44	0.44	0.88	0.88	0.88	0.0	0.44	0.87	0.0	127.0	149.5	0.73	22.5	1575.7	0.6346	0.07
0.0	1.76	1.32	1.31	1.32	1.75	1.76	1.76	0.0	1.31	1.30	0.0	127.0	149.5	1.51	22.5	1550.5	0.6449	0.15
0.0	3.08	2.20	1.31	0.88	1.75	1.32	1.76	0.0	0.44	0.87	0.0	127.0	149.5	1.51	22.5	1554.9	0.6431	0.30
0.0	3.96	3.52	2.63	2.63	3.06	3.07	3.51	0.0	2.18	3.04	0.0	126.5	149.5	3.07	23.0	1500.2	0.6666	0.43
0.0	3.96	3.52	2.63	2.63	2.63	3.07	3.07	0.0	2.18	2.61	0.0	126.5	149.5	2.92	23.0	1505.0	0.6645	0.67
0.0	3.08	3.08	2.19	2.19	2.63	2.63	2.64	0.0	1.75	1.30	0.0	126.5	149.5	2.39	23.0	1518.9	0.6584	0.73
0.0	3.96	3.08	3.07	2.63	3.06	3.07	3.07	0.0	2.18	2.17	0.0	126.5	149.9	2.92	23.4	1511.2	0.6617	0.97
0.0	3.96	3.08	3.07	3.07	3.50	3.07	3.07	0.0	2.18	2.17	0.0	126.5	149.9	3.02	23.4	1507.8	0.6632	1.17
0.0	3.96	3.52	2.63	3.07	3.94	3.51	3.51	0.0	2.18	2.61	0.0	126.5	149.9	3.22	23.4	1501.6	0.6660	1.28
0.0	3.96	3.08	3.07	3.07	3.50	3.51	3.51	0.0	3.05	2.61	0.0	127.0	149.9	3.26	23.0	1506.7	0.6637	1.40
0.0	4.40	3.08	2.63	3.07	3.06	3.07	3.51	0.0	2.18	2.17	0.0	127.0	149.9	3.02	23.0	1515.3	0.6599	1.57
0.0	3.96	3.08	2.63	3.50	3.50	3.07	3.07	0.0	2.18	2.61	0.0	126.5	149.9	3.07	23.4	1506.3	0.6639	1.72

*******RUN NO51.*******

FERRIC OXIDE CONC (PPM) 3750.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.9 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:138.4 DEG F
KINEMATIC
VISCOSITY:0.480 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26486.8
PRANDTL NO 3.03

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15633.8 BTU/HR
HEAT LOST 723.0 BTU/HR
PERCENT HEAT LOST 4.42
HEAT FLUX TRANS. BTU/SQFT-HR 89746.
NUSSELT NO 121.3
RFILM 0.624
RWALL 0.143
RTOTAL 0.766 SQFT-HR-DEG F/BTU

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	179.8	179.4	186.5	186.1	187.6	184.1	184.1	0.0	191.2	197.0	0.0	127.0	149.9	186.2	23.0	1485.0	0.6734	0.0
0.0	179.4	178.6	186.1	185.7	187.6	183.7	183.3	0.0	190.4	195.8	0.0	126.5	149.9	185.6	23.4	1495.6	0.6686	0.08
0.0	179.0	179.6	185.7	185.7	186.8	183.3	182.9	0.0	190.4	195.8	0.0	127.0	149.9	185.4	23.0	1511.3	0.6617	0.13
0.0	179.0	178.2	185.3	185.3	166.5	182.9	132.5	0.0	189.6	195.1	0.0	126.5	149.9	184.9	23.4	1519.4	0.6582	0.30
0.0	179.0	178.2	185.7	185.3	186.5	182.5	182.5	0.0	189.6	195.1	0.0	126.5	149.9	184.9	23.4	1519.9	0.6579	0.45
0.0	178.6	177.8	185.3	184.9	186.5	182.5	182.1	0.0	188.8	194.3	0.0	126.5	149.9	184.5	23.4	1532.0	0.6527	0.57
0.0	179.0	177.8	184.5	184.1	185.7	181.7	181.7	0.0	188.8	193.9	0.0	127.0	149.9	184.1	23.0	1555.4	0.6427	0.68
0.0	178.6	177.8	184.5	184.5	185.7	181.7	181.7	0.0	188.8	194.3	0.0	127.0	149.9	184.2	23.0	1552.9	0.6440	0.90
0.0	178.2	177.4	184.1	184.1	185.3	181.7	181.7	0.0	188.8	194.3	0.0	127.0	149.9	184.0	23.0	1559.5	0.6412	1.07
0.0	177.4	177.0	184.1	183.7	185.3	181.3	181.3	C.0	188.8	193.9	0.0	127.0	149.5	183.7	22.5	1561.1	0.6406	1.23
0.0	178.2	177.8	184.5	184.5	185.7	182.1	181.7	0.0	198.8	193.9	0.0	127.0	149.9	184.1	23.0	1552.8	0.6440	1.37
0.0	177.8	177.0	184.1	183.7	185.3	181.3	181.3	0.0	188.4	193.5	0.0	127.0	149.9	183.6	23.0	1571.1	0.6365	1.55

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1485.0	0.6734	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	149.9	-0.63	23.4	1495.6	0.6686	0.08
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-0.92	23.0	1511.3	0.6617	0.13
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	149.9	-1.41	23.4	1519.4	0.6582	0.30
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	149.9	-1.41	23.4	1519.9	0.6579	0.45
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	149.9	-1.85	23.4	1532.0	0.6527	0.57
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-2.28	23.0	1555.4	0.6427	0.68
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-2.24	23.0	1552.9	0.6440	0.90
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-2.48	23.0	1559.5	0.6412	1.07
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.5	-2.82	22.5	1561.1	0.6406	1.23
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-2.28	23.0	1552.8	0.6440	1.37
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	-2.87	23.0	1571.1	0.6365	1.55

*******RUN NO52.*******

FERRIC OXIDE CONC (PPM) 3750.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.9 DEG F

FLOW RATE 0.1688 LBS.M/SEC

AVG TEMP:138.4 DEG F
KINEMATIC
VISCOSITY:0.480 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26486.8
PRANDTL NO 3.03

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15633.8 BTU/HR
HEAT LOST 723.0 BTU/HR
PERCENT HEAT LOST 4.42
HEAT FLUX TRANS. BTU/SQFT-HR 89746.
NUSSELT NO 121.3
RFILM 0.624
RWALL 0.143
RTOTAL 0.766 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.29324 .74973
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.30072E-01 .97211E-01
ESTIMATE OF RO,RINF,AND B IN RF=RINF*(1.-EXP(-B*TIME)
.0 3.3367 .86103

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.22	0.73	0.59
0.40	1.12	0.99
0.50	1.36	1.19
0.93	1.85	1.87
1.25	2.05	2.23
1.42	2.24	2.38
1.62	2.44	2.54
1.90	2.78	2.71
2.33	3.02	2.91
2.47	2.83	2.96
2.65	3.12	3.01
2.80	2.97	3.05
2.90	3.22	3.08

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	175.8	175.0	182.9	182.5	184.1	179.4	178.6	0.0	187.2	192.3	0.0	127.0	149.9	182.0	23.0	1629.5	0.6137	0.0
0.0	175.8	175.8	182.9	182.9	184.5	180.6	180.2	0.0	187.6	193.5	0.0	127.0	149.9	182.6	23.0	1602.7	0.6240	0.22
0.0	176.2	176.2	183.3	183.3	184.9	180.9	180.6	0.0	188.0	193.5	0.0	127.0	149.9	183.0	23.0	1589.9	0.6290	0.40
0.0	176.6	176.2	183.3	183.3	184.9	181.3	180.9	0.0	188.4	193.9	0.0	127.0	149.9	183.2	23.0	1582.2	0.6320	0.50
0.0	177.0	176.6	183.7	183.7	185.3	181.7	181.7	0.0	188.8	194.3	0.0	126.5	149.9	183.7	23.4	1559.2	0.6413	0.93
0.0	177.0	177.0	184.1	184.5	185.7	181.7	181.7	0.0	188.8	193.9	0.0	127.0	149.9	183.8	23.0	1560.0	0.6410	1.25
0.0	177.0	176.6	184.1	184.1	186.1	182.1	182.1	0.0	189.2	194.7	0.0	127.0	149.9	184.0	23.0	1552.8	0.6440	1.42
0.0	177.0	177.0	184.1	184.9	186.1	182.5	182.1	0.0	189.6	194.3	0.0	127.0	149.9	184.2	23.0	1546.2	0.6468	1.62
0.0	177.4	177.4	184.5	184.9	186.5	182.5	182.5	0.0	189.6	195.1	0.0	127.0	149.9	184.5	23.0	1536.9	0.6507	1.90
0.0	177.4	177.0	184.9	185.7	186.8	182.9	182.5	0.0	190.0	195.1	0.0	127.0	149.9	184.7	23.0	1528.0	0.6544	2.33
0.0	177.0	177.4	184.9	185.3	186.5	182.9	182.1	0.0	189.6	195.1	0.0	127.0	149.9	184.5	23.0	1534.4	0.6517	2.47
0.0	177.0	177.8	185.7	185.7	186.8	182.9	182.5	0.0	189.6	195.1	0.0	126.5	149.5	184.8	23.0	1511.4	0.6616	2.65
0.0	177.4	177.8	185.3	185.3	186.5	182.9	182.1	0.0	189.6	195.1	0.0	127.0	149.9	184.7	23.0	1531.4	0.6530	2.80
0.0	177.8	177.8	186.1	185.7	186.8	182.9	182.5	0.0	189.6	194.7	0.0	127.0	149.9	184.9	23.0	1524.1	0.6561	2.90

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1629.5	0.6137	0.0
0.0	0.0	0.88	0.0	0.44	0.44	1.32	1.76	0.0	0.44	1.31	0.0	127.0	149.9	0.73	23.0	1602.7	0.6240	0.22
0.0	0.44	1.32	0.44	0.88	0.88	1.76	2.70	0.0	0.87	1.31	0.0	127.0	149.9	1.12	23.0	1589.9	0.6290	0.40
0.0	0.88	1.32	0.44	0.88	0.88	2.20	2.64	0.0	1.31	1.74	0.0	127.0	149.9	1.36	23.0	1582.2	0.6320	0.50
0.0	1.32	1.76	0.88	1.32	1.31	2.64	3.52	0.0	1.75	2.18	0.0	126.5	149.9	1.85	23.4	1559.2	0.6413	0.93
0.0	1.32	2.70	1.32	2.19	1.75	2.64	3.52	0.0	1.75	1.74	0.0	127.0	149.9	2.05	23.0	1560.0	0.6410	1.25
0.0	1.32	1.76	1.32	1.75	2.19	3.08	3.95	0.0	2.18	2.61	0.0	127.0	149.9	2.24	23.0	1552.8	0.6440	1.42
0.0	1.32	2.20	1.32	2.63	2.19	3.51	3.95	0.0	2.62	2.18	0.0	127.0	149.9	2.44	23.0	1546.2	0.6468	1.62
0.0	1.76	2.64	1.75	2.63	2.63	3.51	4.39	0.0	2.62	3.04	0.0	127.0	149.9	2.78	23.0	1536.9	0.6507	1.90
0.0	1.76	2.20	2.19	3.51	3.06	3.95	4.39	0.0	3.06	3.04	0.0	127.0	149.9	3.02	23.0	1528.0	0.6544	2.33
0.0	1.32	2.64	2.19	3.07	2.63	3.95	3.95	0.0	2.62	3.04	0.0	127.0	149.9	2.83	23.0	1534.4	0.6517	2.47
0.0	1.32	3.07	3.07	3.51	3.06	3.95	4.39	0.0	2.62	3.04	0.0	126.5	149.5	3.12	23.0	1511.4	0.6616	2.65
0.0	1.76	3.09	2.63	3.07	2.63	3.95	3.95	0.0	2.62	3.04	0.0	127.0	149.9	2.97	23.0	1531.4	0.6530	2.80
0.0	2.20	3.09	3.50	3.51	3.06	3.95	4.39	0.0	2.62	2.61	0.0	127.0	149.9	3.22	23.0	1524.1	0.6561	2.90

