AN ABSTRACT OF THE THESIS OF

Sai Heep Lee for the degree of Master of Science in Chemical Engineering

Dept. presented on July 18, 1978

Title: Deposition Charateristics of Magnesium Silicate and Calcium Carbonate in Cooling Tower Water

Abstract approved: Redacted for Privacy

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Deposition characteristics of magnesium silicate and calcium carbonate on a heated surface in cooling tower water using city water as make-up was investigated. Flow velocity, bulk temperature and calcium hardness were maintained constant at 5.3 ft/sec, 95°F and 150 ppm as $CaCO_3$ respectively whereas surface temperature varied from 105°F to 165°F. Other water parameters varied over the duration of the investigation; pH increased slightly from 8.9 to 9.2; silica concentration changed from 80 to 135 ppm as SiO_2; magnesium hardness was relatively constant at 60 $\pm$ 10 ppm as $CaCO_3$; methyl orange alkalinity varied from 150 to 270 ppm as $CaCO_3$. It was found that the type of deposit formed is a strong function of methyl orange alkalinity and the criteria for the deposition of magnesium silicate and calcium carbonate have been defined. Asymptotic fouling resistances were correlated with surface temperatures according to an Arrhenius type equation.

Deposition Characteristics of Magnesium Silicate and Calcium Carbonate in Cooling Tower Water

by

Sai Heep Lee

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed July 18, 1973

Commencement June 1979

APPROVED:

Redacted for Privacy

Professor of Chemical Engineering Department in charge of major

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Date thesis is presented July 18, 1978

Typed by Ellen Chambers for Sai Heep Lee

ACKNOWLEDGMENT

I would like to express my sincere gratitude and appreciation to my major professor, Dr. James G. Knudsen for his guidance and patience throughout the course of this study, and for his critical reading of the manuscript.

Special thanks are due to Mr. Ken Carter for his help in water analysis.

Gratitude is also extended to the following organizations:

Heat Transfer Research Inc. for the donation of experimental equipment and technical assistance.

Nalco Chemical Company for deposit analysis and water analysis.

Chemax Incorporated Industrial Chemistry for providing chemical reagents for water analysis.

National Science Foundation and American Society of Heating, Refrigerating and Air-Conditioning Engineers for the research grant.

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DEPOSITION CHARACTERISTICS OF MAGNESIUM SILICATE AND CALCIUM CARBONATE IN COOLING TOWER WATER

I. INTRODUCTION

Deposition of undesirable materials occurs occasionally on heat exchanger surfaces, resulting in an increase in the overall resistance to heat transmission. When this happens, the heat exchanger is said to be 'fouled'. Potential foulants may be crystals, sediment, microorganisms, corrosion products, or a combination of these.

Crystallization of inverse solubility salts such as calcium carbonate is the most common deposition mechanism in cooling tower water. In addition, sedimentation of suspended solids, polymerization of chemicals or biofouling is also observed under favorable conditions. For instance, it is likely that suspended solids will settle on a rough heated surface under the operating conditions of low flow rate coupled with a high concentration of total solids. In general, variables that affect deposition characteristics include surface temperature, flow velocity, water chemistry and surface conditions.

The extent of fouling deposition on the heat exchanger surface can be measured by the increase in fouling resistance which is defined as the difference between the overall fouling resistances at fouled and clean conditions.

For cooling tower water, the fouling resistance is observed to increase pseudoasymptotically with time. In other words, the fouling resistance tends to level off gradually, approaching an asymptotic

value. Models [7,22,27] have been proposed to simulate this unique deposition behavior of cooling tower water. According to the modified deposition - removal model proposed by Heat Transfer Research Inc.[22], the asymptotic fouling resistance is a function of surface temperature, flow velocity and water chemistry. However, a general functional relationship among these variables is still lacking.

For preliminary studies, it is advisable to investigate the effects of each variable separately on the asymptotic fouling resistance and the deposition behavior, while maintaining other variables constant. The purpose of this study is therefore to investigate the effects of surface temperature under a constant flow velocity and water quality.

Due to the limitation of the water quality control, only one of the water parameters, namely, calcium carbonate could be maintained unchanged. Other water parameters such as methyl orange alkalinity and silica varied over the duration of the investigation. Consequently three types of fouling deposits were formed, namely, magnesium silicate, magnesium silicate - calcium carbonate mixture and calcium carbonate. Preliminary criteria based on methyl orange alkalinity have been established to indicate whether the deposit will be magnesium silicate, calcium carbonate or a mixture of these.

Accordingly the asymptotic fouling resistance of magnesium silicate and magnesium silicate - calcium carbonate mixture were correlated with the surface temperature. Correlation of calcium carbonate is not possible due to lack of data.

II. GENERAL INFORMATION AND LITERATURE SURVEY

BASIC EQUATION

The overall heat transfer coefficient based on the outside surface area of a fouled heat transfer equipment is calculated by the following equation:

$$\frac{1}{U_o} = \frac{1}{h_{in}} \frac{A_o}{A_{in}} + \frac{1}{h_o} + R_{f_o} + R_{f_{in}} \frac{A_o}{A_{in}} + R_w \qquad (2\text{-}1)$$

where U = overall heat transfer coefficient

h = heat transfer film coefficient

R = heat transfer resistance

A = surface area

and subscripts

o = outside

in = inside

f = fouled

w = wall

The design of heat transfer equipment is based on Eq. (2-1). Values and correlations of heat transfer film coefficient and wall resistance are readily available under most operating conditions. But estimation of fouling resistances is still difficult because of lack of general correlation equations. Often, arbitary values based on experience such as those recommended by Tubular Exchangers Manufactures Association (TEMA) have to be assumed. As a result, the heat transfer equipment will either be over designed or under

designed, depending on the operating conditions of a process.

In spite of the recent effort in this area, further research is urgently needed. This study is part of the systematic research program initiated by Heat Transfer Research Inc. (HTRI) to further understanding of this problem.

MECHANISM OF DEPOSITION

Deposition of foulants occurs in a variety of heat transfer processes. Here we only focus on the deposition characteristics of cooling tower water.

No single mechanism can be generalized to describe the deposition behavior due to its complexity. The most common deposition mechanism in cooling water is the crystallization of inverse solubility salts although sedimentation of suspended solids, polymerization of chemicals, biofouling, or a combination of these occurs occasionally. The general characteristics of these mechanism are discussed briefly as follows.

The solubility of inverse solubility salts ($CaCO_3$, $Mg(OH)_2$ etc.) decreases with an increase in temperature. Therefore when water containing these inverse solubility salts is in contact with the heated surface where the solubility is greatly reduced, crystallization occurs. Crystals thus formed start to build up gradually on the surface.

Before a sudden increase in crystalline deposit occurs, an induction period is usually observed. During this period, only a small amount of micro-nucleation sites are formed which have little effect on the total heat transfer resistance. As the nucleation sites

grow, the fouling rate accelerates and the fouling resistance increases rapidly.

The rate of deposition by this type of mechanism is generally sensitive to the surface temperature.

Corrosion products and suspended particles in the circulating water tend to settle in the cavities formed by crystallization. This process creates more cavities and thus enhances a chain reaction for further deposition.

Chemical reaction type of deposition occurs when there is an excess amount of chemicals which polymerize easily or undergo some other reaction by which solid products are produced near the heat transfer surface.

Biofouling is common in processes using untreated water and sea water which is rich in microorganisms. Active bacteria, fungi and algae as well as their remains cling to the heat exchanger surface and to themselves, forming a structure which provides resistance to heat transmission.

PERTINENT VARIABLES

Variables that have a significant effect on the deposition process include: (1) surface temperature, (2) flow velocity, (3) water chemistry and (4) surface conditions. The relative importance of each depends on the type of fouling mechanism.

SURFACE TEMPERATURE

For inverse solubility crystallization or polymerization, the deposition rate is an exponential function of the reciprocal of

surface temperature.

In addition, the temperature in contact with the heat transfer surface increases when foulants accumulate. In some cases the properties and the crystalline structure of the deposit changes with temperature, resulting in a change in the bonding strength of deposit.

FLOW VELOCITY

Shear stress is approximately proportional to the square of the flow velocity. Therefore it is very unlikely for potential foulants to deposit if the flow velocity, and thus the shear stress is high; the deposit will be swept off immediately after it is deposited on the surface. In cases where deposition does occur, a strong shear stress will tear it off more readily at high flow velocity, limiting the chance of further deposition. For a mass diffusion controlled process, flow velocity enhances the rate of deposition by increasing the convective mass transfer coefficient.

WATER CHEMISTRY

In general, important water parameters include the concentrations of inverse solubility salts, alkalinities, hardnesses and pH. The relative amount of each not only determines the type of deposit to be formed, but also dictates the type of deposition mechanism. For instance, water which is high in suspended solids shows sedimentation deposition characteristics whereas the same water would shift to crystallization deposition if it is supersaturated with inverse solubility salts.

Langelier [10] proposed a fouling index for calcium carbonate

deposition. The Langelier Saturation Index (LSI) is defined as

$$LSI = pH - pH_s \tag{2-2}$$

where pH = true pH of water.

pH_s = pH of water when it is saturated with calcium carbonate.

The pH_s value can be calculated from various water parameters as follows [12] :

$$pH_s = E + F + 9.3 - (G + H) \tag{2-3}$$

where

$$E = \frac{2.5\ (TS/40000)^{0.5}}{1 + 5.3\ (TS/40000)^{0.5} + 5.5\ (TS/40000)}$$

$$F = 10^{(-1.37864 + 1040.92/T_b - 75500/T_b^2)}$$

$$G = \log\ (0.4\ CaH)$$

$$H = \log\ (m - alkalinity)$$

TS = total solids in ppm

T_b = bulk temperature in ^oR

CaH = calcium hardness in ppm as $CaCO_3$

m - alkalinity = methyl orange alkalinity in ppm as $CaCO_3$

If LSI is greater than 1.0, it is likely that deposition of calcium carbonate will occur.

Ryznar [19] proposed a stability index RSI defined as

$$RSI = 2pH_s - pH \tag{2-4}$$

If RSI is greater than 6.0, deposition of calcium carbonate will result.

SURFACE CONDITIONS

The surface conditions of a heat exchanger affect the initial deposition rate. A rough surface with a large cavity density provides neucleation sites for crystallization and sedimentation of foulants in

the water.

DEPOSITION MODELS

Generally, models for deposition characteristics of cooling tower water include both a deposition and removal term. If the removal term is small the fouling factor may increase indefinitely until the tube is plugged. If the removal term is significant a point may be reached where deposition and removal rate become equal and the fouling factor becomes constant. This latter model appears to apply for cooling tower water.

The deposition - removal model can be formulated as

$$\begin{matrix}\text{rate of accumulation} \\ \text{of deposit}\end{matrix} = \text{rate of deposition} - \begin{matrix}\text{rate of} \\ \text{removal}\end{matrix}$$

or

$$\frac{dR_f}{d\theta} = \emptyset_d - \emptyset_r \qquad (2\text{-}5)$$

For Eq. (2-5) to have any practical value, the two terms on the right hand side must be related to variables such as surface temperature, water chemistry, flow conditions and surface conditions.

The importance of each to a deposition process depends on the type of deposition mechanism. For instance, surface temperature effect would be more significant in a reaction rate controlling process than in a mass diffusion rate controlling process. Removal rate, on the other hand, is a strong function of shear stress and bonding strenth of deposits.

Mathematical models based on the concept of Eq. (2-5) have been proposed over the years. However there are disagreements of the significance of the important variables. Some of the models omit the removal term completely. The variations are due mostly to the fact

that different operating conditions and water were used. Despite of their limited applicability, each model shows a certain aspect of the deposition process and no doubt sheds some light on the overall understanding of this complex problem.

KERN - SEATON MODEL [7,8]

The pioneer work of Kern and Seaton introduced the concept of the dynamic relationship between the deposition rate and the removal rate in the deposition process.

First they assumed that the deposition rate is proportional to the product of foulant concentration and flow rate, which are considered to be constant. That is

$$\text{rate of deposition} = K_1 C_b' W' \tag{2-6}$$

where C_b' = bulk foulant concentration

W' = mass flow rate

K_1 = proportionality constant

Furthermore, they assumed that the removal rate is proportional to the shear stress and the instantaneous thickness of the deposit.

$$\text{rate of removal} = k_2 \tau X_\theta \tag{2-7}$$

where τ = shear stress

X_θ = instantaneous deposit thickness

k_2 = proportionality constant

The resulting equation according to the formulation of Eq. (2-4) is then

$$\frac{dX_\theta}{d\theta} = k_1 C' W' - k_2 \tau X_\theta \tag{2-8}$$

If the thickness of the deposit is small compared to the tube

diameter, the change in flow velocity is minimal. In other words, the shear stress remains relatively constant. Then the solution to Eq. (2-8) has the form

$$R_f = R_f^* (1 - e^{-B\theta}) \tag{2-9}$$

where R_f = fouling resistance

$= x_\theta / k_f$

k_f = thermal conductivity of deposit

R_f^* = asymptotic fouling resistance

and $$R_f^* = \frac{K_1 C' W'}{K_2 k_f \gamma} \tag{2-10}$$

$$B = K_2 \gamma \tag{2-11}$$

This model indeed predicted the asymptotic behavior generally observed for cooling tower water. Unfortunately no experimental work was done to correlate the important variables involved. Watkinson and Epstein [25] studied the deposition characteristics of a sour petroleum gas oil system and concluded that the initial deposition rate was proportional to the mass flow rate and the asymptotic fouling resistance was inversely proportional to the mass flow rate square. These results were contradictary to the assumptions of Kern and Seaton which stated that both were proportional to the mass flow rate. However, another study by Watkinson and Epstein [26] of a sand-water slurry system confirmed the assumptions of Kern and Seaton. Therefore it appears that the Kern-Seaton model is only applicable to a particulate deposition system.

WATKINSON - EPSTEIN MODEL [26]

In an attempt to resolve the above apparent contradication, Watkinson and Epstein proposed a transfer-adhesion model in which deposition is controlled by mass transfer and/or adhesion of foulants. They reasoned that not all of the foulants being transported to the surface adhered to the deposit structure. They postulated a 'sticking probability', S, which is proportional to the adhesive force and inversely proportional to the hydrodynamic forces at the interface. The deposition rate was formulated to be proportional to the product of the mass flux normal to the surface and the 'sticking probability'. The mass flux, J, is defined as

$$J = k_m (C_b' - C_s') \tag{2-12}$$

where k_m = convective mass transfer coefficient

C_s' = concentration of foulant at the interface

Assuming a removal term similar to that postulated by Kern and Seaton, the change of deposit thickness with time is then

$$\frac{dX_\theta}{d\theta} = K_3 JS - K_4 \gamma X_\theta \tag{2-13}$$

where K_3, K_4 = proportionality constants

HEAT TRANSFER RESEARCH INC. MODEL [22]

Extending the idea of Kern and Seaton, Heat Transfer Research Inc. (HTRI) further refined the deposition-removal concept. First of all, it was assumed that the deposition mechanism is reaction rate controlling. Also a 'water characteristic factor' was introduced to account for the water quality effect. In addition, the probable

effect of the residence time of potential foulants as a probability function of velocity was considered. Expressing the deposition rate in an Arrhenius type equation, the deposition term was formulated as

$$\phi_d = K_5 Pd\ (\Omega)^n \exp\ (-E_a/R_g\ T_s) \qquad (2\text{-}14)$$

where Pd = probability function

Ω = water characteristic factor

E_a = activation energy of deposit

R_g = gas constant

T_s = surface temperature

K_5 = proportionality constant

n = dimensionless empirical constant

The removal rate was postulated as a function of shear stress, scale thickness and the bonding strength of the deposit.

$$\phi_r = K_6 \frac{\tau}{\psi} \left(\frac{X_\theta}{k_f}\right)^q \qquad (2\text{-}15)$$

where ψ = deposit bonding strength factor

q = dimensionless empirical constant

Therefore, the resulting differential equation is

$$\frac{dR_f}{d\theta} = K_5 Pd\ (\Omega)^n \exp\ (-E_a/R_g\ T_s) - K_6 \frac{\tau}{\psi} \left(\frac{X_\theta}{k_f}\right)^q \qquad (2\text{-}16)$$

If q = 1, the solution to Eq. (2-16) assumes the form of Eq. (2-9) which predicts asymptotic fouling behavior.

For the above model, it was reported that the standard deviation for the ratio of experimental value to the predicted value of fouling factor is 40%.

WATKINSON - MARTINEZ MODEL [27]

Watkinson and Martinez studied the deposition of calcium carbonate at constant tube wall temperature. They modified the HTRI model by introducing the concept of Reitzer [18] who proposed that the super-solubility of foulant is one of the important driving forces for deposition. The resulting expression is

$$\frac{dX_\theta}{d\theta} = K_7 \exp\left(-\frac{E_a}{R_g T_s}\right)\left(\frac{T_w - T_b}{1 + hX_\theta/k_f}\right)^m - K_8 \tau X_\theta \qquad (2\text{-}17)$$

where T_w = tube wall temperature

T_b = bulk temperature

K_7, K_8 = proportionality constants

m = dimensionless empirical constant

The major difference of Eq. (2-17) from other models is that the deposition term is a time dependent function.

Setting $dX_\theta/d\theta = 0$ at the asymptote and $\tau = fv^2\rho_w/2$ yields

$$R_f^* (1 + hR_f^*)^m = K_9 \exp\left[\frac{-E_a}{R_g\left(T_b^* + \frac{(T_w - T_b)}{1 + hR_f^*}\right)}\right]\frac{(T_w - T_b)^m}{fv^2} \qquad (2\text{-}18)$$

where f = friction factor

v = flow velocity

and superscript * refers to the asymptotic condition.

Eq. (2-18) predicts a maximum asymptotic fouling resistance as T_b^* increases and it was confirmed by the results of these workers.

OTHER MODELS

A number of investigators did not consider a removal mechanism in their analysis.

McCabe and Robinson [13] proposed that

$$\frac{d(1/U)}{d\theta} = K_{10}U \tag{2-19}$$

and the solution to Eq. (2-19) yields

$$R_f = \frac{1}{U_i}\left(1 + K_{11}U_i^2\theta\right)^{\frac{1}{2}} - 1 \tag{2-20}$$

where U_i = initial clean overall heat transfer coefficient

Eq. (2-20) predicts that the asymptotic fouling resistance increased indefinitely with time.

Reitzer [18] proposed that the deposition rate of inverse solubility salts is a function of the supersaturation of foulant in the laminar layer.

$$\phi_d = k_r (C_b - C_s)^P/\rho_f \tag{2-21}$$

where k_r = reaction rate constant

C_b = bulk foulant concentration

C_s = fouland concentration at the interface

ρ_f = density of fouling deposit

P = dimensionless empirical constant

The reaction rate constant k_r was assumed to be constant.

Hasson and co-workers [5] investigated the deposition of calcium carbonate at Reynolds numbers ranging from 13000 to 42000 and concluded that the deposition rate is mass diffusion rate controlling.

III. EXPERIMENTAL EQUIPMENT

The equipment of this study was designed to simulate the operating conditions of a cooling tower system. Major parts of the structure were built and used by previous investigators [15,20] at Oregon State University. However, the system has been modified to accomodate two new test sections and a heating unit has been incorporated in order to control the bulk temperature at 95°F.

Important variables such as flow rate and the temperature of the heated surface are readily adjustable to a desired level so that the effect of each on the deposition characteristics can be determined.

The principal components of the apparatus include (1) cooling tower system, (2) heat exchanger system, (3) Heat Transfer Research Inc. Portable Fouling Research Units (PFRU-I and PFRU-II). Auxiliary equipment includes piping, valves and pumps. Figure 1 shows a schematic flow diagram of the experimental equipment.

PIPING, VALVES AND PUMPS

To eliminate the effect of corrosion on the deposition characteristics as much as possible, non-corrosive materials are used. Therefore, equipment in direct contact with cooling water is either of polyvinylchloride (PVC), chlorinated polyvinylchloride (CPVC), brass or stainless steel.

The piping is mostly 1" and 1½" CPVC, schedule 80, using socket type fittings. PVC piping is used for low temperatue and low pressure applications whereas CPVC piping is used for high temperature and high pressure applications.

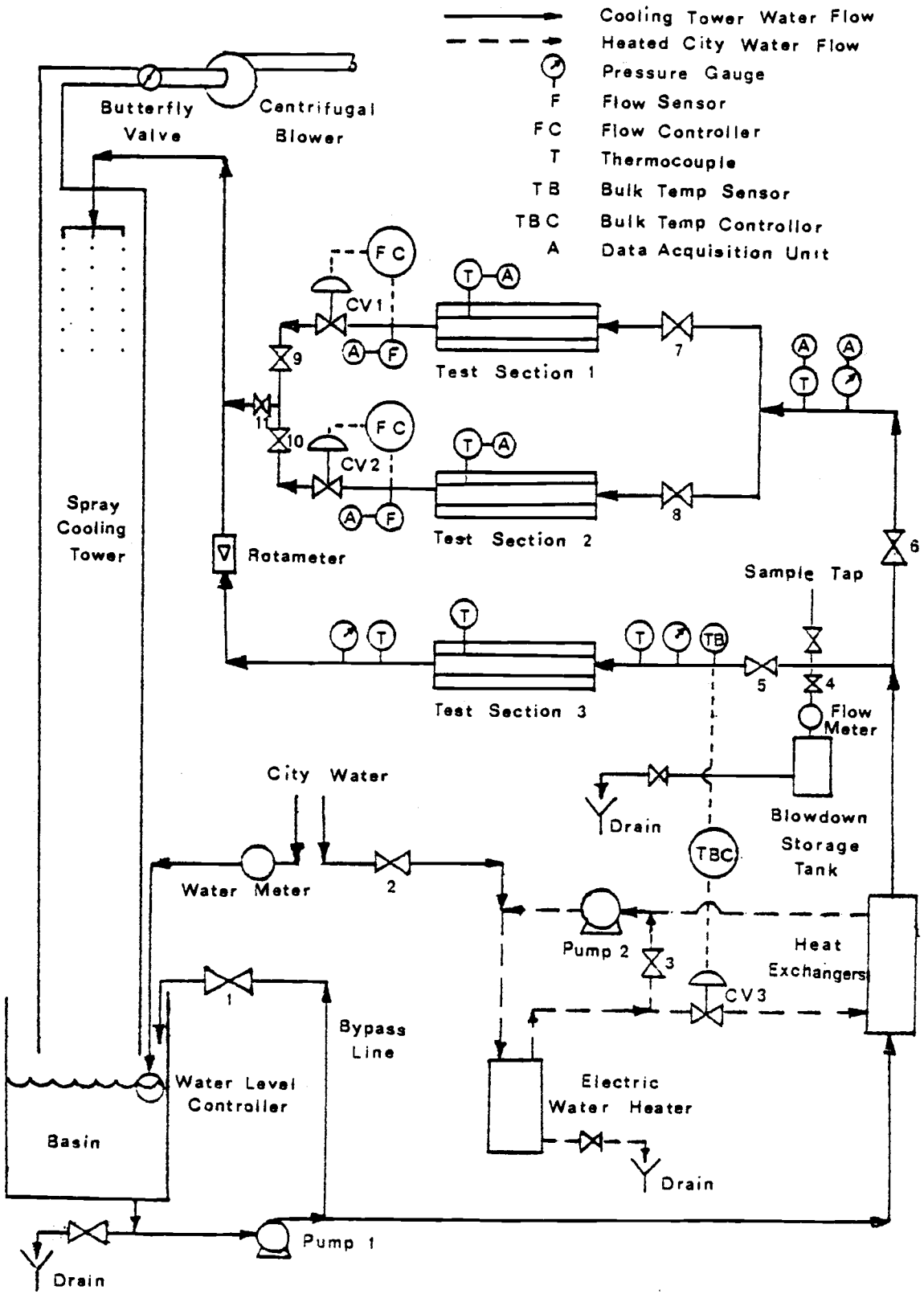


FIGURE 1 SCHEMATIC FLOW DIAGRAM OF EXPERIMENTAL EQUIPMENT

A selected number of valves are labelled in Figure 1. Values 1 through 11 are manually operated valves whereas control valves CV1, CV2 and CV3 are pneumatically operated (output ranging from 3 to 15 psi). Except for valves 2, 3 and CV3, all the other valves are in the cooling tower water circulating loop.

Valves 1, 2, 5 and control valves CV1 and CV2 are constructed of stainless steel, control valve CV3 of cast steel, valves 3 and 4 of brass and valves 6 through 11 of CPVC.

Valve 1 along the bypass line regulates the total flow through the cooling tower water circulating loop. Valve 2 is always open to permit continuous city water supply pressure to be applied to the electric water heater. Valve 3 is partially open for a bypass of heated water if CV3 is closed. Valve 4 is used to control the blowdown rate. Valves 5 through 11 regulate the cooling tower water in and out of the test sections. Control valves CV1 and CV2 control the cooling tower water flow rate through test sections 1 and 2, whereas CV3 controls the heated water flow from the electric water heater to the heat exchangers.

In addition, a butterfly valve which is located along the exhaust air conduit on top of the spray cooling tower regulates the air flow through the tower.

Two pumps are needed. Pump 1, a brass turbine pump, is driven by a 3 HP electric motor at a speed of 1750 rpm. It has a total pumping capacity of approximately 16 gpm. Pump 2, a rotary centrifugal pump, is also equipped with a 3 HP motor. It circulates the heated water in the heat exchanger system. A centrifugal blower with a 3/4 HP

electric motor at a speed of 1725 rpm next to the butterfly valve draws air through the tower.

COOLING TOWER SYSTEM

The cooling tower system consists of 3 major parts: (1) basin, (2) spray cooling tower, (3) blowdown unit.

Fresh water is supplied continuously to the basin to make up for evaporation and blowdown losses. Cooling water is circulated through the system, absorbing heat from heat exchangers and heater rods and being cooled in the spray cooling tower. Blowdown flow rate is manually adjusted on a regular basis to maintain constant composition of the cooling tower water.