*******RUN NO53.*******

FERRIC OXIDE CONC (PPM) 3750.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4 DEG F
KINEMATIC
VISCOSITY:0.496 SQ.CM/SEC

FLUID VELOCITY 3.655 FT/SEC
REYNOLDS NO 19550.0
PRANDTL NO 3.15

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7727.9 BTU/HR
HEAT LOST 345.7 BTU/HR
PERCENT HEAT LOST 4.28
HEAT FLUX TRANS. BTU/SQFT-HR 44362.
NUSSELT NO 94.6
RFILM 0.803
RWALL 0.144
RTOTAL 0.947 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.74217E-01 .28786
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.40168E-01 .15580
ESTIMATE OF RO,RINF,AND B IN RF=RINF*(1.-EXP(-B*TIME)
.0 5.8664 2.7244

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.05	0.30	0.75
0.12	1.61	1.64
0.20	2.01	2.46
0.33	3.21	3.48
0.50	4.41	4.36
0.65	4.91	4.87
0.82	5.62	5.24
1.00	5.92	5.48
1.33	6.42	5.71
1.43	6.62	5.75
1.68	5.82	5.81
1.87	5.62	5.83
2.05	5.22	5.84
2.25	4.72	5.85

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	154.3	154.3	159.9	159.5	160.3	157.5	156.7	0.0	161.9	166.7	0.0	127.0	141.4	159.0	14.4	1410.2	0.7091	0.0
0.0	154.7	154.3	159.9	159.5	160.7	157.5	157.1	0.0	161.9	166.7	0.0	127.0	141.4	159.1	14.4	1402.8	0.7129	0.05
0.0	155.1	154.7	160.3	159.9	161.1	158.3	157.9	0.0	162.7	167.5	0.0	127.0	141.4	159.7	14.4	1369.8	0.7300	0.12
0.0	155.5	155.1	160.3	160.3	161.1	158.3	157.9	0.0	163.1	167.5	0.0	127.0	141.8	159.9	14.9	1373.8	0.7279	0.20
0.0	155.5	155.5	160.7	160.7	161.9	159.1	158.7	0.0	163.9	167.9	0.0	127.0	141.8	160.4	14.9	1342.2	0.7451	0.33
0.0	156.3	155.9	161.5	161.1	162.3	159.5	159.1	0.0	164.3	168.7	0.0	127.0	141.8	161.0	14.9	1317.0	0.7593	0.50
0.0	156.7	155.9	161.9	161.5	162.7	159.5	159.5	0.0	164.3	168.7	0.0	127.0	141.8	161.2	14.9	1306.0	0.7657	0.65
0.0	156.7	156.3	161.9	162.3	163.1	159.9	159.9	0.0	164.7	168.7	0.0	127.0	141.8	161.5	14.9	1289.1	0.7757	0.82
0.0	157.1	156.7	162.3	162.3	163.1	161.1	159.5	0.0	164.3	168.3	0.0	127.0	141.8	161.6	14.9	1283.5	0.7791	1.00
0.0	157.9	157.5	163.1	162.7	163.5	159.9	159.5	0.0	164.3	168.3	0.0	126.5	141.8	161.8	15.3	1268.8	0.7881	1.33
0.0	158.3	157.9	163.5	163.1	163.1	159.9	159.5	0.0	164.3	167.9	0.0	127.0	141.8	161.9	14.9	1276.6	0.7633	1.43
0.0	158.7	158.3	163.5	162.7	162.3	159.5	158.7	0.0	163.1	167.5	0.0	126.5	141.8	161.6	15.3	1290.2	0.7751	1.66
0.0	159.5	158.7	163.1	161.9	161.7	158.7	158.7	0.0	163.5	167.5	0.0	127.0	141.8	161.5	14.9	1310.3	0.7632	1.87
0.0	159.5	158.3	162.3	161.5	161.9	158.7	158.7	0.0	163.5	167.5	0.0	127.0	141.8	161.3	14.9	1318.1	0.7587	2.05
0.0	159.9	157.9	161.5	161.1	161.5	158.7	158.3	0.0	163.5	167.5	0.0	127.0	141.8	161.1	14.9	1331.5	0.7511	2.25

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	141.4	0.0	14.4	1410.2	0.7091	0.0
0.0	0.91	0.0	0.0	0.0	0.90	0.0	0.90	0.0	0.0	0.0	0.0	127.0	141.4	0.30	14.4	1402.8	0.7129	0.05
0.0	1.81	0.91	0.90	0.90	1.80	1.81	2.71	0.0	1.80	1.80	0.0	127.0	141.4	1.61	14.4	1369.8	0.7300	0.12
0.0	2.72	1.81	0.90	1.81	1.80	1.81	2.71	0.0	2.70	1.20	0.0	127.0	141.8	2.01	14.9	1373.8	0.7277	0.20
0.0	2.72	2.72	1.80	2.71	3.61	3.62	4.52	0.0	4.50	2.69	0.0	127.0	141.8	3.21	14.9	1342.2	0.7451	0.33
0.0	4.53	3.62	3.61	3.61	4.51	4.52	5.42	0.0	5.40	4.49	0.0	127.0	141.8	4.41	14.9	1317.0	0.7593	0.50
0.0	5.43	3.62	4.51	4.51	5.41	4.52	6.33	0.0	5.40	4.49	0.0	127.0	141.8	4.91	14.9	1306.0	0.7657	0.65
0.0	5.43	4.53	4.51	6.31	6.31	5.42	7.23	0.0	6.30	4.49	0.0	127.0	141.8	5.62	14.9	1289.1	0.7757	0.82
0.0	6.34	5.43	5.41	6.31	6.31	8.13	6.33	0.0	5.40	3.59	0.0	127.0	141.8	5.92	14.9	1283.5	0.7791	1.00
0.0	8.15	7.24	7.21	7.22	7.21	5.42	6.33	0.0	5.40	3.59	0.0	126.5	141.8	6.42	15.3	1268.8	0.7881	1.33
0.0	9.05	8.15	8.11	9.12	6.31	5.42	6.33	0.0	5.40	2.69	0.0	127.0	141.8	6.62	14.9	1276.6	0.7833	1.43
0.0	9.96	9.05	8.11	7.22	4.51	4.52	4.52	0.0	2.70	1.80	0.0	126.5	141.8	5.82	15.3	1290.2	0.7751	1.66
0.0	11.76	9.96	7.21	5.41	3.61	2.71	4.52	0.0	3.60	1.80	0.0	127.0	141.8	5.62	14.9	1310.3	0.7632	1.87
0.0	11.76	9.05	5.41	4.51	3.61	2.71	4.52	0.0	3.60	1.80	0.0	127.0	141.8	5.22	14.9	1318.1	0.7587	2.05
0.0	12.66	8.15	3.61	3.61	2.71	2.71	3.62	0.0	3.60	1.80	0.0	127.0	141.8	4.72	14.9	1331.5	0.7511	2.25

********RUN NO54.********

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 5.75 AMPS: 162.

HEAT FLOW SUPPLIED 3179.2 BTU/HR
HEAT FLUX SUPPLIED 18250. BTU/SQFT-HR

BETA0.301 TDR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET137.5 DEG F

FLOW RATE 0.0759 LBS.M/SEC

AVG TEMP:132.2 DEG F
KINEMATIC
VISCOSITY:0.506 SQ.CM/SEC

FLUID VELOCITY 1.921 FT/SEC
REYNOLDS NO 10091.5
PRANDTL NO 3.21

HEAT SUPP 3179.2 BTU/HR
HEAT TRANS 2880.5 BTU/HR
HEAT LOST 296.8 BTU/HR
PERCENT HEAT LOST 9.40
HEAT FLUX TRANS. BTU/SQFT-HR 16535.
NUSSELT NO 55.4
RFILM 1.374
RWALL 0.146
RTOTAL 1.520 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.8601EE-01 .20602
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.75429E-01 .18066
ESTIMATE OF RO,RINF,AND B IN RF=RINF(1.-EXP(-B*TIME)
.0 8.7987 .89365

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.07	1.90	0.53
0.13	0.54	0.97
0.28	2.99	1.95
0.38	2.99	2.53
0.53	3.53	3.32
0.62	3.26	3.74
0.72	3.53	4.18
0.92	3.80	4.93
1.03	5.71	5.29
1.10	5.17	5.51
1.28	5.44	6.00
1.35	5.98	6.17
1.65	6.52	6.78
2.08	8.42	7.43
2.23	8.42	7.60
2.42	9.51	7.79
2.58	8.15	7.92
2.77	8.42	8.06
2.92	7.61	8.15
3.42	6.52	8.38

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	142.6	141.7	146.2	146.2	147.0	144.2	143.8	0.0	148.2	151.5	0.0	127.0	137.5	145.7	10.5	967.8	1.0332	0.0
0.0	142.6	142.2	147.0	146.6	147.0	144.2	144.2	0.0	148.6	151.9	0.0	127.0	137.5	146.0	10.5	945.8	1.0573	0.07
0.0	142.6	141.7	147.0	146.6	146.6	144.2	143.8	0.0	148.2	151.5	0.0	127.0	137.5	145.8	10.5	962.2	1.0393	0.13
0.0	142.6	142.6	147.0	147.0	147.4	144.6	144.2	0.0	148.6	151.9	0.0	127.0	137.5	146.2	10.5	932.3	1.0726	0.28
0.0	143.0	142.6	147.0	146.6	147.4	144.6	144.2	0.0	148.6	151.9	0.0	127.0	137.5	146.2	10.5	934.7	1.0698	0.38
0.0	143.0	142.6	147.4	146.6	147.4	144.6	144.2	0.0	148.6	152.3	0.0	127.0	137.5	146.3	10.5	929.3	1.0760	0.53
0.0	143.0	142.2	147.4	146.6	147.4	144.6	144.2	0.0	148.6	152.3	0.0	127.0	137.5	146.2	10.5	931.4	1.0737	0.62
0.0	143.0	142.6	147.4	146.6	147.4	144.6	144.2	0.0	148.6	152.3	0.0	127.0	137.5	146.3	10.5	929.3	1.0760	0.72
0.0	143.0	142.6	147.0	146.6	147.4	144.6	144.2	0.0	149.0	152.7	0.0	127.0	137.5	146.3	10.5	926.6	1.0792	0.92
0.0	143.4	142.6	147.4	147.0	147.8	145.0	144.6	0.0	149.4	152.7	0.0	127.0	137.5	146.7	10.5	905.0	1.1050	1.03
0.0	143.4	142.6	147.4	147.0	147.8	145.0	144.6	0.0	149.0	152.3	0.0	127.0	137.5	146.6	10.5	910.4	1.0984	1.10
0.0	143.4	142.6	147.4	147.0	147.4	145.0	144.6	0.0	149.4	152.7	0.0	127.0	137.5	146.6	10.5	908.6	1.1006	1.28
0.0	143.4	143.0	147.8	147.0	147.8	145.0	144.6	0.0	149.0	152.7	0.0	127.0	137.5	146.7	10.5	903.3	1.1070	1.35
0.0	143.4	143.0	147.8	147.4	147.8	145.0	144.6	0.0	149.4	152.7	0.0	127.0	137.5	146.8	10.5	897.1	1.1147	1.65
0.0	143.8	143.0	147.8	147.8	148.2	145.4	145.0	0.0	149.8	153.1	0.0	127.0	137.5	147.1	10.5	877.3	1.1399	2.08
0.0	143.8	143.0	148.2	147.4	148.2	145.4	145.0	0.0	149.8	153.1	0.0	127.0	137.5	147.1	10.5	877.8	1.1393	2.23
0.0	143.8	143.4	148.2	147.8	146.6	145.4	145.0	0.0	149.8	153.5	0.0	127.0	137.5	147.3	10.5	867.4	1.1529	2.42
0.0	143.8	143.0	148.2	147.8	148.2	145.4	145.0	0.0	149.4	152.7	0.0	127.0	137.5	147.1	10.5	879.8	1.1366	2.58
0.0	143.8	143.0	147.8	147.4	148.2	145.4	145.0	0.0	149.8	153.5	0.0	127.0	137.5	147.1	10.5	878.2	1.1387	2.77
0.0	143.8	143.0	147.4	147.4	148.2	145.4	145.0	0.0	149.4	153.1	0.0	127.0	137.5	147.0	10.5	885.7	1.1290	2.92
0.0	143.4	142.6	147.8	147.0	148.2	145.0	144.6	0.0	149.4	153.1	0.0	127.0	137.5	146.8	10.5	896.4	1.1155	3.42

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	137.5	0.0	10.5	967.8	1.0332	0.0
0.0	0.0	2.45	4.89	2.45	0.0	0.0	2.45	0.0	2.44	2.44	0.0	127.0	137.5	1.90	10.5	945.8	1.0573	0.07
0.0	0.0	0.0	4.89	2.45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	137.5	0.54	10.5	962.2	1.0393	0.13
0.0	0.0	4.91	4.89	4.89	2.44	2.45	2.45	0.0	-2.44	2.44	0.0	127.0	137.5	2.99	10.5	932.3	1.0726	0.28
0.0	2.45	4.91	4.87	2.45	2.44	2.45	2.45	0.0	2.44	2.44	0.0	127.0	137.5	2.99	10.5	93[illegible].7	1.0698	0.38
0.0	2.45	4.91	7.34	2.45	2.44	2.45	2.45	0.0	2.44	4.87	0.0	127.0	137.5	3.53	10.5	929.3	1.0760	0.53
0.0	2.45	2.45	7.34	2.45	2.44	2.45	2.45	0.0	2.44	4.87	0.0	127.0	137.5	3.26	10.5	931.4	1.0737	0.62
0.0	2.45	4.91	7.34	2.45	2.44	2.45	2.45	0.0	2.44	4.87	0.0	127.0	137.5	3.53	10.5	929.3	1.0760	0.72
0.0	2.45	4.91	4.89	2.45	2.44	2.45	2.45	0.0	4.88	7.31	0.0	127.0	137.5	3.80	10.5	926.6	1.0792	0.92
0.0	4.90	4.91	7.34	4.89	4.89	4.90	4.90	0.0	7.33	7.31	0.0	127.0	137.5	5.71	10.5	905.0	1.1050	1.03
0.0	4.90	4.91	7.34	4.89	4.89	4.90	4.90	0.0	4.88	4.87	0.0	127.0	137.5	5.17	10.5	910.4	1.0984	1.10
0.0	4.90	4.91	7.34	4.89	2.44	4.90	4.90	0.0	7.33	7.31	0.0	127.0	137.5	5.44	10.5	908.6	1.1006	1.28
0.0	4.90	7.36	9.78	4.89	4.89	4.90	4.90	0.0	4.88	7.31	0.0	127.0	137.5	5.98	10.5	903.3	1.1070	1.35
0.0	4.90	7.36	9.78	7.34	4.89	4.90	4.90	0.0	7.33	7.31	0.0	127.0	137.5	6.52	10.5	897.1	1.1147	1.65
0.0	7.36	7.36	9.78	9.78	7.33	7.35	7.35	0.0	9.77	9.74	0.0	127.0	137.5	8.42	10.5	877.3	1.1399	2.08
0.0	7.36	7.36	12.22	7.34	7.33	7.35	7.35	0.0	9.77	9.74	0.0	127.0	137.5	8.42	10.5	877.8	1.1393	2.23
0.0	7.36	9.81	12.22	9.78	9.77	7.35	7.35	0.0	9.77	12.18	0.0	127.0	137.5	9.51	10.5	867.4	1.1529	2.42
0.0	7.36	7.36	12.22	9.78	7.33	7.35	7.35	0.0	7.33	7.31	0.0	127.0	137.5	8.15	10.5	879.8	1.1366	2.58
0.0	7.36	7.36	9.78	7.34	7.33	7.35	7.35	0.0	9.77	12.18	0.0	127.0	137.5	8.42	10.5	878.2	1.1387	2.77
0.0	7.36	7.36	7.34	7.34	7.33	7.35	7.35	0.0	7.33	9.74	0.0	127.0	137.5	7.61	10.5	885.7	1.1290	2.92
0.0	4.90	4.91	9.78	4.89	7.33	4.90	4.90	0.0	7.33	9.74	0.0	127.0	137.5	6.52	10.5	896.4	1.1155	3.42

*******RUN NO55.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 7.35 AMPS: 203.

HEAT FLOW SUPPLIED 5092.4 BTU/HR
HEAT FLUX SUPPLIED 29233. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET137.5 DEG F

FLOW RATE 0.1184 LBS.M/SEC

AVG TEMP:132.2 DEG F
KINEMATIC
VISCOSITY:0.506 SQ.CM/SEC

FLUID VELOCITY 2.997 FT/SEC
REYNOLDS NO 15744.0
PRANDTL NO 3.21

HEAT SUPP 5092.4 BTU/HR
HEAT TRANS 4493.9 BTU/HR
HEAT LOST 598.5 BTU/HR
PERCENT HEAT LOST 11.75
HEAT FLUX TRANS. BTU/SQFT-HR 25797.
NUSSELT NO 79.2
RFILM 0.960
RWALL 0.145
RTOTAL 1.106 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.15197 .41471
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.69557E-01 .18981
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 5.4366 1.7417

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.13	1.22	1.10
0.20	1.91	1.60
0.48	2.96	3.08
0.58	3.83	3.46
0.70	3.31	3.83
1.07	4.70	4.59
1.45	4.52	5.00
1.87	6.09	5.23
2.00	4.87	5.27

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	145.0	143.8	149.0	148.6	149.4	146.2	145.4	0.0	150.6	154.3	0.C	126.5	137.5	148.0	11.0	1273.3	0.7853	0.0
0.0	145.0	144.2	149.4	148.6	149.8	146.6	145.8	0.0	151.1	154.7	0.0	126.5	137.5	148.4	11.0	1247.1	C.8C18	0.13
0.0	145.4	144.6	149.8	149.0	149.8	146.6	145.8	C.0	151.1	154.7	0.0	126.5	137.5	148.5	11.0	1236.4	0.8088	0.20
0.0	145.8	144.6	150.2	149.4	150.2	147.0	146.2	0.0	151.1	154.7	0.0	126.5	137.5	148.8	11.0	1215.4	0.8228	0.48
0.0	145.8	145.0	150.2	149.4	150.6	147.0	146.5	0.0	151.5	155.1	0.0	126.5	137.5	149.0	11.0	1198.6	0.8343	0.58
0.0	145.8	145.0	150.2	149.4	150.2	147.0	146.6	C.0	151.1	154.7	0.0	126.5	137.5	148.9	11.0	1208.9	0.8272	0.70
0.0	146.2	145.8	150.2	149.8	151.1	147.0	146.6	0.0	151.5	155.1	0.0	126.5	137.5	149.3	11.0	1185.7	0.8434	1.07
0.0	145.8	145.4	150.2	149.4	150.6	147.0	147.0	0.0	151.9	155.5	0.0	126.5	137.9	149.2	11.4	1202.1	C.8319	1.45
0.0	146.2	145.4	150.6	150.2	151.1	147.4	147.4	C.0	152.3	155.9	0.0	126.5	137.5	149.6	11.0	1157.7	0.8638	1.87
0.0	146.2	145.4	150.2	149.8	150.6	147.4	147.0	0.0	151.9	155.1	0.0	126.5	137.5	149.3	11.0	1180.2	0.8473	2.00

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	137.5	0.0	11.0	1273.3	0.7853	0.0
0.0	0.0	1.57	1.56	0.0	1.56	1.57	1.57	0.0	1.56	1.56	0.0	126.5	137.5	1.22	11.0	1247.1	0.8018	0.13
0.0	1.57	3.14	3.13	1.57	1.56	1.57	1.57	C.0	1.56	1.56	0.0	126.5	137.5	1.91	11.0	1236.4	0.8088	0.20
0.0	3.14	3.14	4.69	3.13	3.13	3.14	3.14	0.0	1.56	1.56	0.0	126.5	137.5	2.96	11.0	1215.4	0.8228	0.48
0.0	3.14	4.71	4.67	3.13	4.69	3.14	4.71	0.0	3.13	3.12	0.0	126.5	137.5	3.83	11.0	1198.6	0.8343	0.58
0.0	3.14	4.71	4.69	3.13	3.13	3.14	4.71	0.0	1.56	1.56	0.0	126.5	137.5	3.31	11.0	1208.9	0.8272	0.70
0.0	4.71	7.85	4.69	4.69	6.25	3.14	4.71	0.0	3.13	3.12	0.0	126.5	137.5	4.70	11.0	1185.7	0.8434	1.07
0.0	3.14	6.28	4.69	3.13	4.69	3.14	6.27	0.0	4.69	4.67	0.0	126.5	137.9	4.52	11.4	1202.1	C.8319	1.45
0.0	4.71	6.28	6.26	6.26	6.25	4.70	7.84	0.0	6.25	6.23	0.0	126.5	137.5	6.09	11.0	1157.7	0.8638	1.87
0.0	4.71	6.28	4.69	4.69	4.69	4.70	6.27	0.0	4.69	3.12	0.0	126.5	137.5	4.87	11.0	1180.2	0.8473	2.00

*******RUN NO56.*******

FERRIC OXIDE CONC (PPM)   2130.

VOLTS:13.50   AMPS: 347.

HEAT FLOW SUPPLIED 15988.2   BTU/HR
HEAT FLUX SUPPLIED   91781.   BTU/SQFT-HR

BETA0.301   TCR=TINLET127.0   DEG F
DENSITY:0.986 GRAM/CC
               T OUTLET157.0   DEG F

FLOW RATE 0.1442   LBS.M/SEC

AVG TEMP:142.0   DEG F
KINEMATIC
VISCOSITY:0.467   SQ.CM/SEC

FLUID VELOCITY 3.664   FT/SEC
REYNOLDS NO 20850.6
PRANDTL NO   2.93

HEAT SUPP   15988.2   BTU/HR
HEAT TRANS   15653.1   BTU/HR
HEAT LOST   335.1   BTU/HR
PERCENT HEAT LOST   2.10
HEAT FLUX TRANS. BTU/SQFT-HR   89857.
NUSSELT NO   100.0
RFILM   0.754
RWALL   0.141
RTOTAL   0.895   SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.28973   .95107
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.69443E-01   .22795
ESTIMATE OF RO,RINF,AND B IN RF=RINF*(1.-EXP(-B*TIME)
.0   2.2801   4.1606

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.07	0.96	0.58
0.13	1.01	0.95
0.30	1.30	1.63
0.37	1.97	1.79
0.45	1.88	1.93
0.58	2.02	2.08
0.77	1.98	2.19
0.98	2.17	2.24
1.20	2.60	2.26

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	186.8	186.0	195.5	195.5	197.4	192.7	193.1	0.0	201.7	209.4	0.0	126.5	157.0	195.4	30.5	1322.8	0.7560	0.0
0.0	187.2	187.6	196.2	196.2	198.2	193.9	193.9	0.0	202.8	210.6	0.0	126.5	157.0	196.3	30.5	1300.9	0.7687	0.07
0.0	188.0	187.6	197.0	196.6	198.2	193.9	193.9	0.0	202.5	209.4	0.0	126.5	157.0	196.3	30.5	1300.8	0.7688	0.13
0.0	187.6	188.0	196.6	196.6	198.6	194.7	194.7	0.0	202.8	209.8	0.0	127.0	157.0	196.6	30.1	1297.8	0.7706	0.30
0.0	188.0	188.0	197.0	197.4	199.3	194.7	195.1	0.0	204.4	211.0	0.0	126.5	157.0	197.2	30.5	1278.3	0.7823	0.37
0.0	188.0	188.4	197.4	197.0	199.3	194.7	195.1	0.0	203.6	210.6	0.0	126.5	157.0	197.1	30.5	1280.8	0.7807	0.45
0.0	188.4	188.8	197.0	197.0	199.3	195.1	195.1	0.0	203.6	211.0	0.0	126.5	157.0	197.3	30.5	1278.5	0.7822	0.58
0.0	188.0	188.4	197.0	197.8	199.7	195.1	195.1	0.0	203.6	210.2	0.0	126.5	157.0	197.2	30.5	1277.9	0.7826	0.77
0.0	188.0	188.4	197.0	197.8	199.7	195.1	195.1	0.0	204.4	211.0	0.0	126.5	157.0	197.4	30.5	1274.0	0.7850	0.98
0.0	188.4	188.8	198.2	198.2	199.3	195.5	195.5	0.0	204.8	211.3	0.0	126.5	157.0	197.8	30.5	1265.7	0.7901	1.20