BASIN

The basin is a stainless steel cylindrical tank 4 feet high, 34 inches in diameter and 1/8 inch in thickness. It serves as a cooling tower water supply tank.

Inlet streams to the basin consists of (1) city water, (2) water from the spray cooling tower, (3) cooling tower water recycling from the bypass line. The well mixed cooling tower water is drawn out of the basin by Pump 1; part of the water circulates through the system and part of it recycles back to the basin, creating a stirring motion for the mixing of the inlet streams. The amount of city water input is indicated by a positive displacement water meter.

The basin is filled to a depth of 34 inches, the level of which is controlled by a liquid level controller (Model 100 of Fluid Master Inc.) sensitive to a water level change of 3/4 inch. The total

volume of cooling tower water in the system is about 135 gallons.

SPRAY COOLING TOWER

The spray cooling tower is a 20 foot long cylindrical column 2 feet in diameter made of 3/16 inch thick fiber glass reinforced plastic. It is mounted directly above the basin concentrically with the basin.

Warm cooling tower water from the system divides into 4 smaller streams at the top of the tower through four ½ inch outlets beneath which is a distributor. Water falls through the tower in droplets, increasing the air-liquid contacting surface area. Fresh air is drawn countercurrent to the falling droplets.

BLOWDOWN UNIT

As the cooling tower water evaporates, the concentration of mineral constituents increases due to the input from city water which is continuously fed into the system to make up for the evaporation loss. In order to maintain a constant cooling tower water quality, an amount has to be purged from the system at a rate which balances the input from city water.

For the present study, a blowdown rate of slightly more than 2 l/hr was maintained by a two-foot section of capilliary glass tubing inserted along the purge line. A flowmeter shows the approximate blowdown rate. Discharged cooling tower water is stored in the blowdown storage tank and the total volume discharged is recorded daily.

HEAT EXCHANGER SYSTEM

In the present work, the cooling tower water was maintained at $95^{o}F$ for all runs. Since the heat from test sections is not sufficient to maintain this temperature, an additional heat source is needed.

The heat exchanger system is a closed loop circulating system. City water, heated in a 40 gallon domestic electric water heater, is pumped to the sheel side of two shell and tube (stainless steel shell and teflon tube) heat exchangers, concurrent with the flow in the tube side. A temperature controller (set point at $95^{o}F$) regulates the heated water flow rate through the heat exchangers. A bypass line is provided to allow some flow even if the control valve CV3 is closed completely.

HTRI PORTABLE FOULING RESEARCH UNITS

The Portable Fouling Research Unit (PFRU) developed by HTRI was specially designed to provide a convenient means for cooling tower water fouling studies. One such unit is on loan to Oregon State University. This unit, PRFU-I, houses test section 3. PRFU-II was donated to Oregon State University and was incorporated into the system in December 1976. It houses test section 1 and test section 2. The basic differences between the two models are that model II provides an additional automatic data acquisition system and flow rate control mechanism.

The critical component of the PFRU is the test section where the heater rod on which fouling occurs is located. For visual observation, a glass tube 18 3/4 inches long and 3/4 inch in inside diameter is

mounted horizontally with a cylindrical plexiglass housing around it for protection. A heater which normally has an outside diameter between 0.45 inch and 0.375 inch is inserted concentric to the glass tube section. Test fluid flows axially through the annular space between the heater rod and the glass tube.

Heater rods were supplied by HTRI. Both stainless steel and copper plated rods were used. Figure 2 shows a schematic diagram of a heater rod. An internal electric heater is embedded in a 4.0 $\pm$ 0.2 inches long heated section as a means of obtaining a desired heat flux.

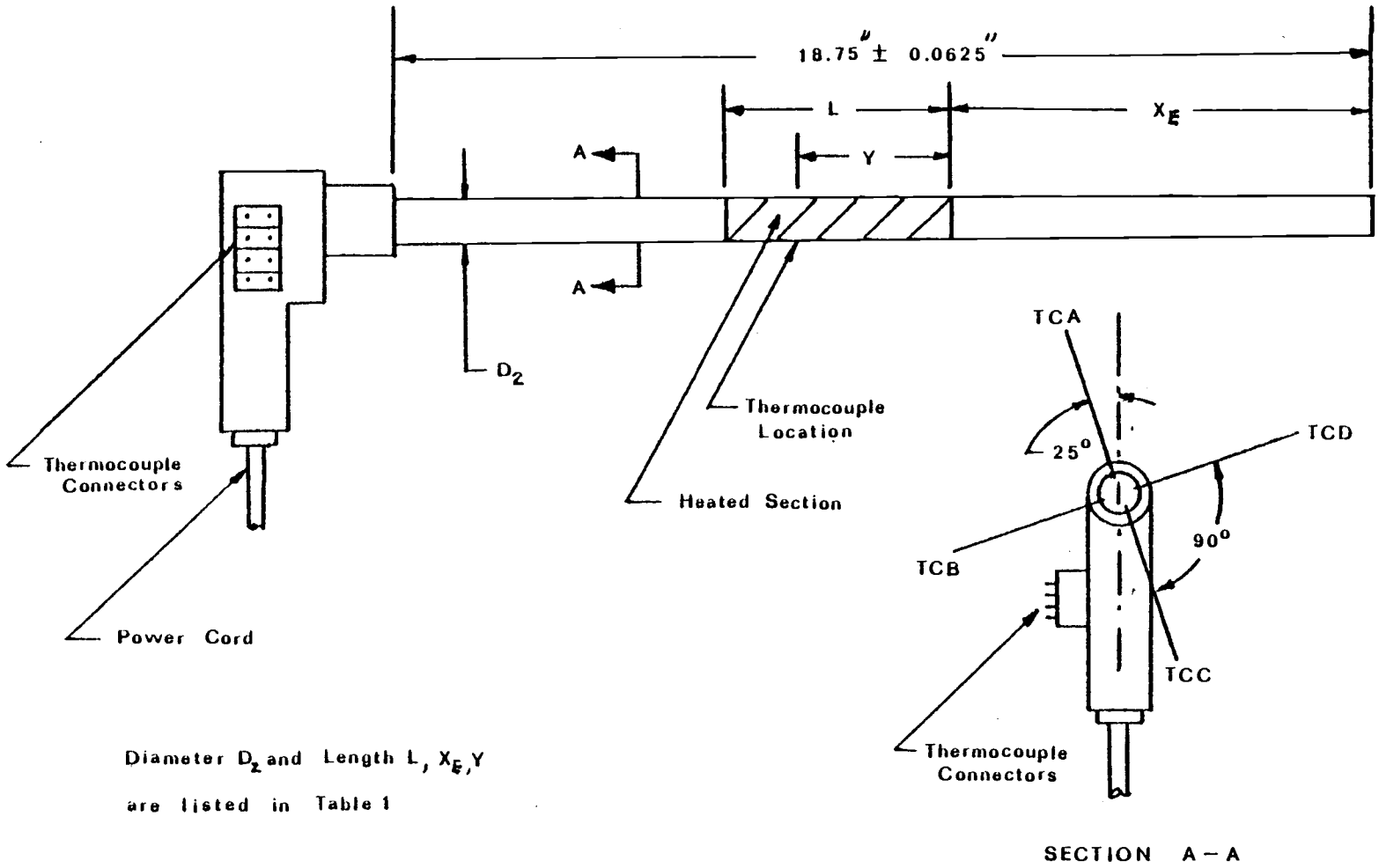
Four chromel-constantan (Type E) thermocouples TCA, TCB, TCC and TCD are located underneath the heated surface to measure the wall temperatures at four different locations.

Figure 2 also shows the relative location of the heated section and wall thermocouples.

The electric power input to the heater rod is regulated by a W10 Vanac transformer.

A chromel-constantan thermocouple (Type E) is also placed at the inlet and outlet of test section 3. A temperature reference junction of $0^{o}C$ is used and the various thermocouple outputs are displayed on a Digitec digital millivolt meter by means of a thermocouple selector switch.

Test sections 1 and 2, however, are not equipped with a thermocouple at the outlet. The temperature reference juction for these two sections is set at $150^{o}F$. In addition to the thermocouple signals, the values of flow rate, pressure and power input are also transformed to millivolt output to be displayed on the digital



Diameter D_2 and Length L, X_E, Y are listed in Table 1

FIGURE 2 HEATER ROD — HEATED SECTION AND THERMOCOUPLE LOCATIONS

millivolt meter. Moreover, an automatic printer which can be programmed to print data at a desired interval (1, 5, 10, 30 or 60 minutes) constitutes part of the data acquisition system.

In order to prevent the heater from overheating when the flow stops inadvertently or because of pump failure, a high temperature cutoff mechanism is provided. Maximum wall temperature is set at $350^{o}F$ for test section 1 and $750^{o}F$ for test sections 1 and 2.

Specifications for all the heater rods used are listed in Table 1. The thermal resistance between the imbedded thermocouple and the metal surface, x/k, is determined by using the Wilson plot [28]. The calibrated value of each thermocouple location of a heater rod is provided by HTRI and the reciprocal, k/x, is also listed in Table 1.

Calibration equations for heat flux, flow rate and temperatures are given in Appendix B.

TABLE 1. HTRI HEATER ROD SPECIFICATIONS

Heater rod identification number		111	164	167	169
Rod material		copper plated stainless steel	stainless steel	stainless steel	copper plated stainless steel
Heater rod outside diameter D_2 (inch)		0.428	0.424	0.423	0.435
Heated section length L (inch)		3.90	4.04	3.90	3.95
Entrance length X_E (inch)		9.33	8.56	8.58	8.60
Distance Y (inch)		3.0	3.0	3.0	3.0
k/x (Btu/ft^2-hr-^0F)	TCA	15044	4374	4397	5081
	TCB	134143	4757	3331	5705
	TCC	498811	8611	4864	3840
	TCD	200069	8850	6547	5694

IV. EXPERIMENTAL PROCEDURES

EXPERIMENTAL PROGRAM

The first run was started on November 7, 1976. It was planned to study the effect of velocity on the deposition characteristics of the cooling tower. In order to raise the bulk temperature to 95°F, the heat exchanger system was initiated after November 17, 1976.

At a flow rate of 5 gpm, deposition of foulants started when calcium hardness reached 150 ppm as $CaCO_3$, the concentration of which was about 5 times that of the make-up city water. The calcium hardness was controlled at that level for all runs although deposition other than the anticipated calcium carbonate was found after Run 3.

Because of this change in deposit properties, the experimental program was modified to study the surface temperature effects and consequently the flow was maintained at 5 gpm.

A total of 24 runs were conducted, the chronology and general information for which are tabulated in Table 2.

RUN INITIATION

The water was circulated through the system after the basin had been filled. The centrifugal blower was turned on and the heat exchanger system was activated. Power input to the heater rod was then adjusted to give a desired surface temperature. When the calcium hardness reached 150 ppm as $CaCO_3$, the blowdown unit was started. When no water quality change occurred between runs no interruption in the blowdown rate was needed.

TABLE 2. CHRONOLOGY AND GENERAL INFORMATION OF RUNS

Run	Starting Date	Completion Date	Duration (days)	Test Section	Heater Rod	Remarks
1	11-07-76	12-16-76	39	3	167	
2	12-16-76	2-17-77	63	3	169	
3	1-05-77	2-02-77	28	2	167	
4	1-11-77	2-19-77	39	1	164	
5	2-02-77	2-17-77	15	2	167	
6	2-17-77	3-15-77	26	3	169	Continuation of Run 2; heat flux increased
7	2-19-77	2-26-77	7	1	111	
8	2-17-77	2-26-77	9	2	167	Continuation of Run 5; heat flux increased
9	2-26-77	3-06-77	8	1	111	Continuation of Run 7; heat flux increased
10	2-26-77	3-06-77	8	2	167	Continuation of Run 8; heat flux increased
11	3-06-77	3-15-77	9	1	111	Continuation of Run 9; heat flux increased
12	3-06-77	3-15-77	9	2	167	Continuation of Run 10; heat flux increased

CONTINUED

TABLE 2. CHRONOLOGY AND GENERAL INFORMATION ON RUNS CONTINUED

Run	Starting Date	Completion Date	Duration (days)	Test Section	Heater Rod	Remarks
13	3-15-77	4-13-77	29	1	111	Continuation of Run 11; heat flux increased
14	3-15-77	4-13-77	29	2	167	Continuation of Run 12; heat flux increased
15	3-15-77	5-04-77	50	3	164	
16	4-13-77	5-04-77	21	1	111	Continuation of Run 13; heat flux increased
17	4-13-77	5-04-77	21	2	167	Continuation of Run 14; heat flux increased
18	5-04-77	6-06-77	33	1	111	Continuation of Run 16; heat flux increased
19	5-04-77	6-06-77	33	2	167	Continuation of Run 17; heat flux increased
20	5-04-77	5-17-77	13	3	169	
21	5-17-77	5-28-77	11	3	169	Continuation of Run 20; heat flux increased
22	5-28-77	7-25-77	58	3	169	Continuation of Run 21; heat flux increased
23	6-08-77	7-05-77	27	1	111	
24	6-13-77	7-05-77	22	2	167	

DATA ACQUISITION AND DATA PROCESSING

For test section 3, data were recorded 3 times a day manually. Data for test sections 1 and 2, were printed automatically in sixty-minute intervals. Raw data for all 24 runs are listed in Appendix C. Selected data were processed by the computer daily.

PROCESS MONITORING

Occasionally adjustment of an offset up to 2% of the power input and flow rate was needed.

One-liter sample of cooling tower water was analysed daily. Constituents determined included total hardness (TH), calcium hardness (CaH), methyl orange alkalinity (m-alkalinity), phenophthalein alkalinity (p-alkalinity), chloride (Cl), silica(Si), total solids (TS), conductivity and pH. Chemical analysis procedures are given in Appendix D. The results are listed and plotted on a monthly basis as shown in Appendix E.

In addition, several cooling tower water samples were analysed by commercial laboratories and the results are also listed in Appendix E.

The city water quality was checked daily for any sudden change. Because of the fact that the quality was relatively constant, only two sets of data in a month are listed in Appendix F.

The blowdown rate was manually controlled to maintain constant compositions. Assuming no loss of mist from the tower, a mass balance on calcium yields

$$Bd = Ev/(Cy - 1) \qquad (4\text{-}1)$$

where Bd = blowdown rate

Ev = evaporation rate

Cy = cycle of concentration

$$= \frac{\text{calcium hardness in cooling tower water}}{\text{calcium hardness in city water}}$$

But since the evaporation rate and the city water quality changed constantly, Eq. (4-1) was hardly used to determine the blowdown rate. It was set according to the daily chemical analysis information on calcium hardness which was pre-selected to be 150 ppm as $CaCO_3$. The result was found to be satisfactory. Appendix G shows a monthly plot of blowdown rate and evaporation rate.

To eliminate the possible effect of biofouling, a daily injection of 100 ml of commercial bleach proved to be effective to prevent any bacteria growth. The biogrowth data prior to the injection of bleach are shown in Appendix E.

RUN TERMINATION

A run was terminated when the fouling factor approached its asymptotic value, or in some cases when no apparent deposition occurred after a reasonably long period (at least one week). For the latter case, the heater rod was usually left untouched in the test section and was used again for the next run.

The deposit on a stainless steel heater rod was scraped off carefully and the rod was then polished by a grade ØØ steel wool. For the copper plated heater rod, it was cleaned by using concentrated hydrochloric acid. The chemical composition of deposits were analysed by Nalco Chemical Company.

V. CALCULATION PROCEDURES

INITIAL CONDITIONS CALCULATIONS

LOCAL BULK TEMPERATURE

Assuming that the bulk temperature increases linearly along the heated section in the direction of the flow, the local bulk temperature, T_b, of test section 3 is given by

$$T_b = (T_{outlet} - T_{inlet}) \times (Y/L) + T_{inlet} \qquad (5\text{-}1)$$

where T_{outlet} = outlet temperature, ^oF

T_{inlet} = inlet temperature, ^oF

Y = distance of thermocouples downstream of the heated section, inch

L = total length of the heated section, inch

Since the outlet temperature is not available for test sections 1 and 2, a simple energy balance gives

$$T_b = \frac{(Q/A)(D_2/12)(Y/12)\pi}{\rho\, C_p\, W_F} + T_{inlet} \qquad (5\text{-}2)$$

where D_2 = outside diameter of the heated section, inch

ρ = density of cooling water, lbm/ft^3

C_p = heat capacity of cooling water, $Btu/lbm\text{-}^oF$

W_F = volumetric flow rate, ft^3/hr

LOCAL SURFACE TEMPERATURE

For a constant heat flux, bulk temperature and flow rate process, the local surface temperature can be calculated by

$$T_{s_i} = T_{w_i} - (Q/A)\,(X/k) \qquad (5\text{-}3)$$

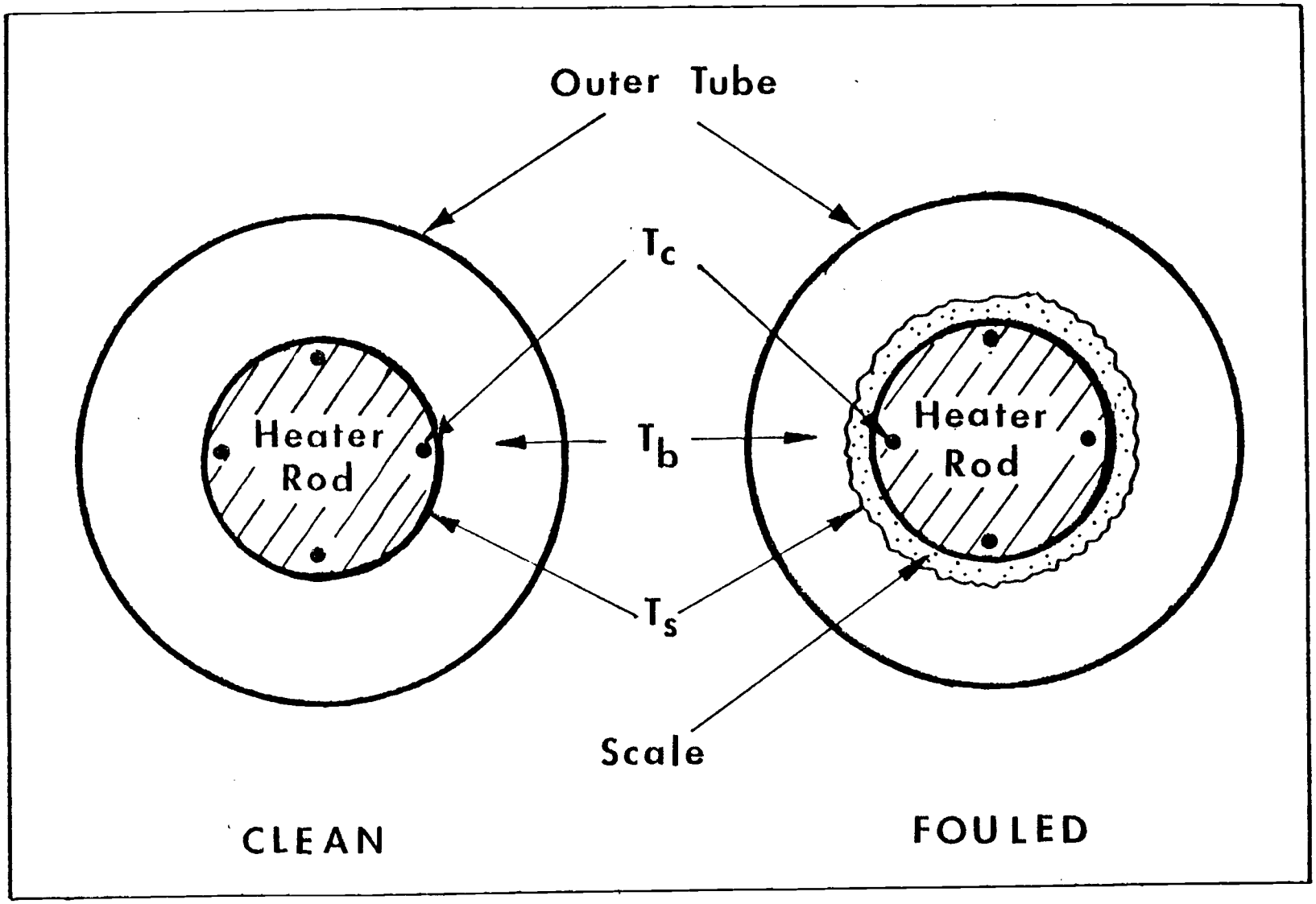


FIGURE 3 CROSS SECTION OF TEST SECTION — CLEAN AND FOULED CONDITIONS

where x/k = thermal resistance of tube material, ft^2-hr-^oF/Btu

T_w = wall temperature, ^oF

and subscript i denotes the initial conditions.

LOCAL FILM COEFFICIENT

The local heat transfer film coefficient of cooling water h_i is calculated by

$$h_i = (Q/A)/(T_{s_i} - T_b) \tag{5-4}$$

The local film coefficient is also related to the flow velocity as

$$h_i = K_i \, v_i^{\,r} \tag{5-5}$$

where v = flow velocity ft/hr

K = proportionality constant

r = 0.7 if v > 4 ft/sec

= 0.93 otherwise

and subscript i denotes initial conditions.

An average of the ratio $h_i/v_i^{\,r}$ of at least ten data points in the beginning of each run gives K_{avg},

$$K_{avg} = \sum_{j=1} h_{ij}/v_{ij}^{\,r} \tag{5-6}$$

This average remains constant during the run if flow rate and bulk temperature remains unchanged.

FOULING CONDITION CALCULATIONS

Local bulk temperature is calculated by using Eq. (5-1) or Eq. (5-2).

For a given velocity, the local film coefficient is given by

$$h = K_{avg}\, v^{r} \tag{5-7}$$

The local surface temperature can then be calculated by

$$T_s = (Q/A)/h + T_b \tag{5-8}$$

Finally, the local fouling resistance, R_f, is calculated by

$$R_f = (T_w - T_s)/(Q/A) - x/k \tag{5-9}$$

A sample calculation is outlined in Appendix H.

COMPUTER PROGRAMS

All of the calculations were done by computer at the Oregon State University Computer Center using the OS3 system. Programs were written in Fortran IV language. Computer program FR is for the calculation of the ratio h_i/v_i^r in the beginning of a run. Computer program FRPLOT is for the plotting of fouling resistance vs time. These two main programs and all the subroutines and functions are listed in Appendix I. The results are shown in Appendix J and the fouling resistance vs time plots are given in Appendix K.

ERROR ESTIMATION

As mentioned in previous chapters, the data aquisition system and calculation procedures for surface temperatures and fouling resistances for test section 3 is different from test sections 1 and 2. As a result, different equations for the error estimation of fouling resistances and surface temperatures are needed. The calibration equations for power input, flow rate and temperature can be found in Appendix B.

Error estimation for test section 3

Differentiation of Eq. (5-1) yields

$$dT_{b_i} = (Y/L)d(T_{outlet} - T_{inlet}) + \frac{(T_{outlet} - T_{inlet})dY}{L}$$

$$- \frac{(T_{outlet} - T_{inlet})YdL}{L^2} + dT_{inlet} \qquad (5\text{-}10)$$

Combining Eq. (5-1) and Eq. (5-10), the maximum relative error of T_{b_i} is

$$\frac{dT_{b_i}}{T_{b_i}} = \frac{T_{outlet}\ Y}{Z_1}\frac{dT_{outlet}}{T_{outlet}} \pm \frac{Y(T_{outlet} - T_{inlet})}{Z_1}\frac{dY}{Y}$$

$$\pm \frac{Y(T_{outlet} - T_{inlet})}{Z_1}\frac{dL}{L} \pm \frac{(L \pm Y)\ T_{inlet}}{Z_1}\frac{dT_{inlet}}{T_{inlet}} \qquad (5\text{-}11)$$

where

$$Z_1 = (T_{outlet} - T_{inlet})\ Y - T_{inlet}\ L \qquad (5\text{-}12)$$

Similarly, from Eq. (5-3) and Eq. (5-4)

$$\frac{dT_{s_i}}{T_{s_i}} = \frac{(k/x)T_{w_i}}{Z_2}\frac{dT_{w_i}}{T_{w_i}} \pm \frac{(Q/A)_i}{Z_2}\frac{d(Q/A)_i}{(Q/A)_i} \pm \frac{(Q/A)_i}{Z_2}\frac{d(k/x)}{(k/x)} \qquad (5\text{-}13)$$

$$\frac{dh_i}{h_i} = \frac{d(Q/A)_i}{(Q/A)_i} \pm \frac{T_{s_i}}{(T_{s_i} - T_{b_i})}\frac{dT_{s_i}}{T_{s_i}} \pm \frac{T_{b_i}}{(T_{s_i} - T_{b_i})}\frac{dT_{b_i}}{T_{b_i}} \qquad (5\text{-}14)$$

where

$$Z_2 = T_{w_i}\ (k/x) - (Q/A)_i \qquad (5\text{-}15)$$

$$\frac{d(Q/A)_i}{(Q/A)_i} = \frac{dQ}{Q} \pm \frac{dD_2}{D_2} \pm \frac{dL}{L} \qquad (5\text{-}16)$$

The relative errors of T_{inlet}, T_{outlet} and T_{w_i} can be calculated by the following general equations

$$\frac{dT}{T} = \frac{0.949\ dTC}{(TC + 0.979)} \qquad TC < 3.041 \tag{5-17}$$

$$\frac{dT}{T} + \frac{0.8765\ dTC}{(TC + 0.679)} \qquad TC \geq 3.041 \tag{5-18}$$

where TC = thermocouple output in millivolt

From Eq. (5-8),

$$\frac{dT_s}{T_s} = \frac{(Q/A)}{Z_3}\frac{d(Q/A)}{(Q/A)} \pm \frac{(Q/A)}{Z_3}\frac{dh}{h} \pm \frac{hT_b}{Z_3}\frac{dT_b}{T_b} \tag{5-19}$$

where $Z_3 = (Q/A) + hT_b$ (5-20)

Since the bulk temperature, flow velocity and heat flux are relatively constant during a run,

$$\frac{d(Q/A)}{(Q/A)} \doteq \frac{d(Q/A)_i}{(Q/A)_i} \tag{5-21a}$$

$$\frac{dT_b}{T_b} \doteq \frac{dT_{b_i}}{T_{b_i}} \tag{5-21b}$$

$$\frac{dh}{h} \doteq \frac{dh_i}{h_i} \tag{5-21c}$$

Therefore Eq. (5-19) becomes

$$\frac{dT_s}{T_s} = \frac{(Q/A)}{Z_3}\frac{d(Q/A)_i}{(Q/A)_i} \pm \frac{(Q/A)}{Z_3}\frac{dh_i}{h_i} \pm \frac{hT_b}{Z_3}\frac{dT_{b_i}}{T_{b_i}} \tag{5-22}$$

Setting appropriate errors to each measured variable

$dQ = \pm 2$ watts

$dD_2 = \pm 0.0005$ inch

$dL = \pm 0.005$ inch

$dY = \pm 0.005$ inch

$$dTC = \pm 0.005 \text{ millivolts}$$

$$d(k/x) = \pm 50 \text{ Btu/ft}^2\text{-hr-}^\circ\text{F}$$

the numerical value of the maximum relative error of the surface temperature can be calculated by Eq. (5-22).

From Eq. (5-9), the maximum relative error of fouling resistance is

$$\frac{dR_f}{R_f} = \frac{(k/x)T_w}{Z_4}\frac{dT_w}{T_w} \pm \frac{(k/x)T_s}{Z_4}\frac{dT_s}{T_s} \pm \frac{(k/x)(T_w - T_s)}{Z_4}\frac{d(Q/A)_i}{(Q/A)_i} \pm \frac{(Q/A)}{Z_4}\frac{d(k/x)}{(k/x)} \tag{5-23}$$

where

$$Z_4 = (k/x)(T_w - T_s) - (Q/A) \tag{5-24}$$

and dT_w/T_w can be calculated by either Eq. (5-17) or Eq. (5-18).

Error Estimation For Test Sections 1 And 2

From Eq. (5-2), the relative error of bulk temperature is

$$\frac{dT_{b_i}}{T_{b_i}} = Z_5\frac{d(Q/A)_i}{(Q/A)_i} \pm Z_5\frac{dD_2}{D_2} \pm Z_5\frac{dY}{Y} \pm Z_5\frac{dW_F}{W_F} \pm \frac{Z_5 W_F T_{inlet}}{Z_6 D_2 Y (Q/A)_i}\frac{dT_{inlet}}{T_{inlet}} \tag{5-25}$$

where

$$Z_5 = \frac{K_{14} D_2 Y (Q/A)_i}{K_{14} D_2 Y (Q/A)_i + T_{inlet} W_F} \tag{5-26}$$

$$K_{14} = \frac{\tilde{\pi}}{144 \rho C_p} \tag{5-27}$$

$$\frac{dW_F}{W_F} = 0.5\frac{dW_{mv}}{W_{mv}} \tag{5-28}$$

and W_{mv} = flow transducer output in millivolt

The equations for computing the relative errors of other variables are identical to Eq. (5-13) through Eq. (5-24). However the relative errors for T_{inlet}, T_{w_i} and T_w are calculated by the following equations

$$\frac{dT}{T} = \frac{0.949\ dTC}{(TC + 5.02)} \qquad TC < -1.0 \tag{5-29}$$

$$\frac{dT}{T} = \frac{0.8765\ dTC}{(TC + 0.8765)} \qquad TC \geq -1.0 \tag{5-30}$$

and the relative error of power input is

$$\frac{dQ}{Q} = \frac{dQ_{mv}}{Q_{mv}} \tag{5-31}$$

where Q_{mv} = power transducer output in millivolt

and $dQ = \pm 0.005$ mv

A sample calculation for error estimation is shown in Appendix H.

VI. RESULTS AND DISCUSSION

OPERATING CONDITIONS

A total number of 24 runs were conducted. The bulk water temperature was maintained at 95 $\pm$ 1^{o}F. The flow velocity was regulated at 5.3 $\pm$ 0.1 ft/sec (N_{Re} = 26,000) except for Runs 4, 23 and 24 for which the velocity was 2.5 ft/sec (N_{Re} = 12,000), 12.4 ft/sec (N_{Re} = 60,000) and 4.6 ft/sec (N_{Re} = 22,000) respectively. The heat flux varied from 15,000 to 115,000 Btu/hr-ft^2, resulting in a range of surface temperature from 100^{o}F to 165^{o}F. The operating conditions are summarized in Tables 3A, 3B, and 3C for test sections 1, 2 and 3 respectively.

The calcium hardness was maintained constant at 150 ppm as $CaCO_3$, the value at which deposition started in Run 1. The total hardness was relatively constant at 225 $\pm$ 15 ppm as $CaCO_3$. Other water parameters varied over the duration of the investigation. The pH increased slightly from 8.9 to 9.2. The silica concentration increased from an average of 100 ppm as SiO_2 in February (not determined prior to this month) to 135 ppm as SiO_2 in July. Total solids changed from an initial value of 367 ppm to 824 ppm in July. More importantly, methyl orange alkalinity (m-alkalinity) increased from an initial value of 150 to 267 ppm as $CaCO_3$ in June.

The average cooling tower water quality for each run is listed in Table 4. The corresponding Langelier Saturation Index (LSI) and Ryznar Stability Index (RSI) are also included. The monthly average of cooling tower water quality and city water quality is given in Appendix E and Appendix F respectively.

TABLE 3A. AVERAGE OPERATING CONDITIONS - TEST SECTION 1

Run	Velocity (ft/sec)	Heat flux (Btu/hr/ ft^2)	Bulk temperature (^oF)	Surface temperature (^oF)				Heater rod	Remarks
				TCA	TCB	TCC	TCD		
4	2.50 (0.03)	40240 (129)	95.0 (0.43)	150.8 (0.69)	146.2 (0.65)	145.9 (0.66)	---	164-SS	
7	5.38 (0.01)	15420 (88)	94.5 (0.39)	104.4 (0.42)	104.8 (0.39)	104.9 (0.46)	104.6 (0.42)	111-Cu	
9	5.38 (0.01)	32870 (111)	94.6 (0.39)	115.4 (0.40)	116.2 (0.40)	116.8 (0.39)	116.1 (0.41)	111-Cu	
11	5.38 (0.01)	46890 (147)	94.8 (0.35)	123.7 (0.36)	124.9 (0.44)	125.9 (0.32)	124.4 (0.31)	111-Cu	
13	5.38 (0.01)	60960 (206)	94.8 (0.44)	136.1 (0.48)	137.6 (0.41)	139.4 (0.50)	136.9 (0.51)	111-Cu	No apparent effect on the deposit due to shut down
16	5.38 (0.01)	75050 (327)	95.0 (0.48)	145.3 (0.56)	147.0 (0.56)	149.6 (0.58)	146.7 (0.55)	111-Cu	
18	5.38 (0.02)	93800 (624)	95.0 (0.66)	157.6 (0.82)	159.5 (0.93)	163.1 (0.75)	159.9 (0.83)	111-Cu	Substantial drop in fouling resistance observed due to power failure
23	12.40 (0.03)	112730 (462)	95.0 (0.92)	134.8 (0.94)	134.1 (0.81)	137.0 (0.98)	136.1 (0.98)	111-Cu	

Notes: (1) Numbers in parenthesis are standard deviations.
(2) SS - stainless steel, Cu - copper plated.
(3) TCA, TCB, TCC and TCD represent thermocouples A, B, C and D respectively

TABLE 3B. AVERAGE OPERATING CONDITIONS - TEST SECTION 2

Run	Velocity (ft/sec)	Heat flux (Btu/hr-ft^2)	Bulk temperature (^oF)	Surface temperature (^oF)				Heater rod	Remarks
				TCA	TCB	TCC	TCD		
3	5.33 (0.02)	94750 (237)	94.6 (1.87)	155.3 (1.91)	141.8 (2.05)	139.7 (1.83)	153.4 (1.94)	167-SS	
5	5.33 (0.01)	15580 (184)	94.2 (0.38)	104.8 (0.41)	102.6 (0.42)	102.0 (0.38)	104.0 (0.40)	167-SS	
8	5.34 (0.01)	33200 (240)	94.7 (0.39)	116.2 (0.41)	112.0 (0.41)	111.1 (0.43)	115.0 (0.39)	167-SS	
10	5.34 (0.01)	47450 (453)	94.8 (0.39)	124.9 (0.42)	119.6 (0.40)	118.0 (0.40)	123.4 (0.41)	167-SS	
12	5.33 (0.01)	61520 (183)	95.0 (0.31)	132.7 (0.32)	126.6 (0.34)	124.4 (0.31)	131.3 (0.28)	167-SS	
14	5.33 (0.01)	75610 (162)	95.0 (0.42)	146.2 (0.46)	137.7 (0.40)	134.4 (0.45)	144.2 (0.51)	167-SS	No apparent effect on the deposit due to shut down
17	5.33 (0.01)	94620 (353)	95.2 (0.46)	158.7 (0.56)	148.2 (0.52)	144.1 (0.54)	156.6 (0.55)	167-SS	
19	5.32 (0.01)	104180 (857)	95.2 (0.54)	164.8 (0.84)	152.9 (0.82)	148.8 (0.69)	162.6 (0.87)	167-SS	Substantial drop in fouling resistance due to power failure
24	4.55 (0.21)	94840 (424)	95.6 (0.9)	159.2 (2.02)	148.0 (1.64)	145.4 (1.71)	157.1 (2.02)	167-SS	

Notes: (1) Numbers in parenthesis are standard deviations
(2) SS - stainless steel, Cu - copper plated
(3) TCA, TCB, TCC, TCD represent thermocouples A, B, C and D respectively

TABLE 3C. AVERAGE OPERATING CONDITIONS - TEST SECTION 3

Run	Velocity (ft/sec)	Heat flux (Btu/hr-ft^2)	Bulk temperature (^oF)	Surface temperature (^oF)				Heater rod	Remarks
				TCA	TCB	TCC	TCD		
1	5.32 (0.03)	94840 (408)	92.6 (1.66)	156.4 (1.68)	145.5 (1.67)	147.4 (1.67)	160.1 (1.69)	167-SS	Slight drop in fouling resistance observed when biocide (bleach) added
2	5.46 (0.06)	15030 (60)	93.3 (1.41)	103.8 (1.41)	103.7 (1.41)	105.7 (1.42)	105.6 (1.42)	169-Cu	
6	5.47 (0.01)	90950 (228)	94.7 (0.38)	154.0 (0.41)	151.1 (0.41)	158.8 (0.42)	161.3 (0.42)	169-Cu	
15	5.34 (0.02)	91280 (261)	94.6 (0.44)	152.8 (0.48)	153.3 (0.48)	153.1 (0.48)	---	164-SS	No apparent effect on deposit due to shut down for one week
20	5.47 (0.02)	50080 (256)	94.0 (0.62)	125.0 0.66	124.7 (0.66)	129.5 (0.67)	129.0 (0.67)	169-Cu	
21	5.47 (0.02)	59190 (89)	94.1 (0.52)	130.6 (0.55)	129.7 (0.55)	135.1 (0.55)	135.1 (0.55)	169-Cu	
22	5.47 (0.04)	68300 (91)	94.3 (0.64)	136.2 (0.70)	135.3 (0.70)	141.7 (0.71)	141.5 (0.71)	169-Cu	Substantial drop in fouling resistance due to power failure

Notes: (1) Numbers in parenthesis are standard deviations
(2) SS - stainless steel, Cu - copper plated
(3) TCA, TCB, TCC and TCD represent thermocouples A, B, C and D respectively

TABLE 4. AVERAGE COOLING TOWER WATER QUALITY, RUNS 1 - 24

Run	TH (ppm $CaCO_3$)	CaH (ppm $CaCO_3$)	m-alkalinity (ppm $CaCO_3$)	Cl (ppm NaCl)	Si (ppm SiO_2)		pH	TS (ppm)	LSI	RSI
					Std method[1]	Hack's method				
1*	205	150	150	90	---	---	8.9	417	1.58	5.74
2	212 (13.7)	150 (4.1)	211 (12.0)	202 (14.3)	88 3.5	---	8.89 (0.07)	556 (37)	1.72	5.54
3	214 (14.4)	151 (3.4)	216 (11.7)	205 (9.6)	---	---	8.9 (0.07)	564 (24)	1.76	5.38
4	220 (12.0)	152 (5.1)	218 (10.1)	211 (12.2)	88 (3.5)	---	8.86 (0.07)	575 (30)	1.71	5.44
5	222 (7.2)	152 (5.3)	215 (7.4)	217 (6.8)	88 (3.5)	---	8.82 (0.06)	588 (26)	1.66	5.50
6	219 (7.8)	152 (4.2)	190 (16.1)	243 (22.3)	75 (3.5)	---	8.97 (0.10)	613 (47)	1.76	5.45
7	217 (4.9)	151 (2.4)	199 (6.9)	216 (6.3)	75 (4.2)	---	8.90 (0.05	568 (25)	1.72	5.46
8	221 (9.3)	154 (5.5)	206 (15.1)	221 (10.1)	75 (4.2)	---	8.89 (0.05)	575 (35)	1.72	5.45
9,10	216 (8.3)	150 (2.7)	183 (8.9)	243 (16.3)	73 (3.0)	---	9.01 (0.10)	604 (32)	1.78	5.45
11,12	218 (5.6)	151 (3.3)	182 (10.9)	266 (8.8)	77 (2.6)	---	9.03 (0.07)	657 (28)	1.80	5.43
13,14	218 (7.8)	149 (6.1)	194 (8.5)	297 (15.9)	86 (3.5)	---	9.00 (0.04)	677 (22)	1.79	5.42

Continued

TABLE 4 (Continued) AVERAGE COOLING TOWER WATER QUALITY, RUNS 1 - 24

Run	TH (ppm $CaCO_3$)	CaH (ppm $CaCO_3$)	m-alkalinity (ppm $CaCo_3$)	Cl (ppm NaCl)	Si (ppm SiO_2)		pH	TS (ppm)	LSI	RSI
					Std method	Hack's method				
15	218 (9.1)	148 (5.6)	210 (20.4)	299 (15.5)	88 (3.9)	---	9.02 (0.05)	683 (45)	1.84	5.34
16,17	218 (10.3)	148 (4.9)	228 (15.8)	301 (14.9)	91 (7.7)	---	9.05 (0.06)	691 (59)	1.92	5.21
18,19	222 (9.7)	152 (4.6)	253 (14.7)	320 (9.8)	---	131 (7.3)	9.09 (0.05)	745 (68)	2.00	5.09
20	223 (8.5)	151 (2.3)	251 (12.7)	316 (10.4)	---	126 (5.1)	9.09 (0.03)	725 (47)	1.99	5.11
21	216 (10.5)	151 (4.5)	253 (4.6)	325 (7.7)	---	129 (4.7)	9.09 (0.06)	752 (90)	1.97	5.13
22	235 (13.1)	152 (4.5)	253 (20.0)	359 (33.3)	---	137 (5.6)	9.13 (0.05)	753 (167)	2.03	5.07
23	244 (11.2)	152 (4.1)	264 (14.2)	348 (17.7)	---	139 (3.8)	9.16 (0.06)	695 (223)	2.10	4.96
24	242 (11.5)	151 (3.8)	263 (14.5)	353 (15.3)	---	140 (3.7)	9.16 (0.05)	730 (176)	2.09	4.98

Notes: 1.*Initial values
2. Numbers in parenthesis are standard deviations

RESULTS

The computer printout of the time dependent fouling resistance and related information for each data point is shown in Appendix J. Plots of fouling resistance (ft^2-hr-^oF/Btu) vs time (hr) are shown in Appendix K.

ASYMPTOTIC FOULING RESISTANCES

The asymptotic fouling resistances, each of which is the average of the last five calculated values, are tabulated in Table 5. Since no asymptotic was apparent for Run 24, the value of the last fouling resistance is listed for each thermocouple location.

CHEMICAL COMPOSITION OF DEPOSITS

Results of the chemical analysis of fouling deposit by Nalco Chemical Company are presented in Table 6. The magnesium silicate deposit of Run 6 was removed from the heater rod by dissolving it in hydrochloric acid. Thus the composition is also shown on a chlorine free basis.

On the basis of chemical composition, the deposits can be divided into three distinct groups: (1) magnesium silicate deposit, (2) magnesium silicate - calcium carbonate mixture and (3) calcium carbonate deposit.

1. Magnesium Silicate Deposit

Runs 1, 3, 4 and 6 belong to this group. Chemical analysis showed that the principal components of this deposit are silicon and magnesium.

TABLE 5. SUMMARY OF ASYMTOTIC FOULING RESISTANCE, RUNS 1-24

Test Section	Run	R_f^* x 10^4 (ft^2-hr-^oF/Btu)			
		TCA	TCB	TCC	TCD
1	4	12.36	10.66	11.5	-----
	7	0.37	0.45	0.42	0.43
	9	0.85	0.90	0.88	1.00
	11	0.72	0.76	0.74	0.88
	13	1.78	1.79	1.77	1.93
	16	3.77	3.71	3.69	3.87
	18	11.31	12.81	9.96	8.71
	18**	3.36	2.74	3.09	3.49
	23	0	0	0	0
2	3	6.68	4.47	3.27	5.06
	5	0.42	0.34	0.24	0.27
	8	0.52	0.40	0.30	0.42
	10	0.93	0.78	0.62	0.76
	12	1.09	0.87	0.53	0.79
	14	2.39	1.67	1.25	1.79
	17	4.62	3.52	2.85	3.64
	19	8.07	5.85	4.62	6.53
	19**	2.71	4.99	4.78	4.00
	24***	42.01	38.99	36.06	39.10
3	1	10.94	8.91	8.75	10.53
	2	0	0	0	0
	6	4.0	4.02	4.92	4.86
	15	9.92	9.73	9.53	-----
	20	0.30	0.31	0.40	0.42
	21	0.55	0.51	0.76	0.81
	22	17.46	18.70	17.32	16.02

** After power failure
*** Last fouling resistance values

TABLE 6. SUMMARY OF CHEMICAL COMPOSITION OF DEPOSITS

Run	1	3	4	6 with chlorine	6 chlorine free	15	18	19	22	24
Si (% as SiO_2)	61	56	58	44	63	44	14	33	2	1
Mg (% as MgO)	28	25	24	14	20	24	9	17	3	3
Zn (% as ZnO)	3	7	8	5	7	8	3	8	--	--
Ca (% as CaO)	2	5	2	1	2	21	40	21	50	51
Fe (% as Fe_2O_3)	1	1	1	1	2	1	1	1	--	--
Cu (% as CuO)	1	1	1	3	4	1	--	1	1	--
Ni (% as NiO)	1	--	--	--	--	--	--	--	--	--
Al (% as Al_2O_3)	1	3	3	1	2	1	1	1	--	--
S (% as SO_3)	1	--	--	--	--	--	--	--	--	--
CO_3 (% as CO_2)	--	--	--	--	--	ND	32	17	43	44
Na (% as Na_2O)	--	1	2	--	--	--	--	--	--	--
Cl (% as Cl)	--	--	--	30	--	--	--	--	--	--
LOSS at 800°C (%)	ND	--	--	32	--	23	ND	ND	43	44

ND denotes 'not determined'

Small amounts of zinc and traces of aluminum, iron, copper and sodium are also present. The combined weight percentages of silicon (as SiO_2) and magnesium (as MgO) were 89%, 81%, 82% and 81% for Runs 1, 3, 4 and 6 respectively. In addition, the mole ratios of silica (SiO_2) to magnesium oxide (MgO) were calculated to be 2.9:2, 3.0:2, 3.2:2 and 4.2:2 for Runs 1, 3, 4 and 6 respectively.

The similarlity in chemical composition among these fouling deposits and the agreement of the mole ratio of silica to magnesium oxide suggest that deposition of magnesium and silica has occurred in an orderly fashion, forming an identifiable crystalline mixture.

Sepiolite, a clay mineral with a chemical formula of $8\ MgO \cdot 12\ SiO_2 \cdot n\ H_2O$ has a similar chemical composition. That is, the mole ratio of SiO_2 to MgO is 3:2. In fact, mineralogical research for the silica-magnesium oxide-water system [28] has shown that reaction of aqueous silica with sea water produces a hydrated magnesium silicate similar to sepiolite. However it has not been possible to confirm that sepiolite was indeed formed in the present study. Structure studies of the fouling deposit were not conclusive.

2. Magnesium Silicate - Calcium Carbonate Mixture

Deposit analysis of Run 15, 18 and 19 indicated the presence of both magnesium silicate and calcium carbonate in various proportions. Small amounts of zinc with traces of iron, copper and aluminum were also detected.

3. Calcium Carbonate Deposit

A complete change of the chemical composition of the fouling deposit of Runs 22 and 24 was detected. The fouling deposit consists mainly of calcium carbonate, the weight percentage of which is 93% for Run 22 and 95% for Run 24. Only 5% of magnesium silicate is present in the fouling deposit of Run 22 and 4% in Run 24.

ALKALINITY EFFECTS

The above three types of deposit occurred successively in the order of magnesium silicate, magnesium silicate-calcium carbonate mixture and calcium carbonate. Possible operating conditions which would have affected this change in deposition characteristic are flow velocity, surface temperature and water quality. The first two factors can be ruled out because of the fact that transition occurred (for example, Run 15) even when these two variables were maintained constant. Water quality did change despite the fact that calcium hardness was maintained at 150 ppm as $CaCO_3$. In fact, three of the water quality parameters - silica, magnesium, and m-alkalinity increased with time. The increase in magnesium and silicate would be expected to bring about an increased tendency to deposit magnesium silicate rather than calcium carbonate. Thus it is suggested that the increase in m-alkalinity brought about the deposition of calcium carbonate.

Methyl orange alkalinity (m-alkalinity), or total alkalinity in water is imparted by bicarbonates, carbonates and hydroxides. The hydroxides are usually negligible in natural water. If the experimental values of m-alkalinity and phenophthalein alkalinity (p-alkalinity) are

known, the bicarbonate alkalinity and carbonate alkalinity can be estimated by the following equations [16],

$$\text{carbonate alkalinity} = 2 \times \text{p-alkalinity} \qquad (6\text{-}1)$$

$$\text{bicarbonate alkalinity} = \text{m-alkalinity} - 4 \times \text{p-alkalinity} \qquad (6\text{-}2)$$

The results for all 24 runs are listed in Table 7. The change of m-alkalinity with time can best be illustrated on a monthly basis as shown in Table 8. Experimental results showed that the m-alkalinity was increasing with time and a sharp increase was observed during the months of April and May.

Rigorous equations [12] have been proposed for calculating the carbonate equilibrium in water. The concentration of bicarbonates and carbonates can be calculated by

$$\underset{\text{ppm } CaCO_3}{\left[HCO_3^-\right]} = 50{,}000 \; \frac{\frac{\left[\text{m-alkalinity}\right]}{50{,}000} + \left[H^+\right] - \frac{K_w'}{\left[H^+\right]}}{1 + \frac{2K_2'}{\left[H^+\right]}} \qquad (6\text{-}3)$$

$$\underset{\text{ppm } CaCO_3}{\left[CO_3^=\right]} = \tfrac{1}{2}\left[\text{m-alkalinity}\right] - \tfrac{1}{2}\underset{\text{ppm } CaCO_3}{\left[HCO_3^-\right]} \qquad (6\text{-}4)$$

where m-alkalinity = ppm methyl orange alkalinity as $CaCO_3$

K_w' = disassociation constant of water

K_2' = disassociation constant of HCO_3^-

and brackets represent concentration in moles/liter except specified otherwise. The results on a monthly basis are listed in Table 8.

Comparison of the theorectical and experimental concentrations shows that the concentration of carbonates is 7-8 times more than the theoretical value. Apparently when water containing appreciable amounts of bicarbonate alkalinity is aerated until equilibrium is obtained, some

TABLE 7. ALKALINITIES - EXPERIMENTAL RESULTS, RUNS 1 - 24

Run(s)	m-alkalinity (ppm $CaCO_3$)	p-alkalinity ppm ($CaCO_3$)	bicarbonate alkalinity (ppm $CaCO_3$) by Eq. (6-1)	carbonate alkalinity (ppm $CaCO_3$) by Eq. (6-2)	% $\frac{\text{carbonate alkalinity}}{\text{m-alkalinity}}$
1*	150	--	---	--	--
2	211	21	126	42	20
3	216	--	---	--	--
4	218	21	134	42	19
5	215	21	130	42	20
6	190	23	98	46	24
7	199	20	117	40	21
8	206	21	122	42	20
9,10	183	23	89	46	26
11,12	182	25	82	50	28
13,14	194	25	94	50	26
15	210	27	103	54	26
16,17	228	29	112	58	25
18,19	253	35	113	70	28
20	251	35	112	70	28
21	253	35	113	70	28
22	253	35	111	70	28
23	264	37	114	74	28
24	263	37	113	74	28

* Initial Values

TABLE 8. ALKALINITIES - EXPERIMENTAL AND THEORETICAL RESULTS, NOV. 76 THROUGH JULY 77

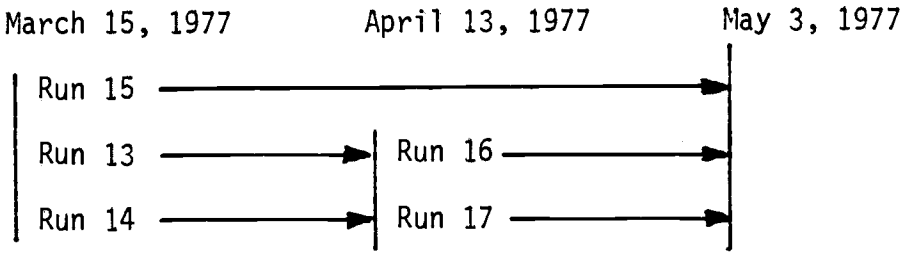
Month	m-alkalinity (ppm $CaCO_3$)	p-alkalinity (ppm $CaCO_3$)	bicarbonate alkalinity (ppm $CaCO_3$)		carbonate alkalinity (ppm $CaCO_3$)		% $\frac{\text{carbonate alkalinity}}{\text{m-alkalinity}}$	
			experimental Eq. (6-1)	theory Eq. (6-3)	experimental Eq. (6-2)	theory Eq. (6-4)	experimental	theory
Nov. 76*	150	--	---	142	--	4	--	3
Dec. 76	201	--	---	190	--	6	--	3
Jan. 77	214	--	---	203	--	6	--	3
Feb. 77	209	21	123	200	42	5	21	2
March 77	187	25	87	175	50	6	27	3
April 77	217	28	105	203	56	7	26	3
May 77	250	34	111	233	68	9	28	4
June 77	267	37	119	246	74	11	28	4
July 77	239	33	105	222	66	9	28	4

* Initial Values

of the half-bound carbon dioxide will be given up to the atmosphere, thus converting some of the bicarbonate to carbonate [12,16]. In fact, it had been demonstrated [16] that 14% of the total bicarbonate content was converted to carbonate at m-alkalinity greater than 100 ppm as $CaCO_3$ at 77°F. Precipitation of calcium carbonate was also observed when calcium hardness exceeded some 200 ppm as $CaCO_3$.