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	157.0	0.0	30.5	1322.8	0.7560	0.0
0.0	0.44	0.87	0.87	0.87	0.87	1.30	0.87	0.0	1.29	1.29	0.0	126.5	157.0	0.96	30.5	1300.9	0.7687	0.07
0.0	1.31	0.87	1.73	1.30	0.87	1.30	0.87	0.0	0.86	0.0	0.0	126.5	157.0	1.01	30.5	1300.8	0.7688	0.13
0.0	0.87	1.31	1.30	1.30	1.30	2.17	1.74	0.0	1.29	0.43	0.0	127.0	157.0	1.30	30.1	1297.8	0.7706	0.30
0.0	1.31	1.31	1.73	2.17	2.16	2.17	2.17	0.0	3.02	1.72	0.0	126.5	157.0	1.97	30.5	1278.3	0.7823	0.37
0.0	1.31	1.75	2.17	1.73	2.16	2.17	2.17	0.0	2.16	1.29	0.0	126.5	157.0	1.88	30.5	1280.8	0.7807	0.45
0.0	1.75	2.18	1.73	1.73	2.16	2.61	2.17	0.0	2.16	1.72	0.0	126.5	157.0	2.02	30.5	1278.5	0.7822	0.58
0.0	1.31	1.75	1.73	2.60	2.60	2.61	2.17	0.0	2.16	0.86	0.0	126.5	157.0	1.98	30.5	1277.9	0.7826	0.77
0.0	1.31	1.75	1.73	2.60	2.60	2.61	2.17	0.0	3.02	1.72	0.0	126.5	157.0	2.17	30.5	1274.0	0.7850	0.98
0.0	1.75	2.18	3.03	3.03	2.16	3.04	2.61	0.0	3.45	2.14	0.0	126.5	157.0	2.60	30.5	1265.7	0.7901	1.20

*******RUN NO57.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS:13.50 AMPS: 356.

HEAT FLOW SUPPLIED 16402.9 BTU/HR
HEAT FLUX SUPPLIED 94161. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.5 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:138.2 DEG F
KINEMATIC
VISCOSITY:0.481 SQ.CM/SEC

FLUID VELOCITY 4.789 FT/SEC
REYNOLDS NO 26439.5
PRANDTL NO 3.03

HEAT SUPP 16402.9 BTU/HR
HEAT TRANS 15345.8 BTU/HR
HEAT LOST 1057.0 BTU/HR
PERCENT HEAT LOST 6.44
HEAT FLUX TRANS. BTU/SQFT-HR 88093.
NUSSELT NO 121.1
RFILM 0.625
RWALL 0.143
RTOTAL 0.767 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.71200 2.7572
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.12561 .48643
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 .99129 7.4673

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.07	0.40	0.40
0.18	0.65	0.73
0.33	1.09	0.91
0.40	0.85	0.94
0.53	1.19	0.97
0.63	0.75	0.98

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	175.4	175.4	182.5	182.5	184.1	179.4	179.8	0.0	187.2	193.5	0.0	126.5	149.5	182.2	23.0	1574.6	0.6351	0.0
0.0	175.8	175.8	182.9	182.9	184.5	179.8	180.2	0.0	187.6	193.5	0.0	126.5	149.5	182.6	23.0	1562.0	0.6402	0.07
0.0	176.6	176.2	183.3	183.3	184.5	180.2	180.2	0.0	187.6	193.1	0.0	126.5	149.5	182.8	23.0	1555.9	0.6427	0.18
0.0	177.0	176.6	183.7	183.7	184.9	180.6	180.6	0.0	188.0	193.5	0.0	126.5	149.5	183.2	23.0	1542.3	0.6484	0.33
0.0	177.4	176.6	183.3	183.3	184.5	180.6	180.6	0.0	187.6	192.7	0.0	126.5	149.5	183.0	23.0	1551.1	0.6447	0.40
0.0	177.4	176.6	183.7	183.7	184.9	180.9	180.6	0.0	188.0	193.5	0.0	126.5	149.5	183.3	23.0	1539.8	0.6494	0.53
0.0	177.0	176.2	182.9	183.3	184.9	180.6	180.2	0.0	187.6	193.1	0.0	126.5	149.5	182.9	23.0	1552.9	0.6440	0.63

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	126.5	149.5	0.0	23.0	1574.6	0.6351	0.0
0.0	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.0	0.45	0.0	0.0	126.5	149.5	0.40	23.0	1562.0	0.6402	0.07
0.0	1.35	0.90	0.89	0.89	0.45	0.90	0.45	0.0	0.45	0.0	0.0	126.5	149.5	0.65	23.0	1555.9	0.6427	0.18
0.0	1.80	1.35	1.34	1.34	0.89	1.34	0.90	0.0	0.89	0.0	0.0	126.5	149.5	1.09	23.0	1542.3	0.6484	0.33
0.0	2.25	1.35	0.89	0.89	0.45	1.34	0.90	0.0	0.45	0.0	0.0	126.5	149.5	0.85	23.0	1551.1	0.6447	0.40
0.0	2.25	1.35	1.34	1.34	0.89	1.79	0.90	0.0	0.89	0.0	0.0	126.5	149.5	1.19	23.0	1539.8	0.6494	0.53
0.0	1.80	0.90	0.45	0.89	0.89	1.34	0.45	0.0	0.45	0.0	0.0	126.5	149.5	0.75	23.0	1552.9	0.6440	0.63

*******RUN NO58.*******

FERRIC OXIDE CONC (PPM)   2130.

VOLTS:13.50   AMPS: 356.

HEAT FLOW SUPPLIED 16402.9   BTU/HR
HEAT FLUX SUPPLIED   94161.   BTU/SQFT-HR

BETA0.301   TOR=TINLET127.0   DEG F
DENSITY:0.986 GRAM/CC
T OUTLET149.5   DEG F

FLOW RATE 0.1888   LBS.M/SEC

AVG TEMP:138.2   DEG F
KINEMATIC
VISCOSITY:0.481   SQ.CM/SEC

FLUID VELOCITY 4.789   FT/SEC
REYNOLDS NO 26439.5
PRANDTL NO   3.03

HEAT SUPP   16402.9   BTU/HR
HEAT TRANS   15345.8   BTU/HR
HEAT LOST   1057.0   BTU/HR
PERCENT HEAT LOST   6.44
HEAT FLUX TRANS. BTU/SQFT-HR   88093.
NUSSELT NO   121.1
RFILM   0.625
RWALL   0.143
RTOTAL   0.767   SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.34707   1.7667
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.51046E-01   .25985
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0   1.5661   8.4349

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.02	0.20	0.24
0.10	1.04	0.89
0.32	1.19	1.46
0.43	1.49	1.52
0.55	1.54	1.55
0.58	1.59	1.55
0.72	1.74	1.56

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	175.0	174.6	182.5	182.5	183.7	179.0	179.4	0.0	186.8	192.3	0.0	127.0	149.5	181.8	22.5	1597.0	0.6262	0.0
0.0	175.0	174.6	182.5	182.5	183.7	179.4	179.8	0.0	186.8	193.1	0.0	127.0	149.5	181.9	22.5	1590.0	0.6289	0.02
0.0	176.2	175.8	182.9	183.3	184.5	180.2	180.2	0.0	187.6	193.5	0.0	127.0	149.5	182.7	22.5	1565.0	0.6390	0.10
0.0	177.0	176.6	183.3	182.9	184.1	180.2	180.6	0.0	187.6	193.1	0.0	127.0	149.5	182.8	22.5	1563.3	0.6397	0.32
0.0	177.4	176.6	183.3	183.3	184.5	180.2	180.6	0.0	188.0	193.9	0.0	127.0	149.5	183.1	22.5	1554.7	0.6432	0.43
0.0	177.4	176.6	183.7	183.7	184.5	180.6	180.6	0.0	188.0	193.1	0.0	126.5	149.5	183.1	23.0	1545.0	0.6473	0.55
0.0	177.8	176.6	183.7	183.3	184.5	180.6	180.6	0.0	188.0	193.5	0.0	126.5	149.5	183.2	23.0	1544.8	0.6473	0.58
0.0	177.4	176.2	184.1	183.3	185.3	180.6	180.9	0.0	188.4	193.5	0.0	126.5	149.5	183.3	23.0	1537.6	0.6503	0.72

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.5	0.0	22.5	1597.0	0.6262	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.45	0.45	0.0	0.0	0.89	0.0	127.0	149.5	0.20	22.5	1590.0	0.6289	0.02
0.0	1.35	1.35	0.45	0.89	0.89	1.34	0.90	0.0	0.89	1.33	0.0	127.0	149.5	1.04	22.5	1565.0	0.6390	0.10
0.0	2.25	2.25	0.89	0.45	0.45	1.34	1.34	0.0	0.89	0.89	0.0	127.0	149.5	1.19	22.5	1563.3	0.6397	0.32
0.0	2.69	2.25	0.89	0.89	0.89	1.34	1.34	0.0	1.34	1.77	0.0	127.0	149.5	1.49	22.5	1554.7	0.6432	0.43
0.0	2.69	2.25	1.34	1.34	0.89	1.79	1.34	0.0	1.34	0.89	0.0	126.5	149.5	1.54	23.0	1545.0	0.6473	0.55
0.0	3.14	2.25	1.34	0.89	0.89	1.79	1.34	0.0	1.34	1.33	0.0	126.5	149.5	1.59	23.0	1544.8	0.6473	0.58
0.0	2.69	1.80	1.79	0.89	1.79	1.79	1.79	0.0	1.78	1.33	0.0	126.5	149.5	1.74	23.0	1537.6	0.6503	0.72

********RUN NO59.********

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 253.

HEAT FLOW SUPPLIED 8073.6 BTU/HR
HEAT FLUX SUPPLIED 46347. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4 DEG F
KINEMATIC
VISCOSITY:0.496 SQ.CM/SEC

FLUID VELOCITY 3.655 FT/SEC
REYNOLDS NO 19550.0
PRANDTL NO 3.15

HEAT SUPP 8073.6 BTU/HR
HEAT TRANS 7727.9 BTU/HR
HEAT LOST 345.7 BTU/HR
PERCENT HEAT LOST 4.28
HEAT FLUX TRANS. BTU/SQFT-HR 44362.
NUSSELT NO 94.6
RFILM 0.803
RWALL 0.144
RTOTAL 0.947 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.18638 .61638
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.10211 .33769
ESTIMATE OF RO,RINF,AND B IN RF=RINF*(1.-EXP(-B*TIME)
.0 3.0701 1.5972

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.02	0.70	0.10
0.05	1.21	0.24
0.17	1.31	0.73
0.40	1.41	1.45
0.68	2.41	2.03
0.73	2.11	2.11
0.98	2.31	2.43
1.12	2.51	2.56
1.33	2.11	2.70
1.50	2.31	2.79
1.75	2.71	2.88
1.98	2.11	2.94
2.18	3.21	2.98
2.47	3.91	3.01
2.90	3.52	3.04