The results of the present study indicates that a substantial amount of bicarbonate was converted. The ratio of carbonate alkalinity to total alkalinity was calculated to be as high as 28%. In other words, the circulating water is supersaturated with carbonates.

Criteria based on m-alkalinity and carbonate alkalinity for the type of fouling deposit can be established when it is superimposed with the water quality history. A chronology of runs at the transition is reconstructed as follows,



From the evidence of the chemical composition of the deposit of Run 15, the transition must have occurred some time between March 15 and May 4. Since the m-alkalinity of Runs 13 and 14 was less than that of Runs 2, 4 and 5, the time can be fixed in the period between April 13 and May 3. In this period the average of m-alkalinity and carbonate alkalinity was 220 ppm as $CaCO_3$ and 56 ppm as $CaCO_3$ respectively over the first five days whereas over the last five days the average was 240 ppm as $CaCO_3$ and 64 ppm as $CaCO_3$ respectively.

Therefore the criteria (with the concentrations of magnesium and silica that were present) are:

1. Deposition of magnesium silicate occurs if m-alkalinity < 220 ppm $CaCO_3$ and carbonate alkalinity < 56 ppm $CaCO_3$.

2. Deposition of magnesium silicate and calcium carbonate occurs if 240 ppm $CaCO_3$ < m-alkalinity > 220 ppm $CaCO_3$ and 64 ppm $CaCO_3$ < carbonate alkalinity > 56 ppm $CaCO_3$.

3. Deposition of calcium carbonate occurs otherwise.

However the above criteria are not in accordance with what the Langiler Saturation Index or the Ryznar Stability Index predicts. Both predict that there is a strong tendency for calcium carbonate to deposit for all runs. Yet only magnesium silicate was formed in many runs.

Little is known concerning the properties of magnesium silicate deposit. If sepiolite can be assumed, its aqueous solution can be represented by the chemical equation [17]

$$2MgO \cdot 3SiO_2 \cdot nH_2O \rightleftharpoons 2\,Mg^{2+} + 3(H_4SiO_4)_{aq} + 4OH^-$$

The activity-product constant, K_{sp} is defined as

$$K_{sp} = (Mg^{2+})^2(H_4SiO_4)^3(OH^-)^4 \qquad (6\text{-}5)$$

where parentheses denote activities.

Using the above equation, the activity-product constant of sepiolite was calculated to be $10^{-34.4}$ which is greater than the theoretical equilibrium value, $10^{-39.7}$ at the same conditions. This indicates that the water was also supersaturated with respect to sepiolite.

The reason why deposition of silicate was favored instead of calcium carbonate was not clear. Further research in this area is needed.

Morse and Knudsen [15] observed a similar effect of m-alkalinity on the chemical composition of fouling deposits. They found that when the water was relatively free of silica (20 ppm as SiO_2) and the calcium hardness and m-alkalinity were above 140 ppm as $CaCO_3$, deposition of calcium carbonate dorminated. When silica was present (> 50 ppm as SiO_2), silicate and impurities were formed at m-alkalinities and calcium hardnesses lower than 115 ppm as $CaCO_3$.

CORRELATIONS

The fouling resistance vs time plots (see Appendix K) of this study generally follow the typical cooling tower water fouling pattern as expressed by Eq. (2-9). Asymptotes were reasonably well defined except for Run 24 where no apparent asymptote was observed before termination of the run.

Assuming that the deposition mechanism is reaction rate controlling, the HTRI deposition model [22] predicts that the asymptotic fouling resistance is a function of surface temperature, flow velocity and water quality. When the last two variables are maintained constant, the asymptotic fouling resistance is related to surface temperature according to the Arrhenius equation,

$$R_f^* = K_{12} \exp(-E_a/R_g T_s) \qquad (6\text{-}7)$$

where K_{12} = proportionality constant.

A plot of the logarithm of R_f^* vs the reciprocal of T_s should yield a straight line with a slope of $-E_a/R_g$.

Story and Knudsen [20] found that the above relationship is applicable for the deposition of calcium carbonate. A similar appraoch was employed

here to correlate the data for the magnesium silicate deposit and magnesium silicate-calcium carbonate mixture. Correlation of the calcium carbonate deposition data was not possible due to insufficient data.

1. Correlation for magnesium silicate

With the exception mentioned below, Runs 1 through 14 were used to correlate the magnesium silicate deposit. Evidence showed that the deposition of Run 1 had been reinforced by biofouling. Run 4 was operated at a velocity different from 5.3 ft/sec. There was no significant fouling deposition for Run 2. Therefore data for these three runs were not included in the correlation.

The logarithm of asymptotic fouling resistance vs the reciprocal of surface temperature is plotted in Figure 4. Least square analysis yields,

$$R_f^* = 9.4246 \times 10^8 \exp\left(-1.7496 \times 10^4/T_s\right) \qquad (6\text{-}8)$$

The coefficient of correlation is -0.95.

The slope was -1.7496×10^4 and the activation energy was calculated to be 34770 Btu/lbmole.

2. Correlation of magnesium silicate - calcium carbonate mixture.

Data for Runs 15, 18, 19, 20 and 21 where deposition of $MgO\text{-}SiO_2\text{-}CaCO_3$ occurred were correlated. Data for Runs 16 and 17 were not included because of the uncertainty of the deposit composition. In addition, data for Runs 18 and 19 after the first major power failure were ignored. The plot of asymptotic fouling resistance vs the reciprocal of surface

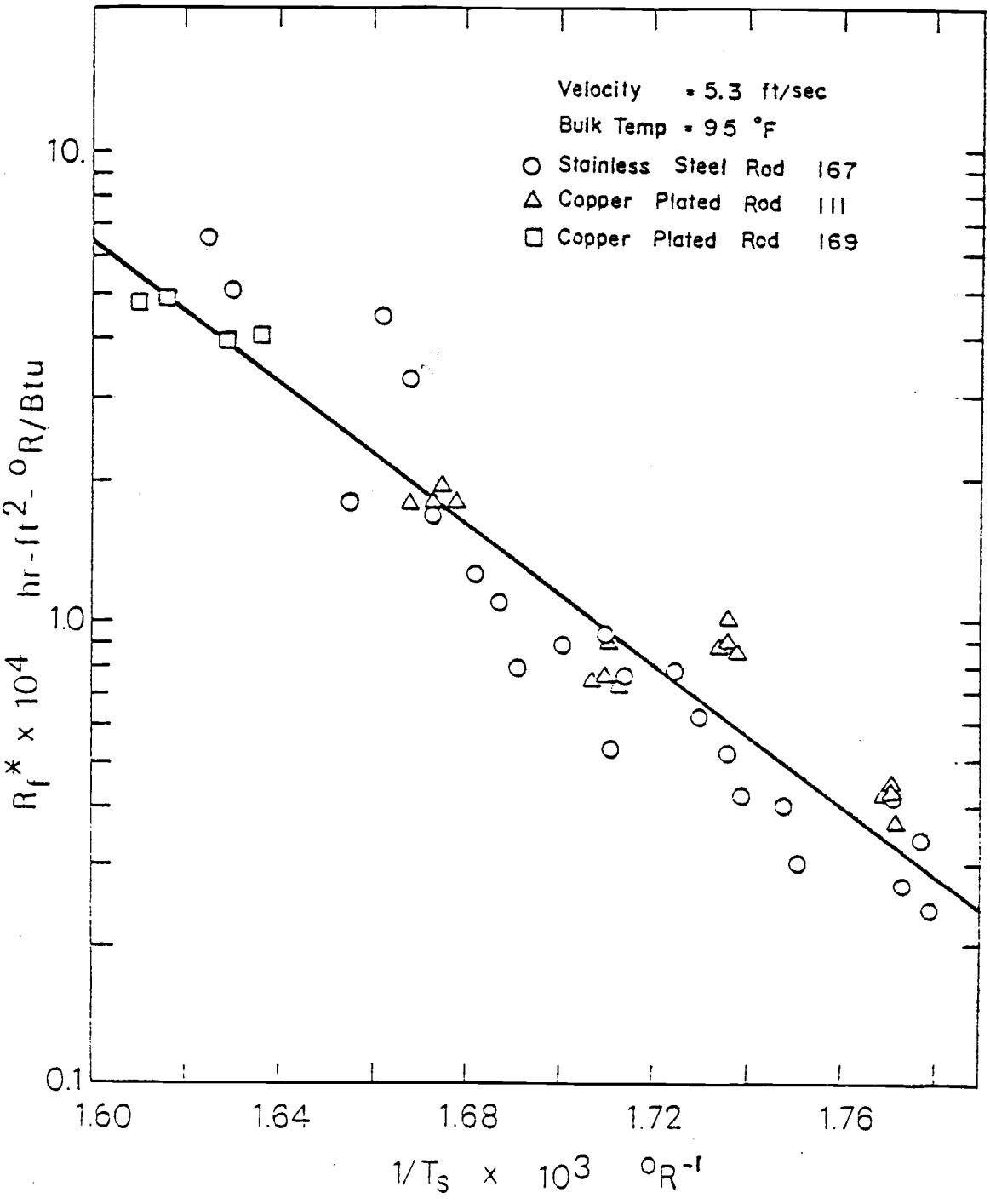


Figure 4. Log R_f^* vs $1/T_s$ - $MgO \cdot SiO_2$ deposit

temperature is shown in Figure 5. Least square analysis yields,

$$R_f^* = 4.8702 \times 10^{22} \exp(-3.6625 \times 10^4 / T_s) \quad (6\text{-}9)$$

The coefficient of correlation is -0.97 and the activation energy of this mixture was calculated to be 72780 Btu/lbmole.

Reitzer [18] proposed that the difference in foulant concentrations at the bulk and at the deposit surface is the principal driving force for fouling deposition. Since the solubility of foultant is a function of temperature, the concentration difference can be related to the temperature difference. Based on the assumptions of this model, the asymptotic fouling resistance was correlated with the difference between the surface temperature and the bulk temperature, that is, $T_s - T_b$. The resulting empirical correlations are listed as follows.

For magnesium silicate deposit

$$R_f^* = 2.01 \times 10^{-5} \exp(0.051(T_s - T_b)) \quad (6\text{-}10)$$

For magnesium silicate - calcium carbonate mixture

$$R_f^* = 1.31 \times 10^{-6} \exp(0.104(T_s - T_b)) \quad (6\text{-}11)$$

The data are plotted in Figures 6 and 7 and the coefficients of correlation are 0.95 and 0.97 respectively.

Both Eq. (2-10) and Eq. (2-11) indicate that the asymptotic fouling resistance increases exponentially with the difference between the surface temperature and the bulk temperature. However no attempt should be made to generalize these two correlations beyond the operating conditions of the present runs during which the bulk temperature was essentially constant. Runs with wide range of bulk temperature variations are needed to justify the correlations.

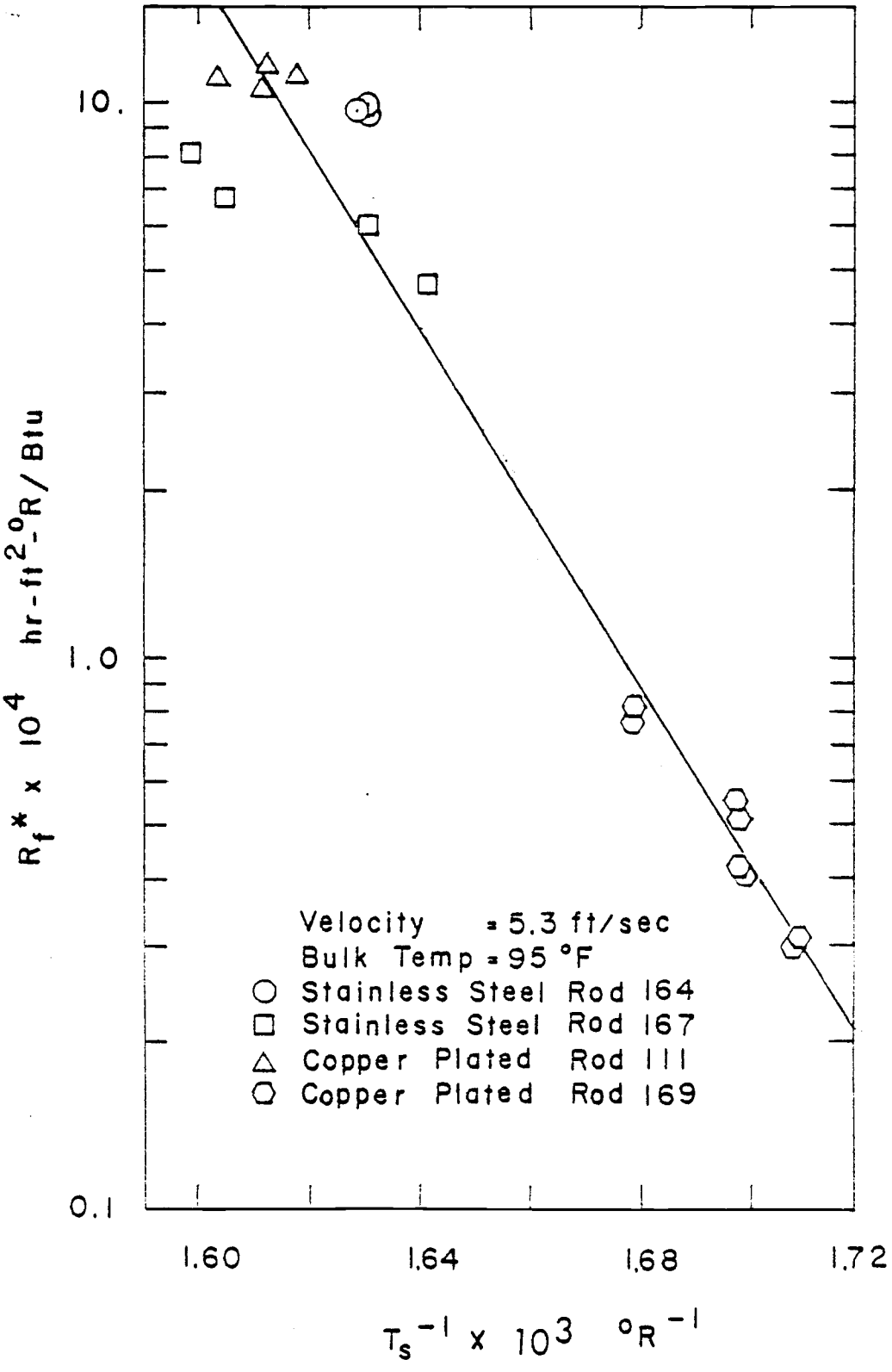


Figure 5. Log R_f^* vs $1/T_s$ - $MgO \cdot SiO_2 \cdot CaCO_3$ deposit

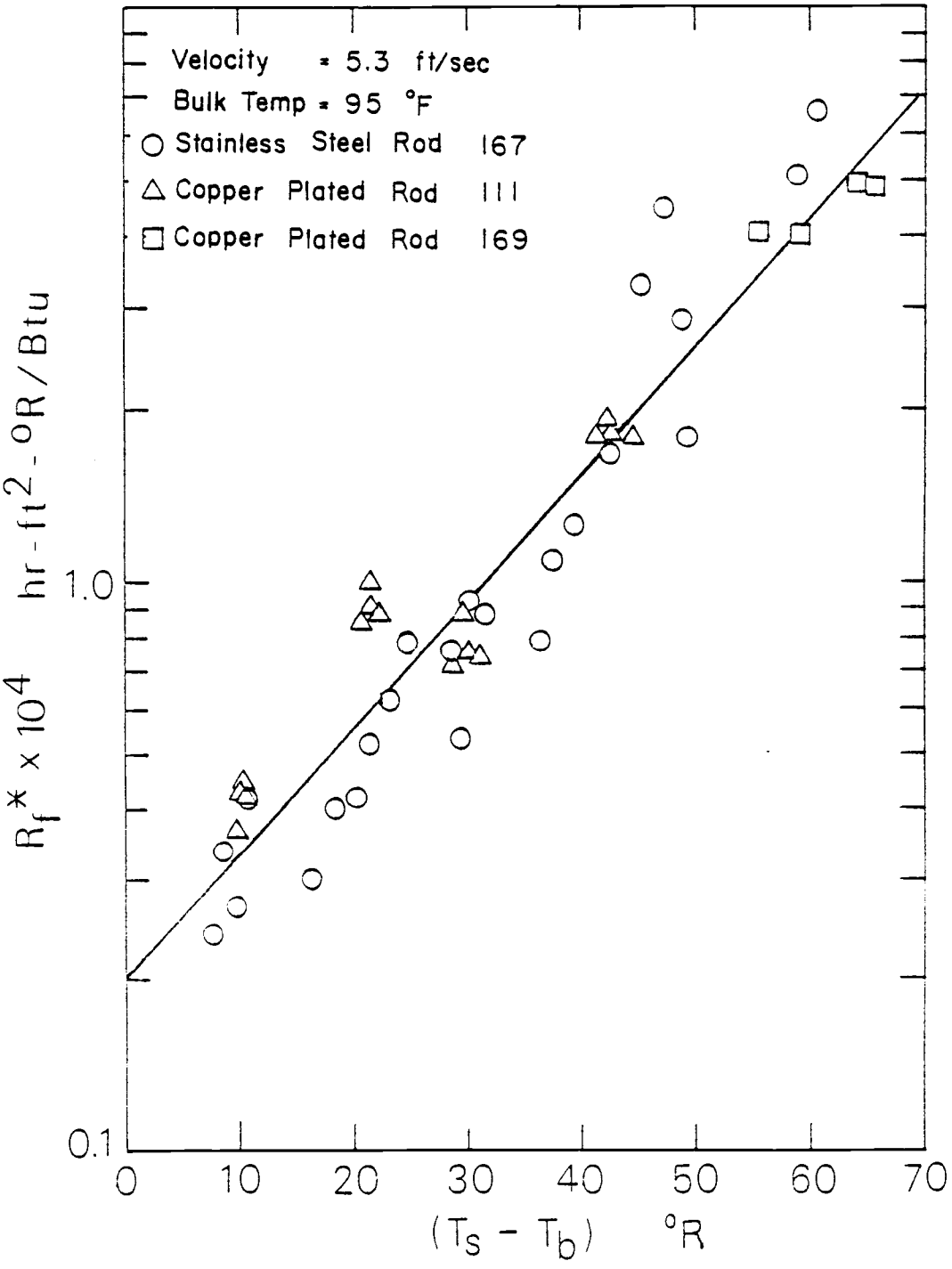


Figure 6. Log R_f^* vs (T_s-T_b) - $MgO \cdot SiO_2$ deposit

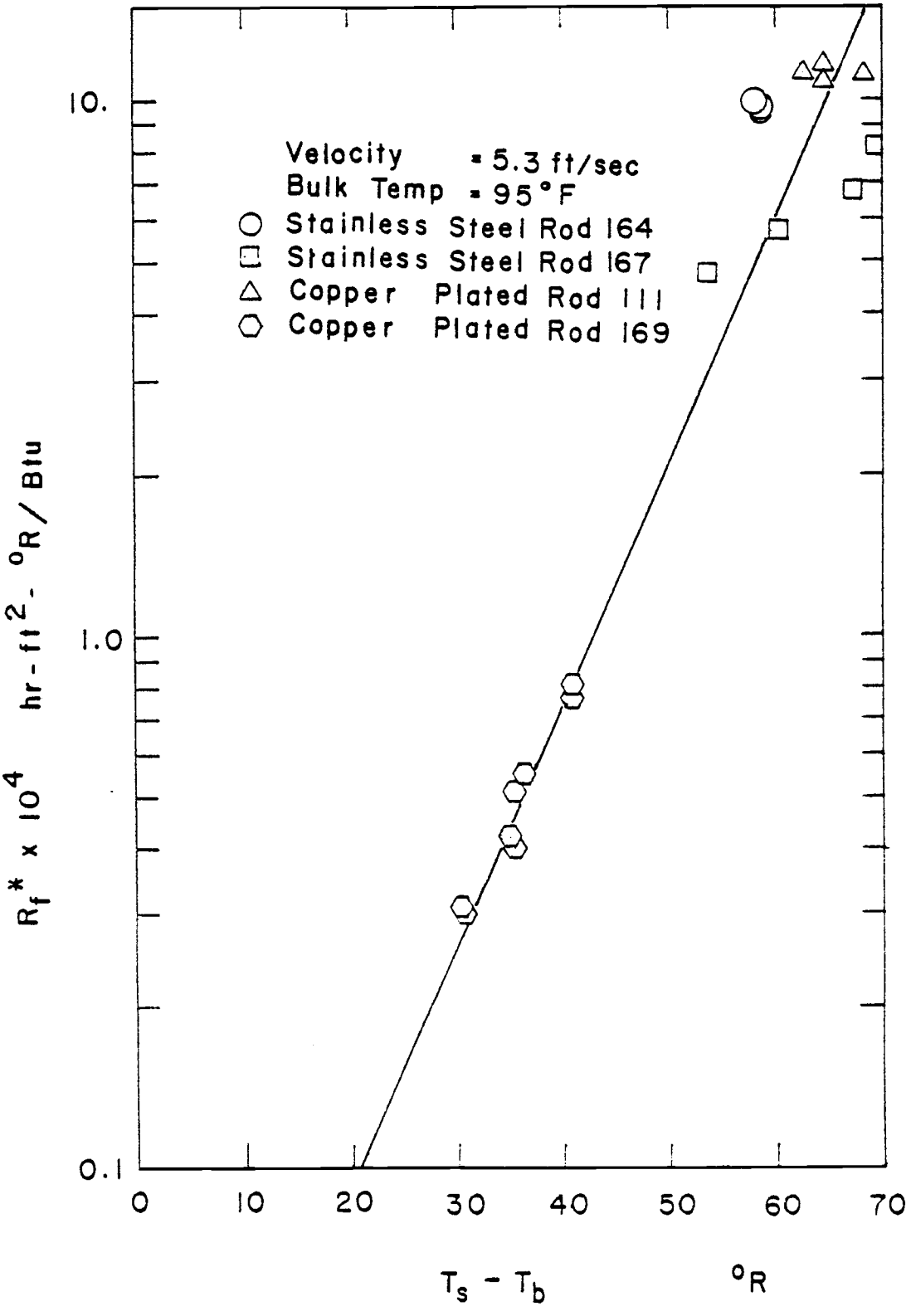


Figure 7. Log R_f^* vs (T_s-T_b) - $MgO \cdot SiO_2 \cdot CaCO_3$ deposit

Watkinson and Martinez [27] modified the idea of Reitzer [18] with the addition of an Arrhenius type temperature dependent term resulting in an expression

$$R_f^* = K_{13} (T_s - T_b)^n \exp (-E_a/R_g T_s) \quad (6\text{-}12)$$

The data were correlated according to the above formulation and the results by linear regression analysis are presented as follows.

For magnesium silicate deposit

$$R_f^* = 6.3865 \times 10^{13} (T_s - T_b)^{-0.4619} \exp (-2.3123 \times 10^4/T_s) \quad (6\text{-}13)$$

where the coefficient of correlation is -0.97.

For magnesium silicate - calcium carbonate mixture

$$R_f^* = 3.26 \times 10^{-41} (T_s - T_b)^{9.048} \exp (3.0102 \times 10^4/T_s) \quad (6\text{-}14)$$

where the coefficient of correlation is 0.97.

Likewise the correlations presented in Eq. (6-13) and Eq. (6-14) can only apply to the present operating conditions.

Finally there appears to be a critical surface temperature below which fouling deposition is negligible. For example, fouling resistance for Run 2 was essentially zero when the surface temperature was 105°F. However the critical surface temperature was not determined exactly. It appears that the critical surface temperature for the deposition of magnesium silicate at a bulk temperature of 95°F lies between 105°F and 115°F.

EFFECTS OF FLOW VELOCITY AND SURFACE CONDITIONS

EFFECT OF FLOW VELOCITY

It was found that the asymptotic fouling resistance is definitely a strong function of flow velocity. Run 4 was operated at a flow velocity of 2.5 ft/sec and the resulting asymptotic fouling resistances ($hr\text{-}ft^2\text{-}^oF/Btu$) were 12.36×10^{-4}, 10.66×10^{-4}, and 11.5×10^{-4} for location A, B and C respectively. The values predicted by Eq. (6-5) at identical operating conditions but with a flow velocity of 5.3 ft/sec are 3.42×10^{-4}, 2.75×10^{-4} and 2.71×10^{-4} for location A, B and C respectively. Comparison of these results indicates that as the flow velocity is reduced by 50%, the asymptotic fouling resistance increased four-fold. Furthermore there was no significant deposition observed for Run 23 where the flow velocity was 12 ft/sec whereas at 5.3 ft/sec a substantial amount of deposit was formed. These results indicate qualitatively that asymptotic fouling resistance decreases as flow velocity increases.

EFFECT OF SURFACE CONDITIONS

Two types of tube materials were used: stainless steel and copper plated. It appears that the tube material has no significant effect on the asymptotic fouling resistance.

VII. CONCLUSION

Within the range of the operating conditions reported herein, it is concluded that:

1. For the deposition of magnesium silicate and calcium carbonate, the asymptotic fouling resistance can be correlated by an Arrhenius type equation as shown in Eq. (6-8) and Eq. (6-9).

2. The methyl orange alkalinity and the resultant concentrations of carbonates and bicarbonates in the circulating water affects the type of deposit being formed. Preliminary criteria were established to indicate whether the deposit will be magnesium silicate or calcium carbonate or a mixture of these.

3. The predictive criteria of Langelier Saturation Index or Rynzar Stability Index for the deposition of calcium carbonate is not applicable when magnesium and silica are present in sufficient concentration.

4. The asymptotic fouling resistance was found to decrease as flow velocity increased.

5. The tube material appeared to have no significant effect on the deposition behavior.

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APPENDICES

APPENDIX A

NOMENCLATURE

Symbol	Definition	Unit
A	Area of the heated section	ft^2
B	Variable defined in Eq.(2-9)	hr^{-1}
Bd	Blowdown rate	gph
C	Concentration	$lbmole/ft^3$
C_b, C_b'	Bulk foulant concentrations	$lbmole/ft^3$, lbm/ft^3
C_p	Heat capacity of water	$Btu/lbm-^oF$
C_s,C_s'	Concentrations of foulant at the surface of fouling deposit	$lbmole/ft^3$, lbm/ft^3
Cy	Cycles of concentration	
CaH	Calcium hardness	ppm $CaCO_3$
Cl	Chloride	ppm NaCl
$[CO_3^{=}]$	Carbonate concentration	ppm $CaCO_3$
$dR_f/d\theta$	Rate of change of fouling resistance	ft^2-^oF/Btu
$dX_\theta/d\theta$	Rate of change of the thickness of fouling deposit	ft/hr
D_1	Inside diameter of glass tube	inches
D_2	Outside diameter of heater rod	inches
E	Variable defined in Eq.(2-3)	
E_a	Activation energy	Btu/lbmole
Ev	Evaporation rate of cooling tower water	gpm
f	Friction factor	
F	Variable defined in Eq.(2-3)	
h	Convective heat transfer coefficient	Btu/ft^2-hr-^oF
$[H^+]$	Concentration of hydrogen ion	gm-mole/l

Symbol	Definition	Unit
$[HCO_3^-]$	Bicarbonate concentration	ppm $CaCO_3$
J	Mass flux	lbm/hr
k_f	Thermal conductivity of fouling deposit	Btu/ft-hr-^oF
k_m	Convective mass transfer	ft/hr
k_r	Rate coefficient of surface reaction	ft/hr
$K, K_1, \ldots, K_{14}$	Proportionality constants	units vary
K_{sp}	Activity-product constant of sepiolite	
K_2'	Disassociation constant of bicarbonate ion	lbmole/ft^3
K_w'	Disassociation constant of water	lbmole/ft^3
L	Length of the heated section of a heater rod	inch
l	Number of data points for initial condition calculations	
m,n,p,q,r	Empirical constants	
m-alkalinity	Methyl orange alkalinity	ppm $CaCO_3$
MgH	Magnesium hardness	ppm $CaCO_3$
Pd	Probability function defined in Eq.(2-14)	
P-alkalinity	Phenophthalein alkalinity	ppm $CaCO_3$
pH	Acidity	
pH_s	The pH of water saturated with calcium carbonate	
Q	Heat duty	Btu/ hr
Q/A	Heat flux	Btu/ft^2-hr
Q_{mv}	Power transducer millivolt output	millivolt
R	Heat transfer resistance	ft^2-hr-^oF/Btu
R_f	Fouling resistance	ft^2-hr-^oF/Btu

Symbol	Definition	Unit
R_f^*	Asymptotic fouling resistance	ft^2-hr-^oF/Btu
R_g	Gas constant	Btu/lbmole-^oR
S	Sticking probability defined in Eq.(2-13)	
Si	Silica concentration	ppm SiO_2
T	Temperature	^oF
T_{inlet}	Inlet temperature of test section 3	^oF
T_{outlet}	Outlet temperature of test section 3	^oF
TC	Thermocouple output millivolt	
TH	Total hardness	ppm $CaCO_3$
TS	Total solids	ppm
U	Overall heat transfer coefficient	Btu/ft^2-hr
v	Flow velocity	ft/hr
W_F	Volumetric flow rate	ft^3/hr
W'	Mass flow rate	lbm/hr
W_{mV}	Flow transducer millivolt output	
x/k	Thermal resistance of tube wall	ft^2-hr-^oF/Btu
X_E	Entrance length of test section defined in Figure 2	inch
Y	Length defined in Figure 2	inch
$z_1,\ldots,z_5$	Variables defined in Equations (5-12), (5-15), (5-20), (5-24) and (5-26) respectively	

Subscript	Definition
avg	Average value
b	Bulk conditions
f	Fouled conditions
i	Initial conditions
in	Inside of tube
o	Outside of tube
s	Fouling deposit surface
w	Tube wall

Greek Letter	Definition	Unit
θ	Time	hr
ϕ_d	Rate of deposition of foulant	ft^2-^oF/Btu
ϕ_r	Rate of removal of foulant	ft^2- ^oF/Btu
τ	Shear stress	lbf/ft^2
ψ	Deposit strength factor	lbf/ft^2
Ω	Water characterization factor	
ρ	Density of water	lbm/ft^3
ρ_f	Density of fouling deposit	lbm/ft^3

Abbreviation	Meaning
CPVC	Chlorinated Polyvinyl-Chloride
Cu	Copper plated heater rod
HTRI	Heat Transfer Research Inc.
LSI	Langelier Saturation Index
PFRU	Portable Fouling Research Unit
PVC	Polyvinyl - Chloride
SS	Stainless steel heater rod
TCA	Thermocouple location A
TCB	Thermocouple location B
TCC	Thermocouple location C
TCD	Thermocouple location D
TEMA	Tubular Exchangers Manufacturers Association

APPENDIX B

CALIBRATION EQUATIONS

Test Sections 1 and 2

Watt meter transducer

$$Q = 100 \times Q_{mv}$$

where Q = power input in watts

Q_{mv} = watt meter transducer output in millivolt

Flow meter transducer

$$W_F' = 10X(W_{mv}/20)^{0.5}$$

where W_F' = volumetric flow rate of water, gpm

W_{mv} = flow meter transducer output in millivolt

Chromel-constantan thermocouple (type E) -- reference temperature 150°F

$$T = 32.583\ (TC + 5.02)^{0.949} \qquad TC < -1.0$$

$$T = 38.529\ (TC + 4.72)^{0.8765} \qquad TC \geq -1.0$$

where T = temperature in °F

TC = thermocouple output in millivolt

Test Section 3

Rotameter

$$W_F' = 0.1613 \times Flow$$

where Flow = volumetric flow rate of water, % max flow

Chromel - constantan thermocouple (type E) -- reference temperature 0°C

$$T = 32.583\ (TC + 0.979)^{0.949} \qquad TC < 3.041$$

$$T = 38.529\ (TC + 0.679)^{0.8765} \qquad TC \geq 3.041$$

APPENDIX C

RAW DATA, RUNS 1-24

Nomenclature

TIN = inlet temperature (millivolt)

TOUT = outlet temperature (millivolt)

TWA, B, C, D = wall temperatures at location A, B, C and D

HEAT = power input (millivolt for test sections 1 and 2, watts for test section 3)

FLOW = flow rate (millivolt for sections 1 and 2, % maximum flow for section 3)

DAY = days elapsed.

TIME = 24 - hr clock

Note: 0 denotes no data

RAW DATA--RUN 1

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
10	1020	2.038	2.192	5.120	4.960	4.700	4.980	1.000	31.000
10	16 0	2.024	2.080	5.070	4.920	4.670	4.950	1.000	31.000
10	2310	2.003	2.077	5.030	4.920	4.660	4.960	1.000	31.000
11	1145	2.000	2.053	5.000	4.930	4.670	4.960	1.000	31.000
11	1715	1.997	2.042	5.000	4.920	4.660	4.940	1.000	31.000
11	2245	1.998	2.036	5.010	4.930	4.660	4.880	1.000	31.000
12	1145	1.998	2.028	5.060	4.930	4.620	4.940	1.000	31.000
12	1750	1.998	2.028	5.040	4.920	4.660	4.940	1.000	31.000
12	2345	1.998	2.065	5.080	4.870	4.610	4.910	1.000	31.000
13	1210	1.998	2.079	5.090	4.930	4.660	4.960	1.000	31.000
13	1715	1.998	2.079	5.100	4.940	4.670	4.960	1.000	31.000
13	21 0	1.998	2.091	5.100	4.940	4.670	4.940	1.000	31.000
14	1350	1.998	2.091	5.110	4.940	4.670	4.960	1.000	31.000
14	17 0	1.998	2.099	5.120	4.970	4.690	4.960	1.000	31.000
14	2115	1.998	2.099	5.130	4.980	4.700	4.980	1.000	31.000
15	1125	1.998	2.095	5.120	4.980	4.700	4.980	1.000	31.000
15	18 0	1.998	2.068	5.080	4.940	4.720	4.990	1.000	31.000
15	23 0	1.998	2.068	5.070	4.950	4.710	4.950	1.000	31.000
16	915	1.998	2.068	5.040	4.940	4.700	4.960	1.000	31.000
16	13 0	1.998	2.029	5.040	4.900	4.670	4.920	1.000	31.000
16	1745	1.998	2.025	5.000	4.910	4.670	4.930	1.000	31.000
16	2330	1.998	2.022	5.000	4.940	4.690	4.950	1.000	31.000
17	1025	1.998	2.031	5.050	4.920	4.680	4.950	1.000	31.000
17	1325	1.998	2.044	5.060	4.940	4.700	4.980	1.000	31.000
17	2150	1.998	2.044	5.060	4.940	4.700	4.960	1.000	31.000
18	1410	1.998	2.082	5.110	4.980	4.730	4.990	1.000	31.000
18	1845	1.998	2.067	5.150	5.000	4.750	4.990	1.000	31.000
18	2140	1.998	2.075	5.160	5.000	4.750	4.990	1.000	31.000
19	1330	1.998	2.074	5.190	5.020	4.760	4.990	1.000	31.000
19	2315	1.998	2.013	5.260	5.050	4.780	4.990	1.000	31.000
20	810	1.998	1.972	5.320	5.080	4.830	4.990	1.000	31.000
20	1230	1.998	1.984	5.380	5.110	4.850	4.990	1.000	31.000
20	1930	1.998	1.959	5.440	5.130	4.890	4.990	1.000	31.000
21	815	1.998	1.954	5.460	5.170	4.930	4.990	1.000	31.000
21	1445	1.998	1.977	5.540	5.230	4.970	4.990	1.000	31.000
21	1815	1.998	1.985	5.600	5.260	5.000	4.990	1.000	31.000
21	22 0	1.998	2.003	5.630	5.280	5.030	4.990	1.000	31.000
22	1015	1.998	1.991	5.690	5.310	5.060	4.990	1.000	31.000
22	1315	1.998	2.012	5.730	5.330	5.090	4.990	1.000	31.000
22	17 0	1.998	1.995	5.800	5.330	5.090	4.990	1.000	31.000
22	2250	1.998	1.958	5.860	5.330	5.090	4.990	1.000	31.000
23	945	1.998	1.949	5.930	5.330	5.090	4.990	1.000	31.000
23	1110	1.998	1.938	5.720	5.230	5.000	4.990	1.000	31.000
23	1345	1.998	1.938	5.750	5.280	5.050	4.990	1.000	31.000
23	2315	1.998	1.957	5.880	5.310	5.070	4.990	1.000	31.000
24	345	1.998	1.947	5.950	5.350	5.110	4.990	1.000	31.000
24	1135	1.998	1.982	6.070	5.570	5.320	4.990	1.000	31.000
24	1945	1.998	1.955	6.110	5.660	5.390	4.990	1.000	31.000
24	2355	1.998	1.926	6.190	5.730	5.460	4.990	1.000	31.000
25	830	1.998	1.889	6.260	5.740	5.480	4.990	1.000	31.000
25	1130	1.998	1.872	6.300	5.730	5.480	4.990	1.000	31.000
25	24 0	1.998	1.933	6.360	5.740	5.500	4.990	1.000	31.000
25	930	1.998	1.940	6.420	5.780	5.530	4.990	1.000	31.000
25	1745	1.998	1.966	6.480	5.820	5.580	4.990	1.000	31.000
25	2345	1.998	1.962	6.550	5.850	5.600	4.990	1.000	31.000
26	1020	1.998	2.023	6.590	5.880	5.620	4.990	1.000	31.000
26	1715	1.998	1.990	6.660	5.970	5.720	4.990	1.000	31.000
26	2245	1.998	1.970	6.680	5.940	5.680	4.990	1.000	31.000
27	1145	1.998	1.991	6.680	5.960	5.700	4.990	1.000	31.000
27	1750	1.998	1.979	6.720	6.020	5.760	4.990	1.000	31.000
27	2345	1.998	1.984	6.780	6.020	5.850	4.990	1.000	31.000
28	1210	1.998	1.966	6.830	6.080	5.910	4.990	1.000	31.000
28	1715	1.998	1.994	6.880	6.150	5.980	4.990	1.000	31.000
28	21 0	1.998	1.996	6.930	6.200	6.020	4.990	1.000	31.000
29	1350	1.998	1.996	6.980	6.270	6.100	4.990	1.000	31.000
29	17 0	1.998	2.059	7.030	6.330	6.150	4.990	1.000	31.000
29	2115	1.998	2.087	7.080	6.370	6.200	4.990	1.000	31.000
30	1125	1.998	2.092	7.130	6.420	6.250	4.990	1.000	31.000
30	1825	1.998	2.074	7.150	6.470	6.290	4.990	1.000	31.000
30	23 0	1.998	2.066	7.200	6.510	6.330	4.990	1.000	31.000
31	915	1.998	2.037	7.270	6.550	6.370	4.990	1.000	31.000
31	1530	1.998	2.007	7.330	6.580	6.400	4.990	1.000	31.000
31	2310	1.998	1.977	7.390	6.630	6.440	4.990	1.000	31.000
32	915	1.998	1.967	7.450	6.670	6.480	4.990	1.000	31.000
32	1130	1.998	1.993	7.510	6.710	6.520	4.990	1.000	31.000
32	1430	1.998	2.023	7.560	6.750	6.560	4.990	1.000	31.000
32	1730	1.998	2.050	7.610	6.790	6.600	4.990	1.000	31.000
32	2330	1.998	2.117	7.640	6.830	6.640	4.990	1.000	31.000
33	930	1.998	2.117	7.680	6.870	6.680	4.990	1.000	31.000
33	1530	1.998	2.117	7.720	6.910	6.720	4.990	1.000	31.000
34	2310	1.998	2.117	7.760	6.950	6.760	4.990	1.000	31.000
34	1130	1.998	2.117	7.800	6.990	6.800	4.990	1.000	31.000
34	2330	1.998	2.117	7.840	7.030	6.840	4.990	1.000	31.000

RAW DATA--RUN 2

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
7	9 0	2.036	2.053	2.511	2.492	2.607	2.561	.165	30.800
7	174 30	2.053	2.069	2.511	2.510	2.621	2.576	.165	31.000
8	8 30	2.018	2.036	2.501	2.480	2.592	2.548	.165	31.000
8	21 30	2.020	2.035	2.501	2.479	2.593	2.549	.165	31.000
9	9 30	2.012	2.017	2.444	2.461	2.571	2.529	.165	31.000
9	19 30	2.027	2.038	2.492	2.468	2.584	2.546	.165	31.000
10	9 45	2.034	2.050	2.506	2.517	2.629	2.585	.165	31.000
10	8 35	2.050	2.065	2.521	2.500	2.613	2.573	.165	31.000
11	18 0	2.049	2.065	2.507	2.515	2.632	2.587	.165	31.000
11	18 30	2.065	2.080	2.522	2.476	2.591	2.547	.165	31.000
12	9 0	2.081	2.097	2.537	2.475	2.564	2.523	.165	31.000
12	19 0	2.097	2.113	2.551	2.435	2.544	2.507	.165	31.000
13	9 0	2.113	2.130	2.566	2.431	2.545	2.498	.165	31.000
13	19 30	2.130	2.146	2.580	2.538	2.655	2.606	.165	31.000
14	9 0	2.146	2.163	2.595	2.556	2.672	2.625	.165	31.000
14	16 30	2.163	2.179	2.609	2.494	2.586	2.537	.165	31.000
15	9 0	2.179	2.196	2.624	2.527	2.595	2.549	.165	31.000
15	19 30	2.196	2.212	2.638	2.544	2.613	2.566	.165	31.000
16	9 0	2.212	2.229	2.653	2.560	2.630	2.582	.165	31.000
16	19 30	2.229	2.245	2.667	2.538	2.656	2.607	.165	31.000
17	9 0	2.245	2.262	2.682	2.524	2.642	2.591	.165	31.000
17	19 30	2.262	2.278	2.696	2.537	2.626	2.577	.165	31.000
18	9 0	2.278	2.295	2.711	2.524	2.599	2.563	.165	31.000
18	19 30	2.295	2.311	2.725	2.525	2.620	2.582	.165	31.000
19	9 0	2.311	2.328	2.740	2.508	2.600	2.566	.165	31.000
19	19 30	2.328	2.344	2.754	2.499	2.590	2.556	.165	31.000
20	9 0	2.344	2.361	2.769	2.539	2.630	2.597	.165	31.000
20	19 30	2.361	2.377	2.783	2.466	2.557	2.512	.165	31.000
21	9 0	2.377	2.394	2.798	2.413	2.504	2.459	.165	31.000
21	19 30	2.394	2.410	2.812	2.420	2.511	2.467	.165	31.000
22	9 0	2.410	2.427	2.827	2.393	2.487	2.441	.165	31.000
22	19 30	2.427	2.443	2.841	2.299	2.393	2.363	.165	31.000
23	9 0	2.443	2.460	2.856	2.530	2.519	2.489	.165	31.000
23	19 30	2.460	2.476	2.870	2.535	2.544	2.505	.165	31.000
24	9 0	2.476	2.493	2.885	2.522	2.531	2.487	.165	31.000
24	19 30	2.493	2.509	2.899	2.495	2.505	2.457	.165	31.000
25	9 0	2.509	2.526	2.914	2.518	2.614	2.577	.165	31.000
25	19 30	2.526	2.542	2.928	2.489	2.577	2.538	.165	31.000
26	9 0	2.542	2.559	2.943	2.497	2.588	2.550	.165	31.000
26	19 30	2.559	2.575	2.957	2.506	2.595	2.568	.165	31.000
27	9 0	2.575	2.592	2.972	2.520	2.610	2.584	.165	31.000
27	19 30	2.592	2.608	2.986	2.501	2.591	2.564	.165	31.000
28	9 0	2.608	2.625	3.001	2.502	2.592	2.562	.165	31.000
28	19 30	2.625	2.641	3.015	2.488	2.578	2.551	.165	31.000
29	9 0	2.641	2.658	3.030	2.488	2.578	2.564	.165	31.000
29	19 30	2.658	2.674	3.044	2.510	2.598	2.572	.165	31.000
30	9 0	2.674	2.691	3.059	2.530	2.618	2.592	.165	31.000
30	19 30	2.691	2.707	3.073	2.497	2.586	2.562	.165	31.000
31	9 0	2.707	2.724	3.088	2.516	2.604	2.582	.165	31.000
31	19 30	2.724	2.740	3.102	2.502	2.593	2.564	.165	31.000
32	9 0	2.740	2.757	3.117	2.502	2.587	2.564	.165	31.000
32	19 30	2.757	2.773	3.131	2.504	2.592	2.566	.165	31.000
33	9 0	2.773	2.790	3.146	2.497	2.583	2.560	.165	31.000
33	19 30	2.790	2.806	3.160	2.517	2.602	2.579	.165	31.000
34	9 0	2.806	2.823	3.175	2.502	2.587	2.564	.165	31.000
34	19 30	2.823	2.839	3.189	2.502	2.587	2.564	.165	31.000
35	9 0	2.839	2.856	3.204	2.502	2.587	2.564	.165	31.000
35	19 30	2.856	2.872	3.218	2.502	2.587	2.564	.165	31.000
36	9 0	2.872	2.889	3.233	2.502	2.587	2.564	.165	31.000
36	19 30	2.889	2.905	3.247	2.502	2.587	2.564	.165	31.000
37	9 0	2.905	2.922	3.262	2.502	2.587	2.564	.165	31.000
37	19 30	2.922	2.938	3.276	2.502	2.587	2.564	.165	31.000
38	9 0	2.938	2.955	3.291	2.502	2.587	2.564	.165	31.000
38	19 30	2.955	2.971	3.305	2.502	2.587	2.564	.165	31.000
39	9 0	2.971	2.988	3.320	2.502	2.587	2.564	.165	31.000
39	19 30	2.988	3.004	3.334	2.502	2.587	2.564	.165	31.000
40	9 0	3.004	3.021	3.349	2.502	2.587	2.564	.165	31.000
40	19 30	3.021	3.037	3.363	2.502	2.587	2.564	.165	31.000
41	9 0	3.037	3.054	3.378	2.502	2.587	2.564	.165	31.000
41	19 30	3.054	3.070	3.392	2.502	2.587	2.564	.165	31.000
42	9 0	3.070	3.087	3.407	2.502	2.587	2.564	.165	31.000
42	17 30	3.087	3.103	3.421	2.502	2.587	2.564	.165	31.000
43	9 0	3.103	3.120	3.436	2.502	2.587	2.564	.165	31.000
43	17 30	3.120	3.136	3.450	2.502	2.587	2.564	.165	31.000
44	9 0	3.136	3.153	3.465	2.502	2.587	2.564	.165	31.000
44	17 30	3.153	3.169	3.479	2.502	2.587	2.564	.165	31.000
45	9 0	3.169	3.186	3.494	2.502	2.587	2.564	.165	31.000
45	17 30	3.186	3.202	3.508	2.502	2.587	2.564	.165	31.000
46	9 0	3.202	3.219	3.523	2.502	2.587	2.564	.165	31.000
46	17 30	3.219	3.235	3.537	2.502	2.587	2.564	.165	31.000
47	9 0	3.235	3.252	3.552	2.502	2.587	2.564	.165	31.000
47	17 30	3.252	3.268	3.566	2.502	2.587	2.564	.165	31.000
48	9 0	3.268	3.285	3.581	2.502	2.587	2.564	.165	31.000
48	17 30	3.285	3.301	3.595	2.502	2.587	2.564	.165	31.000
49	9 0	3.301	3.318	3.610	2.502	2.587	2.564	.165	31.000
49	17 30	3.318	3.334	3.624	2.502	2.587	2.564	.165	31.000
50	9 0	3.334	3.351	3.639	2.502	2.587	2.564	.165	31.000
50	17 30	3.351	3.367	3.653	2.502	2.587	2.564	.165	31.000
51	9 0	3.367	3.384	3.668	2.502	2.587	2.564	.165	31.000
51	17 30	3.384	3.400	3.682	2.502	2.587	2.564	.165	31.000

RAW DATA--RUN 3

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
11	1	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	2	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	3	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	4	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	5	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	6	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	7	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	8	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	9	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	10	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	11	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	12	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	13	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	14	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	15	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	16	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	17	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	18	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	19	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	20	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	21	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	22	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	23	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
11	24	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	1	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	2	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	3	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	4	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	5	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	6	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	7	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	8	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	9	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	10	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	11	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	12	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	13	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	14	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	15	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	16	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	17	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	18	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	19	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	20	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	21	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	22	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	23	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
12	24	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	1	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	2	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	3	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	4	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	5	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	6	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	7	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	8	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	9	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	10	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	11	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	12	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	13	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	14	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	15	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	16	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	17	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	18	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	19	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	20	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	21	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	22	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	23	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0
13	24	2.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0

RAW DATA--RUN +

DAY	TIME	TIN	TOUT	TWA	TAB	TAC	TWO	HEAT	FLOW

RAW DATA--RUN 5

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW

RAW DATA--RUN 6

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	1010	2.036	2.991	4.950	5.670	5.250	5.350	31.000	31.000
0	1510	2.022	3.115	4.930	5.650	5.210	5.320	31.000	31.000
0	2310	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
1	1050	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
1	1550	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
1	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
2	1150	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
2	1650	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
2	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
3	1250	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
3	1750	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
3	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
4	1350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
4	1850	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
4	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
5	1450	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
5	1950	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
5	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
6	1550	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
6	2050	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
6	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
7	1650	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
7	2150	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
7	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
8	1750	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
8	2250	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
8	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
9	1850	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
9	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
10	1950	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
10	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
11	2050	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
11	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
12	2150	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
12	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
13	2250	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
13	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
14	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
15	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
16	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
17	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
18	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
19	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
20	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
21	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
22	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
23	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
24	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
25	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000
26	2350	2.006	3.022	4.930	5.650	5.210	5.320	31.000	31.000