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TH DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	154.3	153.9	159.5	159.5	160.7	157.9	156.7	0.0	162.3	167.5	0.0	127.0	141.8	159.1	14.9	1413.6	0.7074	0.0
0.0	155.1	154.3	160.3	159.9	160.7	157.1	157.5	C.0	163.1	167.1	0.0	126.5	141.8	159.4	15.3	1387.3	0.7208	0.02
0.0	155.5	154.7	160.3	160.3	161.1	157.5	157.5	C.0	163.1	167.1	0.0	127.0	141.8	159.7	14.9	1387.2	0.7209	0.05
0.0	155.5	155.1	160.3	160.3	161.1	157.5	157.5	0.0	163.1	167.1	0.0	127.0	141.8	159.7	14.9	1385.5	0.7218	0.17
0.0	155.5	155.1	160.7	160.3	160.7	157.5	157.9	C.0	163.1	167.1	0.0	126.5	141.8	159.8	15.3	1371.7	0.7290	0.40
0.0	156.3	155.5	161.1	160.7	161.1	157.9	157.9	C.0	163.5	167.9	0.0	127.0	141.8	160.2	14.9	1361.8	0.7343	0.68
0.0	156.3	155.5	160.7	160.3	161.5	157.9	157.9	0.0	163.1	167.5	0.0	127.0	141.8	160.1	14.9	1368.3	0.7308	0.73
0.0	156.7	155.9	161.1	160.3	161.1	157.9	157.9	0.0	163.1	167.5	0.0	127.0	141.8	160.2	14.9	1366.7	0.7317	0.98
0.0	156.7	155.9	161.1	160.7	161.1	157.9	157.9	0.0	163.5	167.5	0.0	127.0	141.8	160.2	14.9	1361.4	0.7345	1.12
0.0	156.7	155.5	160.7	160.3	161.1	157.5	157.9	0.0	163.5	167.5	0.0	127.0	141.8	160.1	14.9	1371.1	0.7293	1.33
0.0	156.7	155.9	161.1	160.3	161.1	157.9	157.9	0.0	163.1	167.5	0.0	127.0	141.8	160.2	14.9	1366.7	0.7317	1.50
0.0	157.1	155.9	161.5	160.7	161.5	157.9	157.5	C.0	163.5	167.5	0.0	127.0	141.8	160.3	14.9	1350.5	0.7361	1.75
0.0	156.7	155.5	160.7	160.3	161.1	157.5	157.9	0.0	163.5	167.5	0.0	127.0	141.8	160.1	14.9	1371.1	0.7293	1.98
0.0	157.1	155.9	161.5	161.1	161.9	158.3	158.3	0.0	163.5	167.5	0.0	127.0	141.8	160.6	14.9	1343.7	0.7442	2.18
0.0	157.1	156.7	161.9	161.5	162.3	158.3	158.3	0.0	163.9	167.9	0.0	127.0	141.8	160.9	14.9	1328.6	0.7527	2.47
0.0	157.9	157.1	161.5	161.1	161.5	157.9	158.3	C.0	163.5	167.5	0.0	127.0	141.8	160.7	14.9	1343.7	0.7442	2.90

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	141.8	0.0	14.9	1413.6	0.7074	0.0
0.0	1.81	0.91	1.81	0.90	0.0	0.0	1.81	0.0	1.80	0.0	0.0	126.5	141.8	0.70	15.3	1387.3	0.7208	0.02
0.0	2.72	1.81	1.81	1.81	0.90	0.0	1.81	0.0	1.80	0.0	0.0	127.0	141.8	1.21	14.9	1387.2	0.7209	0.05
0.0	2.72	2.72	1.81	1.81	0.90	0.0	1.81	0.0	1.80	0.0	0.0	127.0	141.8	1.31	14.9	1385.5	0.7218	0.17
0.0	2.72	2.72	2.71	1.81	0.0	0.0	2.71	0.0	1.80	0.0	0.0	126.5	141.8	1.41	15.3	1371.7	0.7290	0.40
0.0	4.53	3.62	3.61	2.71	0.90	0.0	2.71	0.0	2.70	0.90	0.0	127.0	141.8	2.41	14.9	1361.8	0.7343	0.68
0.0	4.53	3.62	2.71	1.81	1.80	0.0	2.71	0.0	1.80	0.0	0.0	127.0	141.8	2.11	14.9	1368.3	0.7308	0.73
0.0	5.43	4.53	3.61	1.81	0.90	0.0	2.71	0.0	1.80	0.0	0.0	127.0	141.8	2.31	14.9	1366.7	0.7317	0.98
0.0	5.43	4.53	3.61	2.71	0.90	0.0	2.71	0.0	2.70	0.0	0.0	127.0	141.8	2.51	14.9	1361.4	0.7345	1.12
0.0	5.43	3.62	2.71	1.81	0.90	0.0	2.71	0.0	2.70	0.0	0.0	127.0	141.8	2.11	14.9	1371.1	0.7293	1.33
0.0	5.43	4.53	3.61	1.81	0.90	0.0	2.71	0.0	1.80	0.0	0.0	127.0	141.8	2.31	14.9	1366.7	0.7317	1.50
0.0	6.34	4.53	4.51	2.71	1.80	0.0	1.81	0.0	2.70	0.0	0.0	127.0	141.8	2.71	14.9	1358.5	0.7361	1.75
0.0	5.43	3.62	2.71	1.81	0.90	0.0	2.71	0.0	2.70	0.0	0.0	127.0	141.8	2.11	14.9	1371.1	0.7293	1.98
0.0	6.34	4.53	4.51	3.61	2.71	0.90	3.62	0.0	2.70	0.0	0.0	127.0	141.8	3.21	14.9	1343.7	0.7442	2.18
0.0	6.34	6.34	5.41	4.51	3.61	0.90	3.62	0.0	3.60	0.90	0.0	127.0	141.8	3.91	14.9	1328.6	0.7527	2.47
0.0	8.15	7.25	4.51	3.61	1.80	0.0	3.62	0.0	2.70	0.0	0.0	127.0	141.8	3.52	14.9	1343.7	0.7442	2.90

*******RUN NO61.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 234.

HEAT FLOW SUPPLIED 7467.3 BTU/HR
HEAT FLUX SUPPLIED 42866. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET134.9 DEG F

FLOW RATE 0.2563 LBS.M/SEC

AVG TEMP:130.9 DEG F
KINEMATIC
VISCOSITY:0.511 SQ.CM/SEC

FLUID VELOCITY 6.487 FT/SEC
REYNOLDS NO 33701.3
PRANDTL NO 3.25

HEAT SUPP 7467.3 BTU/HR
HEAT TRANS 7311.3 BTU/HR
HEAT LOST 156.0 BTU/HR
PERCENT HEAT LOST 2.09
HEAT FLUX TRANS. BTU/SQFT-HR 41971.
NUSSELT NO 145.8
RFILM 0.522
RWALL 0.146
RTOTAL 0.668 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.16295 .81869
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.52425E-01 .26339
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 2.2385 6.1736

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.03	0.75	0.38
0.17	1.72	1.45
0.25	1.61	1.76
0.28	1.72	1.84
0.40	1.82	2.05
0.58	2.14	2.18
0.85	1.82	2.23
0.97	2.04	2.23
1.15	2.15	2.24
1.37	1.93	2.24
1.43	2.36	2.24
1.65	2.89	2.24
2.48	2.68	2.24

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	141.7	140.5	145.4	145.0	145.0	141.7	141.3	0.0	145.8	149.0	0.0	127.0	134.9	144.0	7.9	2556.8	0.3911	0.0
0.0	142.2	140.9	145.4	145.0	145.4	142.2	141.7	0.0	146.2	149.4	0.0	127.0	134.9	144.3	7.9	2497.2	0.4004	0.03
0.0	142.6	141.3	145.8	145.4	145.8	142.6	142.2	C.0	146.6	149.8	0.0	127.0	134.9	144.7	7.9	2423.3	0.4127	0.17
0.0	142.6	141.3	145.8	145.4	145.8	142.6	142.2	0.C	146.6	149.4	0.0	127.0	134.9	144.6	7.9	2429.8	0.4116	0.25
0.0	142.6	141.3	145.8	145.4	145.8	142.6	142.6	0.0	146.6	149.4	0.0	127.0	134.9	144.7	7.9	2419.2	0.4134	0.28
0.0	142.6	141.3	146.2	145.4	145.8	142.6	142.6	C.0	146.6	149.4	0.0	127.0	134.9	144.7	7.9	2411.6	0.4147	0.40
0.0	142.6	141.3	146.2	145.4	145.8	143.0	142.6	C.0	147.0	149.8	0.0	127.0	134.9	144.9	7.9	2386.5	0.4190	0.58
0.0	142.6	141.3	146.2	145.4	145.8	142.6	142.6	0.0	146.6	149.4	0.0	127.0	134.9	144.7	7.9	2411.6	0.4147	0.85
0.0	142.6	141.3	146.2	145.4	145.8	143.0	142.6	C.0	146.6	149.8	0.0	127.0	134.9	144.8	7.9	239[illegible].6	0.4176	0.97
0.0	142.6	141.7	146.2	145.4	145.8	143.0	142.6	C.0	146.6	149.8	0.0	127.0	134.9	144.9	7.9	2389.2	0.4185	1.15
0.0	142.6	141.7	145.8	145.8	145.8	143.0	142.6	0.0	146.2	149.4	0.0	127.0	134.9	144.8	7.9	2402.5	0.4162	1.37
0.0	142.6	141.7	146.2	145.8	146.2	143.0	142.6	0.0	146.6	149.8	0.0	127.0	134.9	144.9	7.9	2370.5	0.4219	1.43
0.0	143.0	141.7	146.6	145.8	146.2	143.0	143.0	0.0	147.0	150.2	0.0	127.0	134.9	145.2	7.9	2336.5	0.4280	1.65
0.0	143.0	141.7	146.2	145.8	146.2	143.0	143.0	0.0	147.0	149.8	0.0	127.0	134.9	145.1	7.9	2349.8	0.4256	2.48

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	134.9	0.C	7.9	2556.8	0.3911	0.0
0.0	0.97	0.97	0.0	0.0	0.96	0.97	0.97	0.0	0.96	0.96	0.0	127.0	134.9	0.75	7.9	2497.2	0.4004	0.03
0.0	1.93	1.93	0.96	0.96	1.93	1.93	1.93	0.0	1.93	1.92	0.0	127.0	134.9	1.72	7.9	2423.3	0.4127	0.17
0.0	1.93	1.93	0.96	0.96	1.93	1.93	1.93	0.0	1.93	0.96	0.0	127.0	134.9	1.61	7.9	2429.8	0.4116	0.25
0.0	1.93	1.93	0.96	0.96	1.93	1.93	2.90	0.0	1.93	0.96	0.0	127.0	134.9	1.72	7.9	2419.2	0.4134	0.28
0.0	1.93	1.93	1.93	0.96	1.93	1.93	2.90	0.0	1.93	0.96	0.0	127.0	134.9	1.82	7.9	2411.6	0.4147	0.40
0.0	1.93	1.93	1.93	0.96	1.93	2.90	2.90	0.0	2.89	1.92	0.0	127.0	134.9	2.14	7.9	2386.5	0.4190	0.58
0.0	1.93	1.93	1.93	0.96	1.93	1.93	2.90	0.0	1.93	0.96	0.0	127.0	134.9	1.82	7.9	2411.6	0.4147	0.85
0.0	1.93	1.93	1.93	0.96	1.93	2.90	2.90	0.0	1.93	1.92	0.0	127.0	134.9	2.04	7.9	2394.6	0.4176	0.97
0.0	1.93	2.90	1.93	0.96	1.93	2.90	2.90	0.0	1.93	1.92	0.0	127.0	134.9	2.15	7.9	2389.2	0.4185	1.15
0.0	1.93	2.90	0.96	1.93	1.93	2.90	2.90	0.0	0.96	0.96	0.0	127.0	134.9	1.93	7.9	2402.5	0.4162	1.37
0.0	1.93	2.90	1.93	1.93	2.89	2.90	2.90	0.0	1.93	1.92	0.0	127.0	134.9	2.36	7.9	2370.5	0.4219	1.43
0.0	2.90	2.90	2.89	1.93	2.89	2.90	3.87	0.0	2.89	2.88	0.0	127.0	134.9	2.89	7.9	2336.5	0.4280	1.65
0.0	2.90	2.90	1.93	1.93	2.89	2.90	3.87	0.0	2.89	1.92	0.0	127.0	134.9	2.68	7.9	2349.8	0.4256	2.48

*******RUN NO62.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS: 9.35 AMPS: 254.

HEAT FLOW SUPPLIED 8105.5 BTU/HR
HEAT FLUX SUPPLIED 46530. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET141.8 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:134.4 DEG F
KINEMATIC
VISCOSITY:0.496 SQ.CM/SEC