RAW DATA---RUN 8

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW

RAW DATA--RUN 9

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RAW DATA--RUN 10

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	1237	-1.960	0	-0.430	0	-0.740	0	5.[illegible]	5.020
0	1238	-1.960	0	-0.430	0	0	-0.610	5.[illegible]	5.[illegible]
0	1543	-1.940	0	-0.430	0	0	-0.610	5.[illegible]	5.[illegible]
0	1544	-1.940	0	-0.420	0	-0.730	0	5.[illegible]	5.[illegible]
0	[illegible]	-1.940	0	-0.420	-0.500	0	0	5.[illegible]	5.[illegible]
0	[illegible]	-1.940	0	-0.410	0	-0.730	0	5.[illegible]	5.[illegible]
0	[illegible]	-1.930	0	-0.410	0	0	-0.610	4.[illegible]	5.[illegible]
1	[illegible]	-1.960	0	-0.440	-0.530	0	0	4.970	5.030
1	[illegible]	-1.960	0	-0.420	-0.520	0	0	4.990	5.[illegible]
1	1220	-1.960	0	-0.430	-0.520	0	0	4.990	5.[illegible]
1	1246	-1.970	0	-0.420	0	-0.760	0	4.990	5.[illegible]
1	1247	-1.970	0	-0.430	0	0	-0.620	5.020	5.[illegible]
1	1551	-1.960	0	-0.410	0	-0.740	0	5.[illegible]	5.[illegible]
1	1552	-1.960	0	-0.410	0	0	-0.600	5.[illegible]	5.[illegible]
1	[illegible]	-1.960	0	-0.410	-0.510	0	0	4.[illegible]	5.[illegible]
1	21 7	-1.970	0	-0.420	0	-0.750	0	4.[illegible]	5.[illegible]
2	21 8	-1.970	0	-0.420	0	0	-0.610	4.[illegible]	4.990
2	[illegible]	-1.970	0	-0.410	-0.530	0	0	4.[illegible]	5.[illegible]
2	10	-1.960	0	-0.330	-0.430	0	0	5.[illegible]	5.[illegible]
2	1120	-1.970	0	-0.400	0	-0.730	0	5.[illegible]	5.330

RAW DATA--RUN 11

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RAW DATA--RUN 12

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	1418	-1.960	0	.100	-0	0	0	6.520	4.990
0	1420	-1.950	0	.090	0	-0.320	0	6.520	5.020
0	1421	-1.950	0	.090	0	0	-0.150	[illegible]	[illegible]
0	1833	-1.950	0	.090	0	0	-0.170	[illegible]	[illegible]
0	1840	-1.950	0	.080	0	-0.330	0	[illegible]	[illegible]
0	21 0	-1.950	0	.090	-0.010	0	0	[illegible]	[illegible]
0	2230	-1.940	0	.090	0	-0.320	0	[illegible]	[illegible]
0	23 0	-1.950	0	.090	0	0	-0.160	[illegible]	[illegible]
1	0 0	-1.960	0	.080	-0.030	0	0	[illegible]	[illegible]
1	5 0	-1.970	0	.070	-0.030	0	0	[illegible]	[illegible]
1	1117	-1.970	0	.070	0	-0.350	0	[illegible]	[illegible]
1	1119	-1.970	0	.070	0	0	-0.190	[illegible]	[illegible]
1	12 0	-1.960	0	.090	-0.020	0	0	[illegible]	[illegible]
1	15 2	-1.960	0	.090	0	-0.330	0	[illegible]	[illegible]
1	15 ?	-1.950	0	.090	0	0	-0.170	[illegible]	[illegible]
1	1755	-1.950	0	.100	0	-0.330	0	[illegible]	[illegible]
1	1757	-1.950	0	.090	0	0	-0.170	[illegible]	[illegible]
1	18 0	-1.960	0	.090	-0.010	0	0	[illegible]	[illegible]
1	2252	-1.950	0	.090	0	-0.330	0	[illegible]	[illegible]
1	2254	-1.950	0	.100	0	0	-0.160	[illegible]	[illegible]
2	0 0	-1.950	0	.100	-0	0	0	[illegible]	[illegible]
2	5 0	-1.950	0	.100	-0	0	0	[illegible]	[illegible]
2	1136	-1.970	0	.090	0	-0.340	0	[illegible]	[illegible]
2	1525	-1.960	0	.110	0	-0.310	0	[illegible]	[illegible]
2	1523	-1.950	0	.110	0	0	-0.150	[illegible]	[illegible]
2	1853	-1.950	0	.110	0	-0.320	0	[illegible]	[illegible]
2	1857	-1.960	0	.110	0	0	-0.160	[illegible]	[illegible]
2	2217	-1.950	0	.120	0	-0.320	0	[illegible]	[illegible]
2	2219	-1.950	0	.120	0	0	-0.170	[illegible]	[illegible]
3	0 0	-1.960	0	.110	-0	0	0	[illegible]	[illegible]
3	6 0	-1.940	0	.130	0	0	0	[illegible]	[illegible]
3	1117	-1.970	0	.110	0	-0.320	0	[illegible]	[illegible]
3	1129	-1.940	0	.140	0	0	-0.120	[illegible]	[illegible]
3	12 0	-1.960	0	.130	-0	0	0	[illegible]	[illegible]
3	143?	-1.940	0	.150	0	-0.310	0	[illegible]	[illegible]
3	1445	-1.940	0	.150	0	0	-0.100	[illegible]	[illegible]
3	1754	-1.960	0	.110	0	-0.320	0	[illegible]	[illegible]
3	1755	-1.960	0	.120	0	0	-0.140	[illegible]	[illegible]
3	18 0	-1.970	0	.110	-0.010	0	0	[illegible]	[illegible]
4	0 0	-1.970	0	.120	-0	0	0	[illegible]	[illegible]
4	6 0	-1.940	0	.140	.020	0	0	[illegible]	[illegible]
4	1052	-1.940	0	.160	0	-0.290	0	[illegible]	[illegible]
4	1053	-1.940	0	.140	0	0	-0.130	[illegible]	[illegible]
4	12 0	-1.950	0	.150	.030	0	0	[illegible]	[illegible]
4	1435	-1.960	0	.130	0	-0.340	0	[illegible]	[illegible]
4	1753	-1.970	0	.130	0	-0.310	0	[illegible]	[illegible]
4	1755	-1.970	0	.120	0	0	-0.130	[illegible]	[illegible]
4	18 0	-1.970	0	.130	0	0	0	[illegible]	[illegible]
4	2238	-1.960	0	.140	0	-0.330	0	[illegible]	[illegible]
5	6 0	-1.960	0	.130	0	0	0	[illegible]	[illegible]
5	1211	-1.980	0	.120	0	0	0	[illegible]	[illegible]
5	1212	-1.980	0	.130	0	-0.330	0	[illegible]	[illegible]
5	1213	-1.970	0	.130	0	0	-0.140	[illegible]	[illegible]
5	1494	-1.960	0	.120	0	-0.310	0	[illegible]	[illegible]
5	1451	-1.960	0	.130	0	0	-0.130	[illegible]	[illegible]
5	1728	-1.940	0	.140	0	-0.300	0	[illegible]	[illegible]
5	1730	-1.950	0	.140	0	0	-0.130	[illegible]	[illegible]
5	19 0	-1.960	0	.120	0	0	0	[illegible]	[illegible]
6	1229	-1.970	0	.120	0	-0.330	0	[illegible]	[illegible]
6	1231	-1.960	0	.120	0	0	-0.160	[illegible]	[illegible]
6	1614	-1.950	0	.130	0	-0.310	0	[illegible]	[illegible]
6	1616	-1.950	0	.130	0	0	-0.150	[illegible]	[illegible]
6	19 0	-1.970	0	.120	-0	0	0	[illegible]	[illegible]
6	2317	-1.940	0	.140	0	-0.320	0	[illegible]	[illegible]
6	2319	-1.940	0	.140	0	0	-0.130	[illegible]	[illegible]
7	0 0	-1.950	0	.130	.010	0	0	[illegible]	[illegible]
7	9 0	-1.940	0	.150	.010	0	0	[illegible]	[illegible]
7	1252	-1.960	0	.120	0	-0.340	0	[illegible]	[illegible]
7	1257	-1.960	0	.120	0	0	-0.150	[illegible]	[illegible]
7	15 0	-1.950	0	.130	.010	0	0	[illegible]	[illegible]
7	1720	-1.950	0	.130	0	-0.340	0	[illegible]	[illegible]
7	1722	-1.950	0	.120	0	0	-0.150	[illegible]	[illegible]
7	21 0	-1.960	0	.110	-0	0	0	[illegible]	[illegible]
7	2328	-1.950	0	.120	0	-0.370	0	[illegible]	[illegible]
7	2330	-1.960	0	.110	0	0	-0.170	[illegible]	[illegible]
8	0 0	-1.940	0	.130	-0	0	0	[illegible]	[illegible]
8	8 0	-1.930	0	.130	0	0	0	[illegible]	[illegible]
8	1217	-1.950	0	.120	0	-0.340	0	[illegible]	[illegible]
8	1220	-1.950	0	.110	0	0	-0.130	[illegible]	[illegible]
8	14 0	-1.970	0	.110	-0.010	0	0	[illegible]	[illegible]
8	1525	-1.970	0	.110	0	-0.370	0	[illegible]	[illegible]
8	1528	-1.970	0	.110	0	0	-0.130	[illegible]	[illegible]
8	1939	-1.950	0	.120	0	-0.340	0	[illegible]	[illegible]
8	1941	-1.950	0	.120	0	0	-0.160	[illegible]	[illegible]
8	20 0	-1.950	0	.120	-0.010	0	0	[illegible]	[illegible]
8	22 7	-1.950	0	.120	0	-0.340	0	[illegible]	[illegible]
9	0 0	-1.950	0	.130	-0	0	0	6.470	4.980
9	5 0	-1.950	0	.130	0	0	0	6.480	5.010
9	1051	-1.970	0	.130	0	-0.340	0	6.490	4.980

RAW DATA--RUN 13

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	0	0	0	0	-0.240	-0.21	-0.23	0	0
0	0	0	0	0	0	-0.22	-0.28	0	0
0	0	0	0	0	0	-0.22	-0.27	0	0
0	0	0	0	0	-0.26	-0.23	-0.26	0	0
0	0	0	0	0	-0.29	-0.25	-0.29	0	0
0	0	0	0	0	-0.26	-0.26	-0.30	0	0
0	0	0	0	0	-0.23	-0.25	-0.26	0	0
0	0	0	0	0	-0.30	-0.25	-0.31	0	0
0	0	0	0	0	-0.23	-0.24	-0.29	0	0
0	0	0	0	0	-0.24	-0.24	-0.29	0	0
0	0	0	0	0	-0.27	-0.20	-0.25	0	0
0	0	0	0	0	-0.23	-0.24	-0.30	0	0
0	0	0	0	0	-0.24	-0.24	-0.29	0	0
0	0	0	0	0	-0.25	-0.22	-0.26	0	0
0	0	0	0	0	-0.24	-0.21	-0.25	0	0
0	0	0	0	0	-0.24	-0.22	-0.27	0	0
0	0	0	0	0	-0.24	-0.23	-0.25	0	0
0	0	0	0	0	-0.21	-0.21	-0.26	0	0
0	0	0	0	0	-0.20	-0.18	-0.24	0	0
0	0	0	0	0	-0.20	-0.17	-0.21	0	0
0	0	0	0	0	-0.20	-0.17	-0.21	0	0
0	0	0	0	0	-0.17	-0.18	-0.22	0	0
0	0	0	0	0	-0.21	-0.17	-0.22	0	0
0	0	0	0	0	-0.18	-0.16	-0.21	0	0
0	0	0	0	0	-0.14	-0.21	-0.19	0	0

RAW DATA--RUN 14

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	1430	-1.930	0	.810	.630	0	0	7.990	5.040
0	1432	-1.930	0	.820	0	.200	0	7.980	5.060
0	1434	-1.930	0	.910	0	0	.460	7.980	5.050
0	1650	-1.950	0	.790	0	.150	0	7.930	5.050
0	1656	-1.960	0	.790	0	0	.420	7.940	5.000
0	2212	-1.950	0	.750	.570	0	0	7.990	5.020
0	1729	-1.950	0	.730	0	.150	0	7.970	5.050
0	1735	-1.960	0	.780	0	.130	0	7.960	5.040
0	1739	-1.960	0	.730	0	.140	0	7.960	5.050
0	1745	-1.960	0	.770	0	.140	0	7.980	5.040
0	1751	-1.950	0	.780	0	.140	0	7.950	5.020
0	18 1	-1.960	0	.770	0	.140	0	7.950	5.050
0	18 5	-1.960	0	.770	0	.130	0	7.960	5.050
0	1811	-1.970	0	.770	0	.130	0	7.950	5.030
0	1821	-1.980	0	.760	0	.110	0	7.960	5.010
0	1827	-1.970	0	.770	0	.130	0	7.980	5.020
0	1833	-1.960	0	.770	0	.140	0	7.980	5.000
0	1946	-1.960	0	.770	0	.100	0	7.990	5.020
0	23 0	-1.950	0	.770	0	0	.410	7.970	5.010
0	23 7	-1.950	0	.750	0	.110	0	7.980	5.010
1	5 0	-1.970	0	.760	.540	0	0	7.950	4.980
1	6 0	-1.970	0	.750	.540	0	0	7.960	4.980
1	1048	-1.940	0	.780	0	.120	0	7.980	4.980
1	1050	-1.950	0	.780	0	0	.410	7.940	4.980
1	12 0	-1.950	0	.780	.570	0	0	7.970	4.980
1	15 3	-1.940	0	.790	0	.130	0	7.970	4.990
1	15 5	-1.940	0	.790	0	0	.420	7.980	4.980
1	19 0	-1.970	0	.750	.540	0	0	7.960	4.970
1	1912	-1.980	0	.740	0	.100	0	7.980	5.010
1	1914	-1.970	0	.750	0	0	.390	7.970	4.990
1	2220	-1.970	0	.750	0	.100	0	7.960	4.990
1	2222	-1.980	0	.760	0	0	.410	7.980	5.000
2	7 0	-1.970	0	.760	.530	0	0	7.960	4.990
2	1213	-1.970	0	.750	0	.090	0	7.970	4.990
2	1217	-1.980	0	.750	0	0	.390	7.990	5.000
2	13 0	-1.990	0	.750	.540	0	0	8.000	4.980
2	15 7	-1.980	0	.750	0	.100	0	7.990	4.970
2	15 9	-1.980	0	.750	0	0	.400	7.970	5.000
2	19 0	-1.970	0	.770	.540	0	0	7.960	4.990
2	1937	-1.960	0	.760	0	.110	0	7.960	4.980
2	1939	-1.960	0	.770	0	0	.400	7.980	4.980
2	2223	-1.960	0	.760	0	.100	0	7.970	4.990
2	2225	-1.960	0	.750	0	0	.400	7.970	4.970
3	0 0	-1.950	0	.800	.550	0	0	7.950	5.000
3	6 0	-1.970	0	.760	.540	0	0	7.960	5.000
3	1132	-1.920	0	.820	0	.150	0	7.990	5.010
3	1134	-1.920	0	.810	0	0	.420	7.980	4.990
3	14 0	-1.970	0	.770	.540	0	0	7.970	5.020
3	1551	-1.980	0	.750	0	.110	0	7.970	4.990
3	1552	-1.980	0	.750	0	0	.400	7.980	4.980
3	1854	-1.970	0	.770	0	.090	0	7.960	4.990
3	1856	-1.970	0	.770	0	0	.400	7.960	4.980
3	20 0	-1.960	0	.780	.560	0	0	7.950	4.970
3	23 4	-1.950	0	.800	0	.130	0	7.980	4.990
3	23 6	-1.950	0	.790	0	0	.430	7.960	4.960
4	10 0	-1.950	0	.810	.530	0	0	7.980	4.980
4	1225	-1.960	0	.800	0	.120	0	7.960	4.990
4	1219	-1.960	0	.790	0	0	.430	7.970	5.000
4	16 0	-1.940	0	.810	.590	0	0	7.950	4.990
4	1931	-1.970	0	.790	0	.100	0	7.960	4.980
4	1933	-1.970	0	.790	0	0	.420	7.980	4.980
4	22 0	-1.960	0	.800	.530	0	0	7.950	5.010
4	2345	-1.980	0	.800	0	.120	0	7.960	5.000
4	2347	-1.980	0	.790	0	0	.430	7.970	5.020
5	0 0	-1.960	0	.810	.590	0	0	7.970	5.010
5	6 0	-1.950	0	.820	.600	0	0	7.970	5.000
5	12 0	-1.970	0	.810	.580	0	0	7.970	4.990
5	1233	-1.980	0	.800	0	.110	0	7.970	4.980
5	1235	-1.950	0	.790	0	0	.420	7.960	4.980
5	18 0	-1.970	0	.800	.530	0	0	7.960	5.000
5	2121	-1.950	0	.830	0	.120	0	7.950	5.000
5	2125	-1.960	0	.830	0	0	.450	7.950	4.980
5	2354	-1.960	0	.830	0	.160	0	7.980	4.990
5	2356	-1.950	0	.830	0	0	.460	7.980	5.020
6	7 0	-1.950	0	.850	.610	0	0	7.960	4.990
6	1153	-1.970	0	.840	0	.160	0	7.980	5.000
6	1155	-1.970	0	.840	0	0	.440	7.970	5.010
6	13 0	-1.960	0	.840	.620	0	0	7.930	4.980

RAW DATA--RUN 15

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWO	HEAT	FLOW
0	1420	2.080	2.130	4.920	4.870	4.550	0	1.000	31.000
0	1850	2.054	2.110	4.910	4.870	4.540	0	1.000	31.000
0	2215	2.058	2.113	4.910	4.860	4.540	0	1.000	31.000
1	11 5	2.065	2.125	4.980	4.940	4.620	0	1.002	30.800
1	16 0	2.079	2.135	4.920	4.890	4.560	0	.996	31.000
1	1911	2.038	2.094	4.910	4.880	4.550	0	1.000	31.000
1	2050	2.068	2.123	4.920	4.890	4.560	0	1.000	31.000
1	2215	2.061	2.116	4.930	4.890	4.560	0	1.000	31.000
2	1225	2.033	2.089	4.960	4.910	4.580	0	1.000	31.000
2	15 5	2.038	2.095	4.960	4.920	4.600	0	1.000	31.000
2	1935	2.057	2.112	4.980	4.950	4.610	0	1.000	31.000
2	2225	2.056	2.111	4.980	4.950	4.620	0	1.000	31.000
3	1140	2.034	2.092	5.040	5.010	4.660	0	1.000	31.000
3	1715	2.036	2.094	5.040	5.000	4.670	0	1.000	31.000
3	19 0	2.049	2.105	5.040	5.010	4.670	0	1.000	31.000
3	2250	2.072	2.127	5.060	5.030	4.700	0	.998	31.000
4	1240	2.059	2.114	5.120	5.090	4.750	0	1.000	31.000
4	17 0	2.076	2.130	5.090	5.050	4.710	0	1.000	31.300
4	1950	2.050	2.106	5.140	5.110	4.760	0	.999	31.000
4	2345	2.044	2.100	5.180	5.150	4.800	0	1.000	31.000
5	1245	2.036	2.093	5.240	5.200	4.860	0	1.000	31.000
5	17 5	2.042	2.099	5.260	5.230	4.870	0	.998	31.000
5	2120	2.067	2.123	5.310	5.270	4.920	0	1.000	31.000
5	2345	2.064	2.119	5.320	5.290	4.920	0	1.000	31.000
6	12 0	2.050	2.106	5.400	5.360	5.000	0	1.000	31.000
6	1537	2.048	2.106	5.400	5.360	5.000	0	1.000	31.000
6	1837	2.031	2.088	5.410	5.370	5.000	0	.999	31.000
6	2320	2.063	2.119	5.450	5.410	5.040	0	.999	31.000
7	1215	2.037	2.093	5.520	5.470	5.100	0	.997	31.000
7	1745	2.045	2.102	5.550	5.490	5.120	1.000	1.000	31.000
7	2313	2.052	2.103	5.580	5.530	5.160	0	.998	31.000
8	1140	2.061	2.118	5.660	5.590	5.220	0	.999	31.000
8	1345	2.043	2.100	5.660	5.600	5.230	1.000	1.000	31.000
8	1515	2.068	2.117	5.680	5.630	5.240	0	.998	31.000
8	1 0	2.049	2.105	5.690	5.620	5.240	0	.998	31.000
8	2220	2.057	2.112	5.720	5.650	5.270	1.000	1.000	31.000
9	1213	2.057	2.115	5.790	5.730	5.350	0	.998	31.000
9	15 0	2.043	2.099	5.820	5.740	5.370	1.000	1.000	31.000
9	1720	2.048	2.106	5.820	5.760	5.380	0	.999	31.000
9	2315	2.071	2.127	5.920	5.840	5.450	1.000	1.000	31.000
10	11 5	2.056	2.112	6.000	5.900	5.520	1.000	1.000	31.000
10	1345	2.045	2.102	6.020	5.930	5.540	1.000	1.000	31.000
10	1735	2.036	2.093	6.040	5.950	5.570	1.000	1.000	31.000
10	23 0	2.068	2.124	6.100	6.000	5.610	1.000	1.000	31.000
11	1150	2.027	2.084	6.130	6.030	5.640	1.000	1.000	31.000
11	1545	2.049	2.106	6.150	6.080	5.690	0	.998	31.000
11	1850	2.057	2.113	6.210	6.110	5.720	1.000	1.000	31.000
11	2255	2.064	2.119	6.220	6.130	5.730	0	.999	31.000
12	1225	2.056	2.113	6.270	6.150	5.770	1.000	1.000	31.000
12	14 0	2.060	2.116	6.270	6.160	5.780	1.000	1.000	31.000
12	17 0	2.053	2.110	6.270	6.150	5.790	1.000	1.000	31.000
12	20 2	2.075	2.130	6.290	6.170	5.800	1.000	1.000	31.000
12	23 0	2.070	2.125	6.300	6.180	5.810	1.000	1.000	31.000
13	1135	2.065	2.121	6.340	6.200	5.840	1.000	1.000	31.000
13	1435	2.059	2.115	6.350	6.200	5.840	1.000	1.000	31.000
13	1715	2.068	2.125	6.370	6.220	5.860	1.000	1.000	31.000
13	2330	2.036	2.092	6.340	6.190	5.840	1.000	1.000	31.000
14	925	2.042	2.100	6.410	6.260	5.910	1.000	1.000	31.000
14	1355	2.077	2.135	6.430	6.280	5.930	0	.998	31.000
14	1130	2.094	2.145	6.400	6.240	5.890	1.000	1.000	31.500
22	12 5	2.061	2.114	6.400	6.260	5.910	0	.999	31.000
22	1320	2.051	2.105	6.370	6.200	5.850	0	.995	31.400
22	1511	2.017	2.072	6.350	6.170	5.820	0	.998	31.000
22	1745	2.044	2.099	6.380	6.210	5.860	0	.998	31.000
22	2235	2.037	2.093	6.380	6.210	5.860	0	.998	31.000
23	1115	2.044	2.099	6.410	6.240	5.890	0	.998	31.000
23	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
23	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
23	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
24	1130	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
24	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
24	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
24	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
25	1130	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
25	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
25	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
25	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
26	1130	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
26	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
26	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
26	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
27	1130	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
27	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
27	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
27	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
28	1130	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
28	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
28	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
28	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
29	1130	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
29	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
29	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
29	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
30	1130	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
30	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
30	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
30	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
31	1130	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
31	1445	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
31	1745	2.046	2.101	6.420	6.250	5.900	0	.998	31.000
31	2230	2.046	2.101	6.420	6.250	5.900	0	.998	31.000

25	1715	2.038	2.096	6.660	6.590	6.220	0	.998	31.000
25	2220	2.065	2.123	6.690	6.620	6.250	0	.998	31.000
26	1235	2.040	2.095	6.710	6.650	6.290	0	.998	31.000
26	1735	2.039	2.097	6.740	6.690	6.310	0	1.000	30.900
26	2210	2.060	2.106	6.760	6.710	6.320	0	.998	31.000
27	1030	2.067	2.125	6.910	6.750	6.370	0	1.000	31.000
27	14 0	2.046	2.105	6.820	6.770	6.380	0	1.000	31.000
27	1725	2.032	2.090	6.810	6.750	6.360	0	.995	31.000
27	2220	2.023	2.080	6.800	6.760	6.370	0	.995	31.000
28	1030	2.083	2.140	6.920	6.870	6.480	0	1.000	31.000
28	1335	2.044	2.103	6.910	6.860	6.460	0	1.000	31.000
28	1825	2.026	2.085	6.890	6.830	6.440	0	1.000	31.000
28	2235	2.034	2.091	6.890	6.840	6.440	0	.997	31.000
29	1040	2.080	2.137	7.000	6.940	6.550	0	1.002	31.000
29	1540	2.072	2.129	6.980	6.930	6.540	0	.998	31.000
29	1825	2.034	2.093	6.980	6.930	6.520	0	.998	31.000
29	20 0	2.051	2.108	6.990	6.930	6.540	0	1.000	31.000
29	2235	2.055	2.112	6.990	6.940	6.540	0	.997	31.000
30	1410	2.070	2.130	7.090	7.030	6.630	0	1.000	30.900
30	18 0	2.038	2.098	7.060	7.000	6.600	0	1.000	31.000
30	2225	2.036	2.092	7.060	7.000	6.600	0	.998	31.000
31	1010	2.039	2.097	7.120	7.060	6.650	0	1.000	30.800
31	1345	2.074	2.133	7.140	7.090	6.690	0	1.000	31.000
31	1910	2.040	2.099	7.110	7.060	6.650	0	.999	31.000
31	2130	2.053	2.110	7.140	7.080	6.670	0	1.000	31.000
32	950	2.030	2.087	7.150	7.090	6.700	0	.995	30.900
32	1320	2.050	2.108	7.180	7.130	6.730	0	1.000	31.000
32	1830	2.039	2.096	7.170	7.120	6.720	0	1.000	31.000
32	23 0	2.059	2.110	7.220	7.160	6.760	0	.997	31.000
33	1055	2.059	2.117	7.290	7.220	6.820	0	1.000	31.000
33	1530	2.055	2.112	7.290	7.240	6.830	0	.998	31.000
33	19 5	2.044	2.102	7.290	7.240	6.840	0	.998	31.000
33	2245	2.046	2.103	7.300	7.240	6.840	0	.996	31.000
34	1030	2.079	2.135	7.410	7.340	6.940	0	1.005	31.000
34	1445	2.050	2.108	7.400	7.330	6.930	0	1.000	31.000
34	1620	2.035	2.093	7.390	7.330	6.910	0	1.000	31.000
34	2315	2.042	2.098	7.390	7.320	6.920	0	.997	31.000
35	1030	2.065	2.123	7.480	7.410	7.010	0	1.000	31.000
35	1420	2.040	2.099	7.490	7.430	7.020	0	1.000	31.000
35	1750	2.031	2.090	7.480	7.420	7.000	0	1.000	31.000
35	22 5	2.025	2.083	7.480	7.410	7.010	0	.998	31.000
36	1015	2.060	2.118	7.600	7.530	7.120	0	1.000	31.000
36	1310	2.052	2.110	7.610	7.540	7.130	0	1.002	31.000
36	1720	2.030	2.087	7.570	7.500	7.090	0	1.000	31.000
36	2350	2.044	2.100	7.580	7.490	7.100	0	.998	31.000
37	1020	2.042	2.099	7.610	7.520	7.120	0	.999	31.000
37	14 0	2.063	2.119	7.640	7.540	7.150	0	1.000	31.000
37	2315	2.053	2.109	7.640	7.520	7.150	0	.998	31.000
38	1710	2.080	2.136	7.720	7.600	7.230	0	1.000	31.000
38	2130	2.052	2.108	7.690	7.580	7.200	0	.997	31.000
39	1030	2.048	2.105	7.800	7.690	7.300	0	.997	31.000
39	1455	2.035	2.092	7.810	7.710	7.310	0	1.000	31.000
39	1630	2.042	2.097	7.820	7.720	7.320	0	1.000	31.000
39	2110	2.065	2.120	7.830	7.730	0	0	.995	31.000
39	2310	2.074	2.130	7.880	7.780	7.400	0	1.000	31.000
40	1325	2.048	2.104	7.930	7.830	7.440	0	1.000	31.000
40	17 0	2.040	2.095	7.940	7.840	7.450	0	1.000	31.000
40	20 0	2.048	2.104	7.950	7.860	7.460	0	1.000	31.000
41	1035	2.048	2.105	8.030	7.940	7.550	0	1.000	31.000
41	1320	2.063	2.120	8.070	7.980	7.570	0	1.000	31.000
41	19 0	2.040	2.096	8.070	7.990	7.580	0	1.000	31.000
41	2343	2.055	2.110	8.100	8.010	7.610	0	1.000	31.000
42	910	2.073	2.128	8.170	8.090	7.690	0	1.000	31.000
42	14 0	2.045	2.104	8.220	8.130	7.720	0	1.005	31.000
42	2230	2.046	2.102	8.130	8.100	7.700	0	.995	31.000
43	930	2.027	2.085	8.250	8.190	7.790	0	1.000	30.800
43	14 0	2.060	2.117	8.260	8.180	7.770	0	1.002	31.000
43	1750	2.029	2.085	8.190	8.110	7.700	0	.997	31.000
43	2230	2.041	2.095	8.200	8.110	7.710	0	.995	31.000
44	930	2.075	2.130	8.290	8.210	7.800	0	1.002	31.000
44	1245	2.064	2.121	8.280	8.210	7.800	0	1.000	31.000
44	1740	2.047	2.103	8.260	8.190	7.770	0	1.000	31.000
44	24 0	2.039	2.094	8.240	8.150	7.750	0	1.000	31.000
45	1020	2.072	2.128	8.320	8.220	7.820	0	1.000	31.000
45	1310	2.064	2.120	8.320	8.220	7.810	0	1.000	31.000
45	1935	2.033	2.089	8.270	8.150	7.760	0	.997	31.000
46	11 0	2.059	2.114	8.300	8.170	7.780	0	1.000	31.000
46	1420	2.018	2.073	8.270	8.130	7.730	0	1.000	31.000
46	1825	2.039	2.094	8.260	8.110	7.720	0	1.000	31.000
46	2215	2.039	2.094	8.250	8.100	7.710	0	.999	31.000
47	1040	2.067	2.123	8.270	8.130	7.730	0	.999	31.000
47	12 0	2.067	2.123	8.290	8.140	7.730	0	1.000	31.000
47	1520	2.054	2.109	8.280	8.140	7.730	0	1.000	31.000
47	2215	2.049	2.103	8.240	8.100	7.700	0	.999	31.000
48	924	2.074	2.128	8.280	8.150	7.740	0	1.001	31.000
48	14 0	2.062	2.117	8.260	8.130	7.710	0	.999	31.100
48	2020	2.086	2.142	8.280	8.160	7.750	0	.995	31.000
48	2230	2.057	2.112	8.310	8.190	7.770	0	1.002	31.000
49	850	2.032	2.089	8.270	8.150	7.730	0	.996	31.000
49	1320	2.080	2.132	8.370	8.250	7.630	0	1.020	31.800
49	1550	2.068	2.121	8.170	8.140	7.760	0	.994	31.000
49	1820	2.041	2.096	8.330	8.190	7.840	0	.998	31.000
49	2030	2.088	2.141	8.360	8.230	7.870	0	1.000	31.000
49	2225	2.050	2.105	8.350	8.220	7.850	0	.998	31.000
50	820	2.059	2.112	8.370	8.240	7.870	0	.998	31.000

RAW DATA--RUN 15

DAY	TIME	TIN	TOUT	TW1	TW2	TW3	TW4	TW5	HEAT	FLOW

RAW DATA--RUN 17

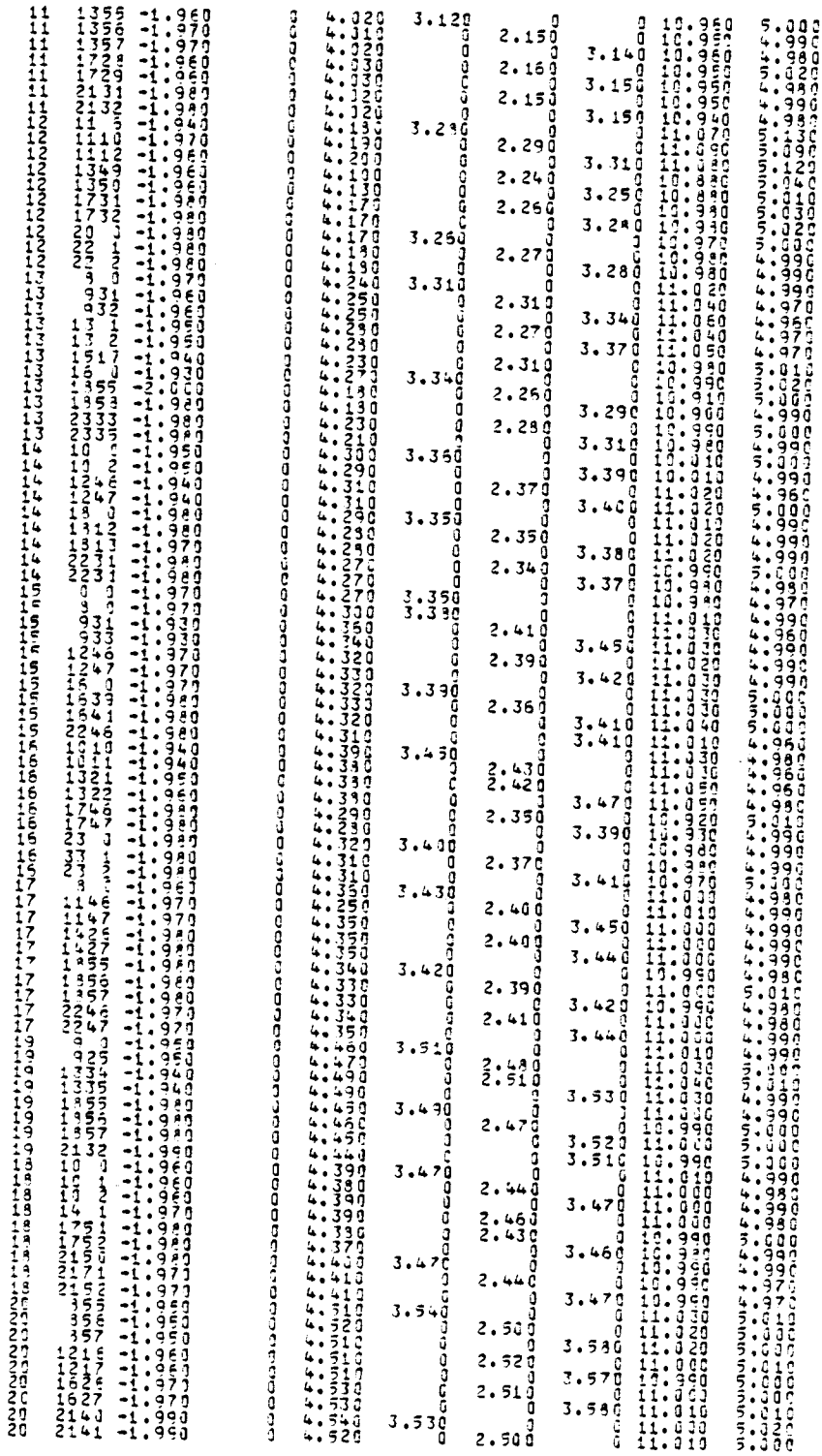
DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
7	1314	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1315	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1316	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1317	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1318	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1319	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1320	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1321	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1322	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1323	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1324	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1325	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1326	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1327	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1328	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1329	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1330	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1331	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1332	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1333	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1334	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1335	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1336	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1337	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1338	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1339	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1340	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1341	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1342	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1343	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1344	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1345	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1346	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1347	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1348	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1349	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1350	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1351	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1352	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1353	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1354	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1355	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1356	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1357	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1358	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1359	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1400	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1401	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1402	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1403	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1404	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1405	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1406	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1407	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1408	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1409	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1410	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1411	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1412	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1413	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1414	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1415	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1416	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1417	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1418	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1419	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1420	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1421	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1422	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1423	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1424	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1425	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1426	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1427	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1428	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1429	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1430	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1431	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1432	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1433	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1434	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1435	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1436	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1437	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1438	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1439	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0
7	1440	1.78	1.75	1.11	1.12	1.63	1.0	0.0	0.0

RAW DATA--RUN 16

DAY	TIME	TIN	TOUT	TW4	TW3	TW2	TW1	HEAT	FLOW

RAW DATA--RUN 19

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	1125	-1.950	0	3.250	2.650	0	0	1.000	.980
0	1211	-1.960	0	3.250	0	1.350	0	1.000	.980
0	2025	-1.930	0	3.290	0	1.870	0	1.000	.980
0	2136	-1.970	0	3.290	0	0	2.530	1.000	.980
0	811	-1.960	0	3.310	0	1.390	0	1.000	.980
0	1213	-1.950	0	3.300	0	1.380	0	1.000	.980
0	1216	-1.960	0	3.290	0	0	2.540	1.000	.980
0	1221	-1.960	0	3.270	0	1.390	0	1.000	.980
0	1600	-1.960	0	3.290	0	0	2.520	1.000	.980
0	2027	-1.970	0	3.250	2.630	0	0	1.000	.980
0	2029	-1.970	0	3.240	0	1.850	0	1.000	.980
0	2030	-1.970	0	3.240	0	0	2.510	1.000	.980
0	756	-1.950	0	3.290	2.670	0	0	1.000	.980
0	1125	-1.950	0	3.290	2.730	0	0	1.000	.980
0	1129	-1.940	0	3.300	0	1.930	0	1.000	.980
0	1130	-1.970	0	3.290	0	0	2.570	1.000	.980
0	1631	-1.960	0	3.270	2.720	0	0	1.000	.980
0	1632	-1.960	0	3.270	0	1.900	0	1.000	.980
0	2130	-1.970	0	3.250	0	0	2.540	1.000	.980
0	2131	-1.970	0	3.250	2.710	0	0	1.000	.980
0	2132	-1.970	0	3.260	0	1.890	0	1.000	.980
0	10	-1.980	0	3.240	0	0	2.530	1.000	.980
0	11	-1.980	0	3.240	2.690	0	0	1.000	.980
0	1533	-1.970	0	3.240	0	1.900	0	1.000	.980
0	1934	-1.960	0	3.220	0	0	2.510	1.000	.980
0	8	-1.960	0	3.260	2.650	0	2.490	1.000	.980
0	917	-1.960	0	3.290	2.700	0	0	1.000	.980
0	918	-1.950	0	3.300	0	1.890	0	1.000	.980
0	1237	-1.970	0	3.300	0	0	2.510	1.000	.980
0	1240	-1.970	0	3.300	0	1.890	0	1.000	.980
0	2317	-1.970	0	3.310	0	0	2.510	1.000	.980
0	8	-1.960	0	3.290	2.670	0	0	1.000	.980
0	933	-1.960	0	3.310	2.630	0	0	1.000	.980
0	934	-1.960	0	3.310	2.710	0	0	1.000	.980
0	1	-1.940	0	3.390	0	1.870	0	1.000	.980
0	3	-1.940	0	3.380	0	1.920	0	1.000	.980
0	1110	-1.940	0	3.360	0	1.920	0	1.000	.980
0	1111	-1.970	0	3.370	2.710	0	2.560	1.000	.980
0	1112	-1.980	0	3.330	0	1.890	0	1.000	.980
0	1113	-1.970	0	3.350	0	1.870	0	1.000	.980
0	2111	-1.980	0	3.350	0	0	2.540	1.000	.980
0	2112	-1.980	0	3.530	2.770	0	0	1.000	.980
0	911	-1.940	0	3.440	0	1.930	0	1.000	.980
0	912	-1.940	0	3.500	0	1.960	0	1.000	.980
0	1114	-1.930	0	3.500	0	0	2.620	1.000	.980
0	1115	-1.930	0	3.510	0	1.880	0	1.000	.980
0	1116	-1.980	0	3.550	0	0	2.670	1.000	.980
0	1117	-1.980	0	3.550	2.750	0	0	1.000	.980
0	2251	-1.980	0	3.550	0	1.890	0	1.000	.980
0	2252	-1.970	0	3.550	0	0	2.680	1.000	.980
0	331	-1.920	0	3.710	2.830	0	0	1.000	.980
0	332	-1.920	0	3.730	0	1.990	0	1.000	.980
0	333	-1.960	0	3.730	0	0	2.739	1.000	.980
0	1131	-1.960	0	3.770	0	1.970	0	1.000	.980
0	1132	-1.960	0	3.770	0	0	2.390	1.000	.980
0	1541	-1.960	0	3.790	0	1.960	0	1.000	.980
0	1542	-1.960	0	3.770	0	0	2.370	1.000	.980
0	2133	-1.960	0	3.770	2.850	0	0	1.000	.980
0	2134	-1.960	0	3.770	0	1.960	0	1.000	.980
0	8	-1.960	0	3.770	0	0	2.360	1.000	.980
0	9	-1.960	0	3.770	2.920	0	0	1.000	.980
0	10	-1.960	0	3.800	0	2.050	0	1.000	.980
0	1132	-1.960	0	3.800	0	2.010	0	1.000	.980
0	1133	-1.960	0	3.770	0	0	2.930	1.000	.980
0	1725	-1.960	0	3.760	2.910	0	0	1.000	.980
0	1726	-1.960	0	3.760	0	1.990	0	1.000	.980
0	1727	-1.960	0	3.750	0	2.000	0	1.000	.980
0	2115	-1.960	0	3.770	0	0	2.910	1.000	.980
0	2116	-1.970	0	3.860	3.000	0	0	1.000	.980
0	2117	-1.970	0	3.870	0	2.060	0	1.000	.980
0	1	-1.960	0	3.870	0	0	3.010	1.000	.980
0	2	-1.960	0	3.870	3.010	0	0	1.000	.980
0	1115	-1.960	0	3.940	0	2.060	0	1.000	.980
0	1116	-1.960	0	3.940	0	2.100	0	1.000	.980
0	1117	-1.960	0	3.930	0	0	3.070	1.000	.980
0	1735	-1.960	0	3.930	3.050	0	0	1.000	.980
0	1737	-1.960	0	3.940	0	2.090	0	1.000	.980
0	1738	-1.960	0	3.940	0	0	3.070	1.000	.980



RAW DATA--RUN 20

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	1030	2.082	2.115	3.530	3.480	3.800	3.630	.550	31.000
0	15 0	2.020	2.056	3.460	3.420	3.740	3.570	.550	31.000
0	2235	2.073	2.107	3.530	3.490	3.810	3.640	.551	31.000
1	1025	2.075	2.110	3.540	3.500	3.820	3.650	.552	31.000
1	13 5	2.053	2.088	3.520	3.480	3.800	3.630	.550	31.000
1	1715	2.050	2.085	3.520	3.470	3.800	3.620	.550	31.000
1	2130	2.042	2.075	3.500	3.460	3.780	3.610	.548	31.000
2	950	2.063	2.097	3.540	3.500	3.820	3.650	.554	31.000
2	1235	2.075	2.109	3.540	3.500	3.820	3.650	.545	31.000
2	1630	2.044	2.079	3.520	3.470	3.790	3.630	.553	31.000
2	2135	2.043	2.077	3.510	3.470	3.790	3.620	.550	31.000
3	1015	2.016	2.052	3.490	3.450	3.770	3.600	.550	31.000
3	1540	2.010	2.046	3.480	3.420	3.760	3.590	.550	31.000
3	1730	2.028	2.063	3.490	3.440	3.760	3.600	.550	31.000
3	23 0	2.036	2.068	3.490	3.440	3.760	3.600	.550	31.000
4	1010	2.044	2.078	3.500	3.460	3.780	3.610	.550	31.000
4	1345	2.038	2.072	3.510	3.470	3.790	3.630	.550	31.000
4	2120	2.038	2.072	3.510	3.470	3.790	3.620	.550	31.000
5	1025	2.055	2.091	3.540	3.490	3.830	3.650	.550	31.000
5	1225	2.047	2.081	3.520	3.470	3.810	3.630	.550	31.000
5	1810	1.973	2.008	3.450	3.410	3.730	3.560	.550	31.000
5	22 0	2.052	2.089	3.500	3.460	3.790	3.620	.550	31.000
6	915	2.065	2.100	3.550	3.500	3.830	3.670	.550	31.000
6	1310	2.083	2.118	3.570	3.520	3.860	3.680	.550	31.000
6	18 0	2.037	2.073	3.530	3.480	3.810	3.650	.545	31.000
6	2225	2.043	2.076	3.530	3.490	3.830	3.650	.548	31.000
7	935	2.093	2.128	3.590	3.550	3.890	3.710	.553	31.000
7	1230	2.056	2.092	3.550	3.510	3.850	3.680	.550	31.000
7	1640	2.044	2.080	3.540	3.500	3.840	3.660	.550	31.000
7	2035	2.028	2.062	3.530	3.480	3.830	3.650	.553	31.000
7	2230	2.031	2.065	3.520	3.480	3.820	3.640	.550	31.000
8	955	2.075	2.108	3.570	3.530	3.860	3.700	.550	31.000
8	1230	2.041	2.076	3.540	3.500	3.840	3.670	.550	31.000
8	18 0	2.024	2.059	3.520	3.480	3.820	3.650	.550	31.000
8	21 5	2.037	2.071	3.530	3.490	3.830	3.650	.548	31.000
9	1050	2.061	2.095	3.560	3.520	3.870	3.690	.552	31.000
9	1250	2.068	2.101	3.570	3.530	3.880	3.700	.551	31.000
9	17 0	2.039	2.075	3.540	3.500	3.850	3.670	.550	31.000
9	2240	2.045	2.071	3.540	3.500	3.850	3.670	.545	31.000
10	14 0	2.045	2.080	3.550	3.510	3.860	3.690	.548	31.000
10	1835	2.034	2.069	3.540	3.500	3.850	3.670	.546	31.000
10	2014	2.050	2.085	3.560	3.520	3.870	3.690	.548	31.000
11	1455	2.057	2.092	3.580	3.540	3.890	3.710	.553	31.000
11	1833	2.056	2.091	3.560	3.530	3.880	3.690	.550	31.000
11	2230	2.038	2.070	3.550	3.510	3.870	3.680	.550	31.000
12	1120	2.079	2.103	3.630	3.590	3.940	3.760	.562	31.000
12	1340	2.080	2.112	3.550	3.510	3.840	3.680	.543	31.100
12	18 0	2.033	2.068	3.520	3.480	3.820	3.650	.546	31.000
12	2255	2.039	2.072	3.520	3.470	3.800	3.640	.548	31.000
13	930	2.050	2.086	3.560	3.490	3.820	3.680	.553	31.000
13	13 0	2.070	2.106	3.570	3.510	3.830	3.690	.550	31.000