FLUID VELOCITY 3.655 FT/SEC
REYNOLDS NO 19550.0
PRANDTL NO 3.15

HEAT SUPP 8105.5 BTU/HR
HEAT TRANS 7727.9 BTU/HR
HEAT LOST 377.6 BTU/HR
PERCENT HEAT LOST 4.66
HEAT FLUX TRANS. BTU/SQFT-HR 44362.
NUSSELT NO 94.6
RFILM 0.803
RWALL 0.144
RTOTAL 0.947 SQFT-HR-DEG F/BTU

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	147.8	148.6	154.7	161.1	155.1	149.4	151.9	0.0	160.3	167.9	0.0	127.0	141.8	155.2	14.9	1684.8	0.5936	0.0
0.0	149.0	150.2	155.5	161.9	156.7	151.5	153.1	C.0	161.1	168.3	0.0	127.0	141.8	156.4	14.9	1591.6	0.6283	0.02
0.0	150.2	151.5	156.3	162.7	157.5	153.1	154.7	C.0	162.7	165.5	0.0	127.0	142.2	157.1	15.3	1545.3	0.6471	0.07
0.0	151.1	152.7	156.7	163.1	156.3	154.7	155.9	0.0	163.5	164.7	0.0	127.0	142.2	157.8	15.3	1495.0	0.6689	0.15
0.0	151.5	153.1	156.7	163.1	158.3	155.1	155.5	0.0	163.5	163.9	0.0	127.0	142.2	157.8	15.3	1496.6	0.6662	0.25
0.0	160.7	162.3	166.7	172.6	168.7	165.9	166.3	C.0	175.0	175.8	0.0	127.4	142.2	168.2	14.8	1041.1	0.9605	4.03
0.0	160.7	162.3	167.5	173.0	169.1	166.3	166.7	0.0	175.0	176.2	0.0	127.0	141.8	168.5	14.9	1017.7	0.9826	4.20
0.0	178.6	179.8	186.8	192.3	186.8	185.7	186.1	0.0	197.4	199.0	0.0	127.0	141.8	188.3	14.9	646.9	1.5459	13.75

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	141.8	0.0	14.9	1684.8	0.5936	0.0
0.0	2.73	3.64	1.81	1.80	3.62	4.55	2.72	0.0	1.80	0.90	0.0	127.0	141.8	2.67	14.9	1591.6	0.6283	0.02
0.0	5.46	6.37	3.62	3.61	5.43	8.18	6.35	C.0	5.41	0.0	0.0	127.0	142.2	4.34	15.3	1545.3	0.6471	0.07
0.0	7.28	9.09	4.53	4.51	7.24	11.90	9.07	0.0	7.21	0.0	0.0	127.0	142.2	5.95	15.3	1495.0	0.6689	0.15
0.0	8.19	10.00	4.53	4.51	7.24	12.71	8.16	C.0	7.21	0.0	0.0	127.0	142.2	5.95	15.3	1496.6	0.6682	0.25
0.0	29.01	30.79	27.07	26.04	30.65	37.07	32.52	0.0	33.21	17.89	0.0	127.4	142.2	29.36	14.8	1041.1	0.9605	4.03
0.0	29.01	30.79	28.86	26.94	31.54	37.97	33.47	0.0	33.21	18.79	0.0	127.0	141.8	30.06	14.9	1017.7	0.9826	4.20
0.0	69.34	70.19	72.53	70.42	76.04	81.68	77.11	0.0	83.65	70.06	0.0	127.0	141.8	74.56	14.9	646.9	1.5459	13.75

*******RUN NO63.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET150.3 DEG F

FLOW RATE 0.1888 LBS.M/SEC

AVG TEMP:138.6 DEG F
KINEMATIC
VISCOSITY:0.479 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26534.0
PRANDTL NO 3.02

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15921.4 BTU/HR
HEAT LOST 435.4 BTU/HR
PERCENT HEAT LOST 2.66
HEAT FLUX TRANS. BTU/SQFT-HR 91397.
NUSSELT NO 121.5
RFILM 0.623
RWALL 0.143
RTOTAL 0.765 SQFT-HR-DEG F/BTU

ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
.18680 .78614
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
.25054E-01 .10544
ESTIMATE OF RO,RINF,AND B IN RF=RINF((1.-EXP(-B*TIME)
.0 2.0669 5.7124

TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.0
0.08	0.77	0.76
0.12	1.15	1.03
0.20	1.29	1.41
0.23	1.58	1.51
0.42	1.82	1.88
0.68	2.01	2.02
0.85	1.77	2.05
1.02	1.92	2.06
1.35	2.11	2.07
1.47	2.16	2.07
1.77	2.25	2.07
1.92	2.20	2.07

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	174.6	174.2	182.5	182.5	183.3	178.6	178.6	0.0	186.5	192.7	0.0	127.0	149.9	181.5	23.0	1676.2	0.5966	0.0
0.0	175.0	175.0	182.1	182.1	184.1	179.4	180.2	0.0	188.0	193.9	0.0	127.0	149.9	182.2	23.0	1648.0	0.6068	0.08
0.0	175.0	175.0	182.5	182.9	184.5	180.2	180.6	0.0	188.4	193.9	0.0	127.0	149.9	182.6	23.0	1632.5	0.6125	0.12
0.0	175.8	175.4	182.5	182.9	184.5	180.2	180.6	0.0	188.4	193.9	0.0	127.0	149.9	182.7	23.0	1630.0	0.6135	0.20
0.0	175.8	175.8	183.3	183.3	184.9	180.2	180.6	0.0	188.4	194.3	0.0	127.0	149.9	183.0	23.0	1620.6	0.6170	0.23
0.0	175.8	175.8	184.1	183.3	184.9	180.6	180.9	0.0	188.4	194.7	0.0	127.0	149.9	183.2	23.0	1612.1	0.6203	0.42
0.0	176.6	176.6	183.7	184.1	185.3	180.6	180.9	0.0	188.4	193.9	0.0	127.0	149.9	183.3	23.0	1607.3	0.6222	0.68
0.0	176.6	176.6	183.7	183.7	184.9	180.2	180.6	0.0	188.0	193.9	0.0	127.0	149.9	183.1	23.0	1616.9	0.6185	0.85
0.0	176.6	176.2	184.1	183.7	185.3	180.6	180.9	0.0	188.0	193.9	0.0	127.0	149.9	183.3	23.0	1610.4	0.6210	1.02
0.0	177.0	176.6	183.7	184.1	185.3	180.6	181.3	0.0	188.4	193.9	0.0	127.0	149.9	183.4	23.0	1604.7	0.6232	1.35
0.0	177.0	177.0	184.1	184.1	185.3	180.6	180.9	0.0	188.4	193.9	0.0	127.0	149.9	183.5	23.0	1604.1	0.6234	1.47
0.0	177.4	177.0	184.5	184.1	185.3	180.9	180.9	0.0	188.4	193.5	0.0	127.0	149.9	183.6	23.0	1601.4	0.6244	1.77
0.0	177.0	177.0	184.1	184.5	185.3	180.6	180.9	0.0	188.4	193.9	0.0	127.0	149.9	183.5	23.0	1602.4	0.6241	1.92

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1676.2	0.5966	0.0
0.0	0.43	0.87	0.0	0.0	0.86	0.86	1.73	0.0	1.72	1.28	0.0	127.0	149.9	0.77	23.0	1648.0	0.6068	0.08
0.0	0.43	0.87	0.0	0.43	1.29	1.73	2.16	0.0	2.15	1.28	0.0	127.0	149.9	1.15	23.0	1632.5	0.6125	0.12
0.0	1.30	1.30	0.0	0.43	1.29	1.73	2.16	0.0	2.15	1.28	0.0	127.0	149.9	1.29	23.0	1630.0	0.6135	0.20
0.0	1.30	1.73	0.86	0.86	1.72	1.73	2.16	0.0	2.15	1.71	0.0	127.0	149.9	1.58	23.0	1620.6	0.6170	0.23
0.0	1.30	1.73	1.72	0.86	1.72	2.16	2.59	0.0	2.15	2.14	0.0	127.0	149.9	1.82	23.0	1612.1	0.6203	0.42
0.0	2.17	2.60	1.29	1.72	2.15	2.16	2.59	0.0	2.15	1.28	0.0	127.0	149.9	2.01	23.0	1607.3	0.6222	0.68
0.0	2.17	2.60	1.29	1.29	1.72	1.73	2.16	0.0	1.72	1.28	0.0	127.0	149.9	1.77	23.0	1616.9	0.6185	0.85
0.0	2.17	2.17	1.72	1.29	2.15	2.16	2.59	0.0	1.72	1.28	0.0	127.0	149.9	1.92	23.0	1610.4	0.6210	1.02
0.0	2.60	2.60	1.29	1.72	2.15	2.16	3.02	0.0	2.15	1.28	0.0	127.0	149.9	2.11	23.0	1604.7	0.6232	1.35
0.0	2.60	3.03	1.72	1.72	2.15	2.16	2.59	0.0	2.15	1.28	0.0	127.0	149.9	2.16	23.0	1604.1	0.6234	1.47
0.0	3.03	3.03	2.15	1.72	2.15	2.59	2.59	0.0	2.15	0.85	0.0	127.0	149.9	2.25	23.0	1601.4	0.6244	1.77
0.0	2.60	3.03	1.72	2.15	2.15	2.16	2.59	0.0	2.15	1.28	0.0	127.0	149.9	2.20	23.0	1602.4	0.6241	1.92

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*******RUN NO64.*******

FERRIC OXIDE CONC (PPM)    2130.

VOLTS:13.50          AMPS: 353.

HEAT FLOW SUPPLIED 16264.6     BTU/HR
HEAT FLUX SUPPLIED   93363.    BTU/SQFT-HR

BETAO.301           TOR=TINLET127.0    DEG F
DENSITY:0.986 GRAM/CC
                    T OUTLET157.0      DEG F

FLOW RATE 0.1442  LBS.M/SEC

AVG TEMP:142.0     DEG F
KINEMATIC
VISCOSITY:0.467   SQ.CM/SEC

FLUID VELOCITY 3.664    FT/SEC
REYNOLDS NO  20850.6
PRANDTL NO   2.93

HEAT SUPP      16264.6   BTU/HR
HEAT TRANS     15653.1   BTU/HR
HEAT LOST        611.6   BTU/HR
PERCENT HEAT LOST      3.76
HEAT FLUX TRANS. BTU/SQFT-HR    89857.
NUSSELT NO     100.0
RFILM     0.754
RWALL     0.141
RTOTAL     0.895      SQFT-HR-DEG F/BTU
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ESTIMATES OF ROOT MEAN SQUARE STATISTICAL ERROR IN THE PARAMETER
 **********          **********
ESTIMATES OF ROOT MEAN SQUARE TOTAL ERROR IN THE PARAMETERS
 **********          **********
ESTIMATE OF RO,RINF,AND B IN RF=RINF*(1.-EXP(-B*TIME)
 .0                  .2744HE 14             .10973E-56
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TIME HOURS	CALC. RESISTANCE ((SQFT-HR-DEGF/BTU)X100,000)	FITTED VALUE
0.0	0.0	-0.00
0.02	7.18	-0.00
0.23	12.84	-0.00
0.45	18.19	-0.00
0.67	21.46	-0.00
1.15	30.68	-0.00
1.95	47.86	-0.00
2.78	58.22	-0.00
3.43	70.30	-0.00
3.95	64.11	-0.00
4.45	71.62	-0.00

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	174.6	174.6	162.1	162.1	183.7	180.2	179.4	0.0	187.2	192.7	0.0	127.0	149.5	181.9	22.5	162- 5	0.6160	0.0
0.0	183.7	195.3	189.6	183.3	199.3	183.3	191.3	0.0	188.8	200.1	0.0	127.0	149.1	188.3	22.1	1422.1	0.7032	0.02
0.0	190.8	188.0	165.3	169.6	205.9	192.3	188.4	0.0	196.2	204.0	0.0	127.4	149.9	193.4	22.5	1298.6	0.7701	0.23
0.0	194.7	192.7	190.4	193.5	210.2	197.4	193.5	0.0	201.7	209.8	0.0	127.4	150.3	196.2	22.9	1197.3	0.8352	0.45
0.0	197.4	195.8	193.5	195.8	213.3	200.5	196.6	0.0	205.2	212.1	0.0	127.0	149.9	201.1	23.0	1132.5	0.8830	0.67
0.0	204.4	202.8	200.9	203.2	220.9	208.3	205.5	0.0	215.9	222.8	0.0	127.0	149.9	209.4	23.0	999.7	1.0003	1.15
0.0	216.7	215.6	215.6	217.5	236.9	224.0	221.3	0.0	234.6	241.7	0.0	128.3	150.8	224.9	22.5	830.2	1.2045	1.95
0.0	224.0	223.2	224.4	227.0	246.2	232.7	231.2	0.0	245.9	253.0	0.0	127.4	149.5	234.2	22.1	739.9	1.3516	2.78
0.0	232.7	233.1	233.8	237.6	258.2	242.9	243.6	0.0	256.3	267.0	0.0	127.4	149.1	245.0	21.7	663.1	1.5081	3.43
0.0	238.7	239.1	240.6	242.9	262.2	244.4	247.0	0.0	211.3	228.9	0.0	127.0	148.6	239.5	21.7	702.1	1.4244	3.95
0.0	247.4	246.6	228.2	242.5	272.9	253.3	255.9	0.0	227.4	241.7	0.0	127.4	149.5	246.2	22.1	657.0	1.5220	4.45

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.5	0.0	22.5	1623.5	0.6160	0.0
0.0	10.10	11.85	8.30	1.31	17.40	3.51	2.19	0.0	1.75	8.24	0.0	127.0	149.1	7.18	22.1	1422.1	0.7032	0.02
0.0	17.96	14.91	3.50	8.30	24.74	13.54	10.07	0.0	10.01	12.55	0.0	127.4	149.9	12.84	22.5	1298.6	0.7701	0.23
0.0	27.31	20.14	9.18	12.66	29.46	19.19	15.73	0.0	16.06	19.00	0.0	127.4	150.3	18.19	22.9	1197.3	0.8352	0.45
0.0	25.34	23.61	12.66	15.26	32.89	27.65	19.20	0.0	19.94	21.57	0.0	127.0	149.9	21.46	23.0	1132.5	0.8830	0.67
0.0	33.12	31.40	20.89	23.48	41.42	31.26	29.13	0.0	31.94	33.51	0.0	127.0	149.9	30.68	23.0	999.7	1.0003	1.15
0.0	46.84	45.56	37.20	39.34	59.15	48.76	46.67	0.0	52.70	54.56	0.0	128.3	150.8	47.86	22.5	830.2	1.2045	1.95
0.0	54.92	54.07	46.99	49.95	69.60	58.48	57.67	0.0	65.25	67.04	0.0	127.4	149.5	58.22	22.1	739.9	1.3516	2.78
0.0	64.63	65.06	57.55	61.74	82.85	69.79	71.51	0.0	76.86	82.67	0.0	127.4	149.1	70.30	21.7	663.1	1.5081	3.43
0.0	71.35	71.77	65.09	67.60	87.38	71.46	75.26	0.0	26.81	40.28	0.0	127.0	148.6	64.11	21.7	702.1	1.4244	3.95
0.0	80.95	80.12	51.22	67.18	99.23	81.43	85.20	0.0	44.69	54.56	0.0	127.4	149.5	71.62	22.1	657.0	1.5220	4.45

*******RUN NO65.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS:13.50 AMPS: 354.

HEAT FLOW SUPPLIED 16310.7 BTU/HR
HEAT FLUX SUPPLIED 93632. BTU/SQFT-HR

BETA0.301 TOR=TINLET127.0 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET157.0 DEG F

FLOW RATE 0.1442 LBS.M/SEC

AVG TEMP:142.0 DEG F
KINEMATIC
VISCOSITY:0.467 SQ.CM/SEC

FLUID VELOCITY 3.664 FT/SEC
REYNOLDS NO 20850.6
PRANDTL NO 2.93

HEAT SUPP 16310.7 BTU/HR
HEAT TRANS 15653.1 BTU/HR
HEAT LOST 657.7 BTU/HR
PERCENT HEAT LOST 4.03
HEAT FLUX TRANS. BTU/SQFT-HR 89857.
NUSSELT NO 100.0
RFILM 0.754
RWALL 0.141
RTOTAL 0.895 SQFT-HR-DEG F/BTU

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X1000	TIME HOURS
0.0	186.8	187.2	196.6	196.6	199.6	184.5	194.3	0.0	203.2	210.2	0.0	127.0	157.0	195.3	30.1	1335.8	0.7486	0.0
0.0	187.6	188.0	195.8	196.6	199.0	184.9	194.7	C.0	203.2	209.8	0.0	127.0	157.0	195.5	30.1	1332.2	0.7506	0.10
0.0	187.2	187.6	196.6	196.6	199.0	184.7	194.3	0.0	203.6	210.2	0.0	127.0	157.0	195.6	30.1	1330.6	0.7515	0.15
0.0	187.6	188.0	197.0	197.4	199.3	185.3	195.1	0.0	203.6	210.6	0.0	127.0	157.0	196.0	30.1	1319.5	0.7579	0.18
0.0	186.0	188.4	196.6	197.4	199.3	185.3	195.1	C.0	204.4	211.0	0.0	127.4	157.0	196.2	29.6	1321.4	0.7568	0.28
0.0	187.6	189.4	196.2	196.2	195.6	184.7	194.3	C.0	204.0	211.0	0.0	127.4	157.0	195.7	29.6	1334.8	0.7492	0.33
0.0	187.6	189.4	197.0	197.0	199.3	185.3	194.7	0.0	204.0	210.2	0.0	127.4	157.0	195.9	29.6	1326.4	0.7539	0.37
0.0	188.0	189.4	196.6	197.0	199.3	185.7	194.7	0.0	203.6	210.2	0.0	127.0	157.0	196.0	30.1	1321.5	0.7567	0.45
0.0	188.8	189.2	197.4	197.4	199.3	185.3	194.7	0.0	204.0	210.6	0.0	127.4	157.0	196.3	29.6	1320.6	0.7572	0.82
0.0	188.4	188.4	197.0	197.4	199.3	185.3	194.7	0.0	204.0	210.6	0.0	127.0	157.0	195.1	30.1	1318.3	0.7566	1.17
0.0	189.2	189.2	197.8	197.8	199.7	185.7	195.1	0.0	204.4	210.6	0.0	127.0	156.6	196.6	29.7	1302.5	0.7678	1.35
0.0	190.0	190.4	199.0	199.0	200.9	186.5	196.2	0.0	205.2	211.7	0.0	127.0	157.0	197.6	30.1	1282.9	0.7795	1.43
0.0	190.0	190.0	199.0	198.6	200.5	186.5	195.8	0.0	204.8	211.0	0.0	127.4	157.0	197.3	29.6	1295.1	0.7721	1.60
0.0	190.4	190.4	199.0	199.0	200.9	186.5	195.8	0.0	204.8	211.7	0.0	127.4	157.0	197.6	29.6	1289.9	0.7753	1.70
0.0	190.4	190.8	199.0	199.7	200.9	186.5	196.2	0.0	205.2	212.1	0.0	127.0	157.0	197.9	30.1	1278.7	0.7820	1.78

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X1000	TIME HOURS
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	157.0	0.0	30.1	1335.8	0.7486	0.0
0.0	0.87	0.87	0.0	0.0	0.43	0.44	0.43	0.0	0.0	0.0	0.0	127.0	157.0	0.19	30.1	1332.2	0.7506	0.10
0.0	0.44	0.44	0.0	0.0	0.43	0.44	0.0	0.0	0.43	0.0	0.0	127.0	157.0	0.24	30.1	1330.6	0.7515	0.15
0.0	0.87	0.87	0.43	0.87	0.87	0.87	0.87	0.0	0.43	0.43	0.0	127.0	157.0	0.72	30.1	1319.5	0.7579	0.18
0.0	1.31	1.31	0.0	0.87	0.87	0.87	0.87	0.0	1.29	0.86	0.0	127.4	157.0	0.92	29.6	1321.4	0.7568	0.28
0.0	0.87	1.31	0.0	0.0	0.0	0.44	0.0	0.0	0.86	0.86	0.0	127.4	157.0	0.39	29.6	1334.8	0.7492	0.33
0.0	0.87	1.31	0.43	0.43	0.87	0.87	0.43	0.0	0.86	0.0	0.0	127.4	157.0	0.68	29.6	1326.4	0.7539	0.37
0.0	1.31	1.31	0.0	0.43	0.87	1.31	0.43	0.0	0.43	0.0	0.0	127.0	157.0	0.68	30.1	1321.5	0.7567	0.45
0.0	2.18	2.18	0.87	0.87	0.87	0.87	0.43	0.0	0.86	0.43	0.0	127.4	157.0	1.06	29.6	1320.6	0.7572	0.82
0.0	1.75	1.31	0.43	0.87	0.87	0.87	0.43	0.0	0.86	0.43	0.0	127.0	157.0	0.87	30.1	1318.3	0.7566	1.17
0.0	2.62	2.18	1.30	1.30	1.30	1.31	0.87	0.0	1.29	0.43	0.0	127.0	156.6	1.40	29.7	1302.5	0.7678	1.35
0.0	3.49	3.49	2.60	2.60	2.59	2.19	2.17	0.0	2.15	1.71	0.0	127.0	157.0	2.55	30.1	1282.9	0.7795	1.43
0.0	3.49	3.05	2.60	2.17	2.16	2.19	1.74	0.0	1.72	0.86	0.0	127.4	157.0	2.22	29.6	1295.1	0.7721	1.60
0.0	3.93	3.49	2.60	2.60	2.59	2.19	1.74	0.0	1.72	1.71	0.0	127.4	157.0	2.51	29.6	1289.9	0.7753	1.70
0.0	3.93	3.92	2.60	3.46	2.59	2.19	2.17	0.0	2.15	2.14	0.0	127.0	157.0	2.60	30.1	1278.7	0.7820	1.78

********RUN NO70.*******

FERRIC OXIDE CONC (PPM) 2130.

VOLTS:13.50 AMPS: 355.

HEAT FLOW SUPPLIED 16356.8 BTU/HR
HEAT FLUX SUPPLIED 93897. BTU/SQFT-HR

BETA0.301 TUR=TINLET127.4 DEG F
DENSITY:0.986 GRAM/CC
T OUTLET150.3 DEG F

FLOW RATE 0.1887 LBS.M/SEC

AVG TEMP:138.9 DEG F
KINEMATIC
VISCOSITY:0.479 SQ.CM/SEC

FLUID VELOCITY 4.790 FT/SEC
REYNOLDS NO 26575.5
PRANDTL NO 3.02

HEAT SUPP 16356.8 BTU/HR
HEAT TRANS 15619.7 BTU/HR
HEAT LOST 737.1 BTU/HR
PERCENT HEAT LOST 4.51
HEAT FLUX TRANS. BTU/SQFT-HR 89665.
NUSSELT NO 121.4
RFILM 0.623
RWALL 0.143
RTOTAL 0.765 SQFT-HR-DEG F/BTU

LOCALIZED FOULING RESISTANCE (SQFT-HR-DEGF/BTU)X100,000

T215	T235	T255	T275	T295	T315	T335	T355	T375	T395	T415	T428	TIN DEG.F	TOUT DEG.F	RFM	DELTA DEG.F	H	RTOT X100	S
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.0	149.9	0.0	23.0	1644.4	0.60	
0.0	9.25	8.37	7.88	6.57	7.00	4.40	6.59	0.0	7.42	6.95	0.0	127.4	150.3	7.16	22.9	1452.2	0.68	.05
0.0	10.56	9.25	8.76	7.01	7.88	6.15	7.47	0.0	7.86	7.39	0.0	127.4	150.3	8.04	22.9	1429.3	0.69	.12
0.0	10.56	9.25	8.32	7.01	7.88	7.03	7.03	0.0	8.29	6.52	0.0	127.4	150.3	7.99	22.9	1429.6	0.69	.22
0.0	7.05	8.37	5.70	5.70	7.88	3.96	7.03	0.0	4.81	7.82	0.0	127.4	150.3	6.48	22.9	1466.7	0.68	.65
0.0	9.25	9.69	6.57	7.45	10.49	6.59	10.09	0.0	8.73	12.15	0.0	127.4	150.3	9.00	22.9	1399.8	0.71	.80
0.0	9.25	7.93	7.45	7.88	10.49	7.91	11.41	0.0	10.47	14.74	0.0	127.4	150.3	9.72	22.9	1379.9	0.72	.87
0.0	12.76	10.13	12.24	8.76	6.57	10.97	14.46	0.0	15.24	17.75	0.0	127.8	150.8	12.10	22.9	1342.0	0.74	.17
0.0	13.19	11.44	13.11	10.94	9.62	14.03	17.08	0.0	17.41	18.18	0.0	127.4	150.3	13.89	22.9	1286.7	0.77	.32
0.0	14.51	11.88	14.42	9.63	10.06	13.59	17.51	0.0	17.64	10.42	0.0	127.4	149.9	13.32	22.5	1292.0	0.77	.43
0.0	16.25	13.63	12.24	10.34	11.80	15.21	17.25	0.0	13.70	13.01	0.0	127.4	149.9	14.67	22.5	1263.9	0.79	.50
0.0	19.31	18.01	14.65	16.16	16.58	20.55	23.16	0.0	25.17	19.90	0.0	127.4	150.3	19.30	22.9	1180.4	0.8	.70
0.0	21.92	18.88	15.72	16.59	14.41	23.16	27.05	0.0	26.46	24.19	0.0	127.4	149.9	20.93	22.5	1150.9	0.8	1.92
0.0	23.23	20.62	16.16	17.89	15.71	24.46	28.78	0.0	28.18	26.76	0.0	127.4	149.9	22.42	22.5	1127.2	0.8	1.97
0.0	24.96	19.75	18.33	20.06	17.45	26.19	30.07	0.0	29.89	28.89	0.0	127.4	150.3	23.95	22.9	1105.9	0.9	2.03
0.0	26.70	20.62	18.76	21.79	19.61	28.35	31.37	0.0	32.46	31.45	0.0	127.4	149.9	25.68	22.5	1076.5	0.9	2.20
0.0	30.60	25.41	22.65	26.11	24.37	31.80	31.37	0.0	38.86	25.47	0.0	127.4	149.9	28.52	22.5	1034.1	0.9	2.40
0.0	31.89	27.58	24.38	28.26	26.52	34.81	34.81	0.0	41.84	30.60	0.0	127.0	149.5	31.19	22.5	992.7	1.0	2.53
0.0	34.48	28.88	26.54	30.41	25.23	37.37	36.95	0.0	43.96	34.00	0.0	127.4	149.9	33.09	22.5	976.8	1.0	2.67
0.0	35.35	30.17	27.83	31.70	27.38	38.67	39.53	0.0	46.08	36.99	0.0	127.4	149.5	34.86	22.1	953.0	1.0	2.77
0.0	37.93	32.77	30.41	33.85	29.96	40.81	42.10	0.0	48.62	39.52	0.0	127.4	149.9	37.33	22.5	928.2	1.0	2.85
0.0	40.08	35.36	32.56	35.56	32.97	43.81	43.81	0.0	47.78	41.64	0.0	127.4	149.5	39.28	22.1	904.6	1.1	3.03
0.0	44.80	38.80	38.13	41.54	38.53	48.92	49.77	0.0	55.37	50.07	0.0	127.4	149.9	45.10	22.5	850.3	1.1	3.28
0.0	49.07	43.53	43.25	46.65	44.50	54.44	55.29	0.0	60.41	55.52	0.0	127.8	149.9	50.29	22.1	806.6	1.2	3.55
0.0	52.06	46.95	47.08	50.47	48.32	58.25	59.10	0.0	65.01	60.95	0.0	127.8	149.9	54.24	22.1	775.5	1.2	3.72
0.0	58.01	52.07	34.28	44.52	24.80	42.53	59.52	0.0	30.32	46.28	0.0	127.4	150.3	43.59	22.9	881.2	1.1	3.93
0.0	59.28	52.50	35.13	45.38	25.66	42.53	33.95	0.0	30.32	47.12	0.0	127.4	150.3	41.32	22.9	916.3	1.0	4.03
0.0	59.70	52.92	35.56	45.80	26.09	42.53	33.52	0.0	30.75	47.54	0.0	127.4	149.9	41.60	22.5	911.2	1.0	4.12
0.0	60.97	54.20	37.70	47.50	28.67	43.38	34.81	0.0	32.03	49.23	0.0	127.4	149.9	43.17	22.5	894.7	1.11	4.30
0.0	61.82	55.48	38.96	48.35	30.39	45.09	36.10	0.0	33.74	51.33	0.0	127.4	149.9	44.59	22.5	879.9	1.13	4.42
0.0	62.66	56.75	39.84	49.20	31.25	45.51	36.96	0.0	34.60	51.75	0.0	127.4	149.9	45.39	22.5	872.3	1.14	4.52
0.0	63.51	57.17	41.12	50.47	30.39	46.79	37.82	0.0	35.88	52.58	0.0	127.4	149.9	46.19	22.5	864.8	1.15	4.65
0.0	65.19	58.45	43.25	52.16	32.11	48.50	39.96	0.0	38.01	54.68	0.0	127.4	150.3	48.03	22.9	849.6	1.17	4.88

LOCALIZED WALL TEMPERATURES (DEG.F)

T215 DEG.F	T235 DEG.F	T255 DEG.F	T275 DEG.F	T295 DEG.F	T315 DEG.F	T335 DEG.F	T355 DEG.F	T375 DEG.F	T395 DEG.F	T415 DEG.F	T428 DEG.F	TIN DEG.F	TOUT DEG.F	TM DEG.F	DELTA DEG.F	H	R X100	TIME HOURS
0.0	174.6	174.2	182.5	182.5	183.3	178.6	178.6	0.0	186.5	192.7	0.0	127.0	149.9	181.5	23.0	1644.4	0.608	.0
0.0	182.9	181.7	189.6	188.4	189.6	182.5	184.5	0.0	193.1	199.0	0.0	127.4	150.3	187.9	22.9	1452.2	0.6881	.05
0.0	184.1	182.5	190.4	188.8	190.4	184.1	185.3	0.0	193.5	199.3	0.0	127.4	150.3	188.7	22.9	1429.3	0.6996	12
0.0	184.1	182.5	190.0	188.8	190.4	184.9	184.9	0.0	193.9	198.6	0.0	127.4	150.3	188.7	22.9	1429.6	0.6995	.22
0.0	180.9	181.7	187.6	187.6	190.4	182.1	184.9	0.0	170.8	199.7	0.0	127.4	150.3	187.3	22.9	1466.7	0.6813	55
0.0	182.9	182.9	188.4	189.2	192.7	184.5	187.6	0.0	194.3	203.6	0.0	127.4	150.3	189.6	22.9	1399.8	0.7144	0
0.0	182.9	181.3	189.2	189.6	192.7	185.7	188.8	0.0	195.8	205.9	0.0	127.4	150.3	190.2	22.9	1379.9	0.7247	
0.0	186.1	183.3	193.5	190.4	189.2	188.4	191.5	0.0	200.1	208.6	0.0	127.8	150.8	192.4	22.9	1342.0	0.7452	
0.0	186.5	184.5	194.3	192.3	191.9	191.2	193.9	0.0	202.1	209.0	0.0	127.4	150.3	194.0	22.9	1286.7	0.7772	
0.0	187.6	184.9	195.5	191.2	192.3	190.9	194.3	0.0	202.5	202.1	0.0	127.4	149.9	193.4	22.5	1292.0	0.7749	
0.0	189.2	186.5	193.5	192.3	193.9	193.1	195.8	0.0	203.2	204.4	0.0	127.4	149.9	194.7	22.5	1263.9	0.7912	
0.0	191.9	190.4	195.8	197.0	198.2	197.0	199.3	0.0	209.0	210.6	0.0	127.4	150.3	198.8	22.9	1180.4	0.8472	
0.0	194.3	191.2	196.6	197.4	196.2	199.3	202.8	0.0	210.2	214.4	0.0	127.4	149.9	200.3	22.5	1150.9	0.8689	
0.0	195.5	192.7	197.0	198.6	197.4	200.5	204.4	0.0	211.7	216.7	0.0	127.4	149.9	201.6	22.5	1127.2	0.8872	.9
0.0	197.0	191.9	199.0	200.5	197.0	202.1	205.5	0.0	213.3	218.6	0.0	127.4	150.3	203.0	22.9	1105.9	0.9042	.03
0.0	198.6	192.7	199.3	202.1	200.9	204.0	206.7	0.0	215.6	220.9	0.0	127.4	149.9	204.5	22.5	1076.5	0.9290	.20
0.0	202.1	197.0	202.8	205.9	205.2	207.1	206.7	0.0	221.3	215.6	0.0	127.4	149.9	207.1	22.5	1034.1	0.9671	2.40
0.0	203.2	199.0	204.4	207.9	207.1	209.8	209.8	0.0	224.0	220.2	0.0	127.0	149.5	209.5	22.5	992.7	1.0073	2.53
0.0	205.5	200.1	206.3	209.8	205.9	212.1	211.7	0.0	225.9	223.2	0.0	127.4	149.9	211.2	22.5	976.8	1.0237	2.67
0.0	206.3	201.3	207.5	211.0	207.9	213.3	214.0	0.0	227.8	225.9	0.0	127.4	149.5	212.8	22.1	953.0	1.0493	2.77
0.0	208.6	203.6	209.8	212.9	210.2	215.2	216.3	0.0	230.1	228.2	0.0	127.4	149.9	215.0	22.5	928.2	1.0774	2.85
0.0	210.6	205.9	211.7	214.4	212.9	217.9	217.9	0.0	229.3	230.1	0.0	127.4	149.5	216.7	22.1	904.6	1.1055	3.03
0.0	214.8	209.0	216.7	219.8	217.9	222.4	223.2	0.0	236.1	237.6	0.0	127.4	149.9	221.9	22.5	850.3	1.1761	3.28
0.0	218.6	213.3	221.3	224.4	223.2	227.4	228.2	0.0	240.6	242.5	0.0	127.8	149.9	226.6	22.1	806.6	1.2398	3.55
0.0	221.3	216.3	224.7	227.8	226.6	230.8	231.6	0.0	244.7	247.4	0.0	127.8	149.9	230.1	22.1	775.5	1.2896	3.72
0.0	226.6	220.9	213.3	222.4	205.5	216.7	231.9	0.0	213.6	234.2	0.0	127.4	150.3	220.6	22.9	881.2	1.1348	3.93
0.0	227.8	221.3	214.0	223.2	206.3	216.7	209.0	0.0	213.6	235.0	0.0	127.4	150.3	218.6	22.9	916.3	1.0913	4.03
0.0	228.2	221.7	214.4	223.6	206.7	216.7	208.6	0.0	214.0	235.4	0.0	127.4	149.9	218.8	22.5	911.2	1.0974	4.12
0.0	229.3	222.8	216.3	225.1	209.0	217.5	209.8	0.0	215.2	236.9	0.0	127.4	149.9	220.2	22.5	894.7	1.1177	4.30
0.0	230.1	224.0	217.5	225.9	210.6	219.0	211.0	0.0	216.7	238.7	0.0	127.4	149.9	221.5	22.5	879.9	1.1365	4.42
0.0	230.8	225.1	218.2	226.6	211.3	219.4	211.7	0.0	217.5	239.1	0.0	127.4	149.9	222.2	22.5	872.3	1.1463	4.52
0.0	231.6	225.5	219.4	227.8	210.6	220.5	212.5	0.0	218.6	239.9	0.0	127.4	149.9	222.9	22.5	864.8	1.1564	4.65
0.0	233.1	226.6	221.3	229.3	212.1	222.1	214.4	0.0	220.5	241.7	0.0	127.4	150.3	224.6	22.9	849.6	1.1771	4.88