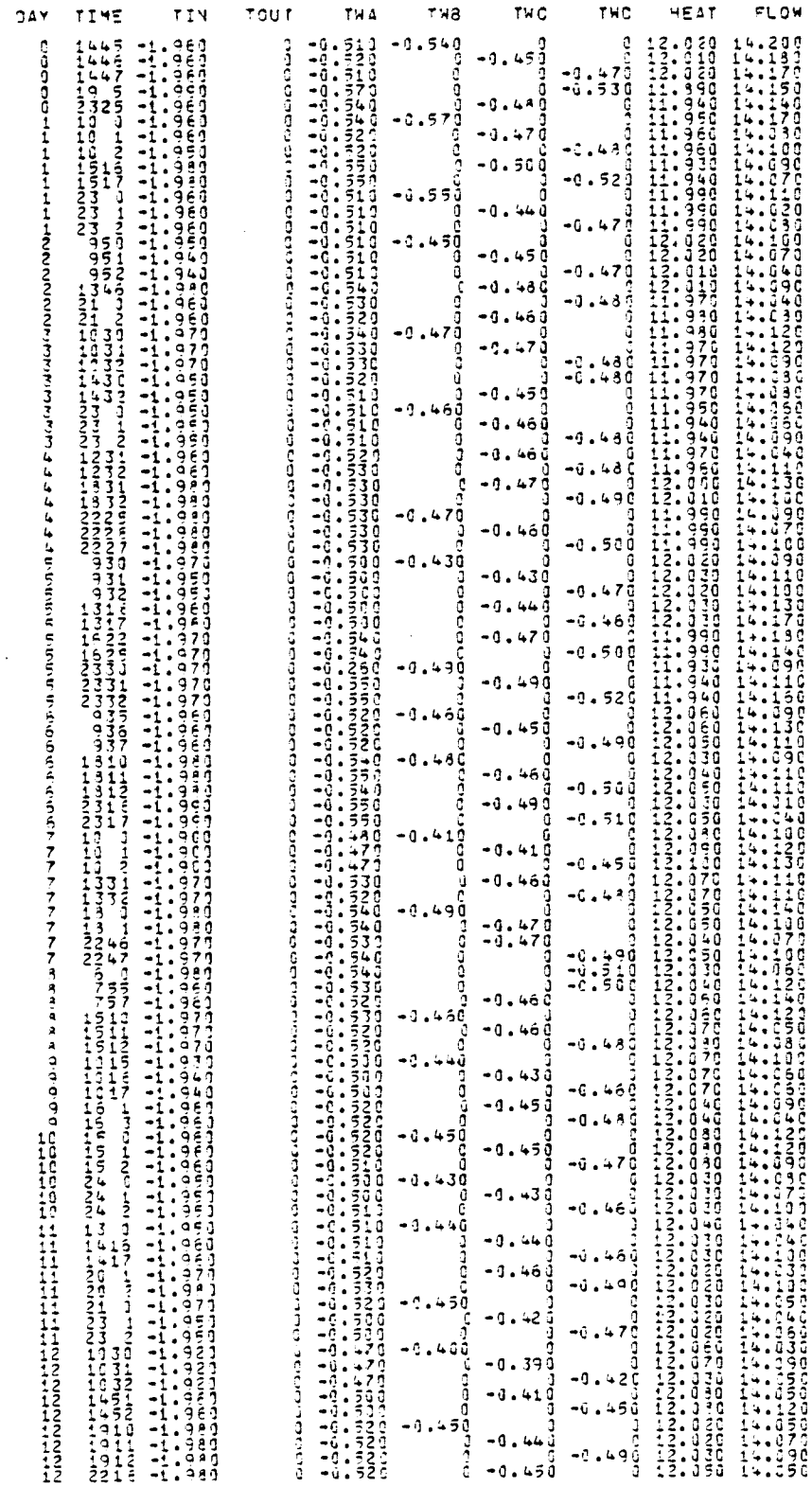
RAW DATA--RUN 21

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	14 0	2.0679	2.1155	3.340	3.760	.150	3.980	.6611	31.000
0	1425	2.0687	2.1122	3.350	3.770	.150	3.990	.6611	31.000
0	15 0	2.0671	2.1112	3.340	3.760	.140	3.980	.6611	31.000
0	1520	2.0667	2.1099	3.340	3.760	.130	3.970	.6611	31.000
0	1550	2.0674	2.1112	3.350	3.770	.140	3.990	.6611	31.000
0	1620	2.0673	2.1112	3.340	3.760	.140	3.980	.6611	31.000
0	1655	2.0667	2.1099	3.340	3.760	.130	3.970	.6611	31.000
0	1730	2.0659	2.0993	3.330	3.740	.130	3.960	.6611	31.000
0	1750	2.0648	2.0979	3.810	3.730	.110	3.950	.6611	31.000
0	1855	2.0616	2.0956	3.790	3.700	.090	3.920	.6611	31.000
0	2030	2.0635	2.0974	3.790	3.720	.110	3.940	.6611	31.000
0	2115	2.0636	2.0975	3.800	3.720	.100	3.940	.6611	31.000
0	2330	2.0627	2.0965	3.790	3.710	.100	3.930	.6611	31.000
1	10 0	2.0675	2.1148	3.340	3.760	.140	3.980	.6611	31.000
1	1245	2.0668	2.1108	3.330	3.750	.120	3.970	.6611	31.000
1	1730	2.0644	2.0983	3.810	3.730	.110	3.950	.6611	31.000
1	2230	2.0643	2.0982	3.810	3.720	.100	3.940	.6611	31.000
2	930	2.0673	2.1111	3.840	3.750	.120	3.980	.6611	31.000
2	1245	2.0642	2.0981	3.820	3.740	.100	3.960	.6611	31.000
2	1640	2.0635	2.0974	3.820	3.730	.110	3.950	.6611	31.000
2	2245	2.0636	2.0976	3.810	3.730	.110	3.950	.6611	31.000
3	1010	2.0676	2.1144	3.850	3.750	.150	3.990	.6611	31.000
3	1320	2.0665	2.1104	3.840	3.750	.140	3.990	.6611	31.000
3	1745	2.0638	2.0978	3.820	3.730	.110	3.950	.6611	31.000
3	1935	2.0637	2.0978	3.810	3.730	.110	3.950	.6611	31.000
3	23 0	2.0632	2.0971	3.810	3.720	.110	3.950	.6611	31.000
4	1145	2.0642	2.0982	3.820	3.730	.110	3.960	.6611	31.000
4	1425	2.0638	2.0978	3.820	3.740	.120	3.960	.6611	31.000
4	1855	2.0631	2.0970	3.820	3.730	.120	3.960	.6611	31.000
4	2245	2.0644	2.0983	3.830	3.740	.130	3.970	.6611	31.000
5	10 0	2.0653	2.0993	3.850	3.770	.150	3.990	.6611	31.000
5	14 0	2.0645	2.0984	3.850	3.750	.150	3.990	.6611	31.000
5	1750	2.0637	2.0976	3.840	3.750	.150	3.990	.6611	31.000
5	2150	2.0643	2.0982	3.850	3.750	.150	3.990	.6611	31.000
6	920	2.0665	2.1105	3.880	3.800	.200	4.030	.6611	31.000
6	1330	2.0678	2.1117	3.900	3.810	.210	4.050	.6611	31.000
6	1740	2.0626	2.0967	3.850	3.770	.170	4.000	.6611	31.000
6	2130	2.0629	2.0969	3.850	3.760	.170	4.000	.6611	31.000
7	855	2.0663	2.1102	3.890	3.810	.210	4.050	.6611	31.000
7	1215	2.0659	2.0998	3.890	3.800	.210	4.050	.6611	31.000
7	1625	2.0647	2.0987	3.880	3.800	.200	4.040	.6611	31.000
7	2140	2.0632	2.0970	3.870	3.780	.180	4.030	.6611	31.000
8	9 0	2.0637	2.0975	3.870	3.780	.200	4.030	.6611	31.000
8	1330	2.0653	2.0992	3.890	3.800	.210	4.050	.6611	31.000
8	18 0	2.0632	2.0972	3.870	3.780	.190	4.030	.6611	31.000
8	22 0	2.0633	2.0972	3.860	3.780	.200	4.030	.6611	31.000
9	930	2.0671	2.1105	3.890	3.810	.240	4.070	.6611	31.000
9	1255	2.0643	2.0981	3.880	3.790	.220	4.050	.6611	31.000
9	18 5	2.0668	2.1104	3.920	3.830	.260	4.090	.6611	31.000
9	2240	2.0630	2.0968	3.840	3.750	.180	4.010	.6611	31.000
10	930	2.0634	2.0973	3.870	3.780	.200	4.040	.6611	31.000
10	1245	2.0672	2.1110	3.890	3.800	.220	4.060	.6611	31.000
10	1840	2.0617	2.0956	3.850	3.750	.180	4.010	.6611	31.000
10	2240	2.0630	2.0968	3.840	3.750	.170	4.000	.6611	31.000
11	1045	2.0651	2.0991	3.870	3.790	.220	4.050	.6611	31.000
11	1425	2.0633	2.0972	3.850	3.770	.200	4.030	.6611	31.000

RAW DATA--RUN 22

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW

RAW DATA--RUN 23



RAW DATA--RUN 24

DAY	TIME	TIN	TOUT	TWA	TWB	TWC	TWD	HEAT	FLOW
0	16 1	-1.970	0	1.110	.950	0	0	10.050	3.610
0	16 2	-1.980	0	1.110	0	.520	0	10.040	3.640
0	16 3	-1.980	0	1.120	0	0	.770	10.040	3.640
0	2331	-1.970	0	1.100	0	.500	0	9.960	3.580
0	2332	-1.970	0	1.070	0	0	.760	9.960	3.590
1	935	-1.960	0	1.120	.950	0	0	10.010	3.560
1	936	-1.960	0	1.130	0	.520	0	10.010	3.570
1	937	-1.960	0	1.100	0	0	.780	10.010	3.570
1	1810	-1.980	0	1.120	.940	0	0	9.970	3.560
1	1811	-1.980	0	1.120	0	.520	0	9.970	3.560
1	1812	-1.980	0	1.110	0	0	.780	9.980	3.560
1	2316	-1.990	0	1.120	0	.530	0	9.990	3.570
2	10 0	-1.900	0	1.210	1.040	0	0	10.020	3.580
2	10 1	-1.900	0	1.210	0	.610	0	10.030	3.570
2	10 2	-1.900	0	1.210	0	0	.870	10.020	3.600
2	1331	-1.970	0	1.190	0	.560	0	10.010	3.580
2	1332	-1.970	0	1.180	0	0	.820	10.010	3.580
2	18 0	-1.980	0	1.170	.980	0	0	10.000	3.590
2	18 2	-1.980	0	1.170	0	0	.810	10.010	3.590
2	2246	-1.970	0	1.200	0	.550	0	10.000	3.580
2	2247	-1.970	0	1.190	0	0	.830	10.010	3.580
3	6 0	-1.980	0	1.210	0	0	.850	9.980	3.550
3	755	-1.960	0	1.240	0	0	.850	9.990	3.560
3	757	-1.960	0	1.250	0	.550	0	9.990	3.580
3	1510	-1.970	0	1.250	1.020	0	0	10.020	3.580
3	1511	-1.970	0	1.260	0	.570	0	10.020	3.580
3	1512	-1.970	0	1.280	0	0	.870	10.030	3.580
3	22 1	-1.970	0	1.290	0	.550	0	10.000	3.570
3	22 2	-1.980	0	1.280	0	0	.870	10.000	3.580
4	1015	-1.930	0	1.400	1.130	0	0	10.020	3.560
4	1016	-1.940	0	1.410	0	.620	0	10.020	3.560
4	1017	-1.940	0	1.410	0	0	.970	10.030	3.560
4	16 1	-1.960	0	1.450	0	.600	0	9.990	3.570
4	16 2	-1.960	0	1.400	0	0	.960	9.990	3.560
4	20 0	-1.980	0	1.420	1.110	0	0	9.990	3.580
4	23 1	-1.970	0	1.440	0	.610	0	9.980	3.570
4	23 3	-1.970	0	1.440	0	0	.980	9.980	3.570
5	1015	-1.970	0	1.540	1.170	0	0	10.000	3.590
5	1017	-1.960	0	1.590	0	0	1.070	10.010	3.590
5	15 1	-1.960	0	1.630	0	.650	0	10.010	3.600
5	15 2	-1.960	0	1.630	0	.650	0	10.010	3.600
5	24 0	-1.950	0	1.830	1.260	0	0	9.990	3.600
6	13 0	-1.950	0	2.240	1.340	0	0	9.980	3.580
6	1416	-1.960	0	2.300	0	.720	0	9.990	3.580
6	20 1	-1.970	0	2.620	0	.730	0	9.980	3.570
6	20 2	-1.980	0	2.640	0	0	1.320	9.990	3.570
6	21 0	-1.970	0	2.670	1.420	0	0	9.980	3.570
6	23 1	-1.950	0	2.900	0	.790	0	9.990	3.570
6	23 2	-1.950	0	2.890	0	0	1.420	9.990	3.560
7	1030	-1.920	0	3.780	1.910	0	0	10.010	3.570
7	1031	-1.920	0	3.790	0	.890	0	10.010	3.570
7	1451	-1.960	0	4.060	0	.900	0	10.010	3.580
7	1910	-1.980	0	4.320	2.320	0	0	9.970	3.570
7	1911	-1.980	0	4.330	0	.900	0	9.970	3.580
7	1912	-1.980	0	4.310	0	0	2.430	9.980	3.580
7	2216	-1.980	0	4.540	0	.950	0	10.000	3.570
7	2217	-1.990	0	4.530	0	0	2.640	10.000	3.570
8	10 0	-1.930	0	5.280	3.210	0	0	10.020	3.570
8	10 1	-1.930	0	5.280	0	1.150	0	10.010	3.580
8	10 2	-1.940	0	5.270	0	0	3.380	10.020	3.570
8	1742	-1.990	0	6.450	0	1.580	0	10.010	3.600
8	1744	-1.980	0	6.430	0	0	4.130	10.010	4.130
8	23 5	-1.970	0	6.530	4.310	0	0	9.990	3.570
8	23 6	-1.970	0	6.550	0	1.430	0	9.990	3.570
8	23 7	-1.970	0	6.490	0	0	4.300	10.000	3.570
9	1035	-1.930	0	6.790	4.860	0	0	10.000	3.550
9	1036	-1.930	0	6.780	0	1.780	0	10.010	3.560
9	1037	-1.940	0	6.760	0	0	4.810	9.990	3.560
9	1316	-1.950	0	6.880	0	1.910	0	10.020	3.560
9	1317	-1.960	0	6.860	0	0	4.950	10.020	3.560
9	1930	-1.970	0	6.870	5.230	0	0	10.000	3.570
9	1931	-1.970	0	6.870	0	2.580	0	10.010	3.570
9	1932	-1.970	0	6.880	0	0	5.220	10.010	3.580
9	22 1	-1.980	0	6.940	0	2.880	0	10.000	3.570
9	22 2	-1.980	0	6.960	0	0	5.380	10.000	3.580

APPENDIX D

CHEMICAL ANALYSIS PROCEDURES

Samples of cooling tower water and city water were analysed daily for total hardness (TH), calcium hardness (CaH), methyl orange alkalinity (m-alkalinity), phenophtahalein alkalinity (p-alkalinity), Chloride (Cl), silica (Si), total Solids (TS) and conductivity (cond). In addition to the chemical analysis, biological growth in the cooling tower water was monitored.

Detailed description of standard procedures for these tests are outlined in Standard Methods [1]. However, simplified procedures together with pre-mixed chemical reagents and apparatus are available from commercial laboratories. Analysis kits developed by Chemax Inc. Industrial chemistry for the determination of TH, CaH, m-alkalinity and Cl were used. For silica, Hach Chemical Company reagents and equipment were used. These simplified tests give less accurate results ($\pm$ ppm as $CaCO_3$ for m-alkalinity and $\pm$ 5 ppm for others), but are satisfactory for daily monitoring of water quality.

CHEMAX DROP TEST PROCEDURES

Basically, procedures for each test are identical. First the titration bottle is filled to the mark (10 ml) with the sample. After an appropriate amount of reagents are added, the sample is titrated dropwise to an end point by observing the change in color.

Total hardness test

Three reagents are used:

(1) reagent 1 - ammonium chloride - ammonium hydroxide buffer

(2) reagent 2 - 0.2% Calmagite solution

(3) reagent 3 - 0.5% EDTA solution

When five drops of reagent 1 and three drops of reagent 2 are added, the solution will be lavender to red if hardness is present. This solution is then titrated with reagent 3 until the last trace of violet has disappeared and the solution turns blue. One drop of reagent 3 equals five ppm total hardness expressed as $CaCO_3$.

Calcium Hardness Test

Three reagents are used:

(1) reagent 1 - 40% sodium hydroxide solution

(2) reagent 2 - Calcon indicator

(3) reagent 3 - EDTA solution

When two drops of reagent 1 and two drops of reagent 2 are added, the solution will be red if calcium is present. This solution is titrated dropwise with reagent 3 until the solution turns blue. One drop of reagent 3 equals five ppm calcium hardness expressed as $CaCO_3$.

Magnesium hardness (MgH) is the difference of total hardness and calcium hardness.

M-Alkalinity Test

The reagent are:

(1) reagent 1 - mixed bromo-cresol green and methyl red solution, 0.1%

(2) reagent 2 - 0.0503 N sulfuric acid

On the addition of one drop of reagent 1, the solution will

be blue-green if alkalinity is present. The solution is titrated dropwise until the solution turns red. One drop of reagent 2 equals ten ppm alkalinity expressed as $CaCO_3$.

Cl Test

Two reagents are used:

(1) reagent 1 - 5% potassium chromate solution

(2) reagent 2 - silver nitrate solution

Two drops of reagent 1 are added to the water sample before it is titrated dropwise with reagent 2 until the solution shows a definite red-orange color. One drop of reagent 2 equals 5 ppm as NaCl.

HACH PROCEDURE FOR SILICA DETERMINATION

The procedure is based on the molybidosilicate method as shown in Standard Methods[1]. Hach Chemical Company provides the needed chemical reagent, namely, oxalic acid, molybdate reagent and acid reagent. They are in powder form and are packaged in individual pre-measured polyethylene 'capsules'. Each capsule contains the exact amount of reagent for each test. Reagents are dissolved in the water sample in the colorimeter bottle. The solution is then checked for its silicate content by using the Hach DR Colorimeter after it has been calibrated by a blank sample. The result is expressed as ppm SiO_2.

MISCELLANEOUS TEST PROCEDURES

pH

The pH value is read directly from a Beckman pH meter. It is calibrated with the appropriate buffer.

Conductivity Test

An Industrial Instrument Inc. conductivity meter is used. The result is expressed as micromhos/cm.

Total Solids Test

A 200 ml sample is evaporated in an oven at $150^{o}F$ for 24 hours. The weight of the residue is the total dissolved solids presented. The result is expressed as ppm.

P-Alkalinity Test

The procedure is described in p. 52 of Standard Methods[1]. A pH meter is used for end point determination, which is 8.3 in this case. The result is expressed as ppm $CaCO_3$.

MICROORGANISM TEST

Microorganism in water can be detected by means of the Total-Count Sampler supplied by Millipore Corporation. The Sampler case is filled with a water sample and the Sampler is inserted into the case. After it has been shaken several times and the sample has been in contact with the Sampler for 30 seconds, the water is emptied. The case with the Sampler in place is then incubated at

$35^{o}C$ for 24 hours. If microorganisms are present, colonies will show on the surface of the Sampler. All colonies should be counted. Results are reported in colonies/ml.

APPENDIX E

COOLING TOWER WATER QUALITY - NOVEMBER 76 - JULY 77

NOMENCLATURE

TH - total hardness (ppm $CaCO_3$)

CaH - calcium hardness (ppm $CaCO_3$)

MgH - magnesium hardness (ppm $CaCO_3$)

m-alk - methyl orange alkalinity (ppm $CaCO_3$)

p-alk - phenophthalein alkalinity (ppm $CaCO_3$)

Cl - chloride (ppm NaCl)

Si - Silica (ppm SiO_2)

pH - acidity

TS - total solids (ppm)

cond - conductivity (micromhos/cm)

Note: 0 denotes no data

NOV 75

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
7	35	25	10	40	25	0	7.6	0
8	55	35	19	45	35	0	7.8	0
9	55	45	10	45	35	0	7.8	0
10	35	45	10	55	35	0	7.8	0
11	70	45	25	55	45	0	7.8	0
12	80	55	25	60	45	0	7.8	0
13	85	55	30	60	45	0	7.8	0
14	85	55	30	60	45	0	7.8	0
15	85	55	30	70	45	0	7.8	0
16	85	65	20	70	45	0	7.8	0
17	100	75	25	70	45	0	7.8	0
18	110	85	25	80	55	0	7.8	0
19	115	85	30	80	55	0	7.8	0
20	115	85	30	80	55	0	7.8	0
21	115	85	30	80	55	0	7.8	0
22	115	85	30	80	55	0	7.8	0
23	115	85	30	80	55	0	7.8	0
24	115	85	30	80	55	0	7.8	0
25	115	85	30	80	55	0	7.8	0
26	115	85	30	80	55	0	7.8	0
27	115	85	30	80	55	0	7.8	0
28	115	85	30	80	55	0	7.8	0
29	115	85	30	80	55	0	7.8	0
30	115	85	30	80	55	0	7.8	0

DEC 76

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
1	210	150	60	160	105	0	8.0	0
2	200	140	60	160	105	0	8.0	0
3	220	140	80	160	115	0	8.0	0
4	220	140	80	160	115	0	8.0	0
5	220	140	80	160	115	0	8.0	0
6	220	140	80	160	115	0	8.0	0
7	220	140	80	160	115	0	8.0	0
8	220	140	80	160	115	0	8.0	0
9	220	140	80	160	115	0	8.0	0
10	220	140	80	160	115	0	8.0	0
11	220	140	80	160	115	0	8.0	0
12	220	140	80	160	115	0	8.0	0
13	220	140	80	160	115	0	8.0	0
14	220	140	80	160	115	0	8.0	0
15	220	140	80	160	115	0	8.0	0
16	220	140	80	160	115	0	8.0	0
17	220	140	80	160	115	0	8.0	0
18	220	140	80	160	115	0	8.0	0
19	220	140	80	160	115	0	8.0	0
20	220	140	80	160	115	0	8.0	0
21	220	140	80	160	115	0	8.0	0
22	220	140	80	160	115	0	8.0	0
23	220	140	80	160	115	0	8.0	0
24	220	140	80	160	115	0	8.0	0
25	220	140	80	160	115	0	8.0	0
26	220	140	80	160	115	0	8.0	0
27	220	140	80	160	115	0	8.0	0
28	220	140	80	160	115	0	8.0	0
29	220	140	80	160	115	0	8.0	0
30	220	140	80	160	115	0	8.0	0
31	215	150	65	160	115	0	8.0	0

JAN 77

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
1	210	150	60	210	195	0	8.5	560
2	220	155	65	220	195	0	8.5	560
3	190	135	55	190	200	0	8.5	560
4	220	155	65	220	210	0	8.5	560
5	220	155	65	220	210	0	8.5	560
6	220	155	65	220	210	0	8.5	560
7	220	155	65	220	210	0	8.5	560
8	220	155	65	220	210	0	8.5	560
9	220	155	65	220	210	0	8.5	560
10	220	155	65	220	210	0	8.5	560
11	215	150	65	220	210	0	8.5	560
12	220	155	65	210	210	0	8.5	560
13	230	155	75	230	220	0	8.5	560
14	220	155	70	220	210	0	8.5	560
15	220	155	65	220	210	0	8.5	560
16	225	155	70	220	210	0	8.5	560
17	220	155	70	220	210	0	8.5	560
18	220	155	75	220	210	0	8.5	560
19	220	155	65	220	210	0	8.5	560
20	225	160	65	220	210	0	8.5	560
21	220	155	65	220	210	0	8.5	560
22	210	145	65	200	195	0	8.5	560
23	220	155	70	220	210	0	8.5	560
24	230	160	70	220	220	0	8.5	560
25	240	165	75	230	220	0	8.5	560
26	230	155	75	230	220	0	8.5	560
27	230	155	75	230	220	0	8.5	560
28	230	155	75	230	220	0	8.5	560
29	230	155	75	230	220	0	8.5	560
30	230	155	75	230	220	0	8.5	560
31	220	150	70	220	210	0	8.5	560

FEB 77

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
1	215	150	65	220	210	0	8.5	560
2	220	155	65	210	210	0	8.5	560
3	230	155	75	230	220	0	8.5	560
4	220	155	70	220	210	0	8.5	560
5	220	155	65	210	210	0	8.5	560
6	230	155	80	230	220	0	8.5	560
7	225	155	75	220	210	0	8.5	560
8	220	155	70	210	210	0	8.5	560
9	220	155	70	210	210	0	8.5	560
10	230	155	75	220	220	0	8.5	560
11	220	155	65	220	220	0	8.5	560
12	225	160	65	220	220	0	8.5	560
13	220	155	65	200	210	0	8.5	560
14	210	145	65	210	210	0	8.5	560
15	220	155	70	220	220	0	8.5	560
16	230	160	70	220	235	0	8.5	560
17	240	165	75	230	240	0	8.5	560
18	230	155	70	230	230	0	8.5	560
19	220	155	65	210	220	0	8.5	560
20	220	155	65	200	220	0	8.5	560
21	215	155	70	200	220	0	8.5	560
22	215	155	70	190	220	0	8.5	560
23	225	155	70	190	220	0	8.5	560
24	230	155	80	180	225	7	8.5	560
25	210	145	60	190	220	7	8.5	560
26	205	145	60	180	225	7	8.5	560

MARCH 77

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
1	215	155	65	190	25	72	8.0	356
2	220	155	70	190	25	74	8.0	362
3	220	155	70	190	25	75	8.0	365
4	220	155	70	190	25	74	8.0	361
5	220	155	70	190	25	75	8.0	365
6	220	155	70	190	25	75	8.0	365
7	220	155	70	190	25	75	8.0	365
8	220	155	70	190	25	75	8.0	365
9	220	155	70	190	25	75	8.0	365
10	220	155	70	190	25	75	8.0	365
11	220	155	70	190	25	75	8.0	365
12	220	155	70	190	25	75	8.0	365
13	220	155	70	190	25	75	8.0	365
14	220	155	70	190	25	75	8.0	365
15	220	155	70	190	25	75	8.0	365
16	220	155	70	190	25	75	8.0	365
17	220	155	70	190	25	75	8.0	365
18	220	155	70	190	25	75	8.0	365
19	220	155	70	190	25	75	8.0	365
20	220	155	70	190	25	75	8.0	365
21	220	155	70	190	25	75	8.0	365
22	220	155	70	190	25	75	8.0	365
23	220	155	70	190	25	75	8.0	365
24	220	155	70	190	25	75	8.0	365
25	220	155	70	190	25	75	8.0	365
26	220	155	70	190	25	75	8.0	365
27	220	155	70	190	25	75	8.0	365
28	220	155	70	190	25	75	8.0	365
29	220	155	70	190	25	75	8.0	365
30	220	155	70	190	25	75	8.0	365
31	220	155	70	190	25	75	8.0	365

APRIL 77

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
1	220	155	65	190	25	75	8.0	365
2	220	155	70	190	25	75	8.0	365
3	220	155	70	190	25	75	8.0	365
4	220	155	70	190	25	75	8.0	365
5	220	155	70	190	25	75	8.0	365
6	220	155	70	190	25	75	8.0	365
7	220	155	70	190	25	75	8.0	365
8	220	155	70	190	25	75	8.0	365
9	220	155	70	190	25	75	8.0	365
10	220	155	70	190	25	75	8.0	365
11	220	155	70	190	25	75	8.0	365
12	220	155	70	190	25	75	8.0	365
13	220	155	70	190	25	75	8.0	365
14	220	155	70	190	25	75	8.0	365
15	220	155	70	190	25	75	8.0	365
16	220	155	70	190	25	75	8.0	365
17	220	155	70	190	25	75	8.0	365
18	220	155	70	190	25	75	8.0	365
19	220	155	70	190	25	75	8.0	365
20	220	155	70	190	25	75	8.0	365
21	220	155	70	190	25	75	8.0	365
22	220	155	70	190	25	75	8.0	365
23	220	155	70	190	25	75	8.0	365
24	220	155	70	190	25	75	8.0	365
25	220	155	70	190	25	75	8.0	365
26	220	155	70	190	25	75	8.0	365
27	220	155	70	190	25	75	8.0	365
28	220	155	70	190	25	75	8.0	365
29	220	155	70	190	25	75	8.0	365
30	220	155	70	190	25	75	8.0	365

MAY 77

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
1	220	150	70	240	295	95	9.10	775
2	220	150	70	250	295	95	9.10	780
3	220	150	70	250	300	95	9.10	795
4	220	150	70	250	300	95	9.10	715
5	220	150	70	250	300	95	9.10	715
6	220	150	70	250	300	95	9.10	715
7	220	150	70	250	300	95	9.10	715
8	220	150	70	250	300	95	9.10	715
9	220	150	70	250	300	95	9.10	715
10	220	150	70	250	300	95	9.10	715
11	220	150	70	250	300	95	9.10	715
12	220	150	70	250	300	95	9.10	715
13	220	150	70	250	300	95	9.10	715
14	220	150	70	250	300	95	9.10	715
15	220	150	70	250	300	95	9.10	715
16	220	150	70	250	300	95	9.10	715
17	220	150	70	250	300	95	9.10	715
18	220	150	70	250	300	95	9.10	715
19	220	150	70	250	300	95	9.10	715
20	220	150	70	250	300	95	9.10	715
21	220	150	70	250	300	95	9.10	715
22	220	150	70	250	300	95	9.10	715
23	220	150	70	250	300	95	9.10	715
24	220	150	70	250	300	95	9.10	715
25	220	150	70	250	300	95	9.10	715
26	220	150	70	250	300	95	9.10	715
27	220	150	70	250	300	95	9.10	715
28	220	150	70	250	300	95	9.10	715
29	220	150	70	250	300	95	9.10	715
30	220	150	70	250	300	95	9.10	715
31	220	150	70	250	300	95	9.10	715

JUNE 77

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
1	220	150	70	250	300	95	9.10	715
2	220	150	70	250	300	95	9.10	715
3	220	150	70	250	300	95	9.10	715
4	220	150	70	250	300	95	9.10	715
5	220	150	70	250	300	95	9.10	715
6	220	150	70	250	300	95	9.10	715
7	220	150	70	250	300	95	9.10	715
8	220	150	70	250	300	95	9.10	715
9	220	150	70	250	300	95	9.10	715
10	220	150	70	250	300	95	9.10	715
11	220	150	70	250	300	95	9.10	715
12	220	150	70	250	300	95	9.10	715
13	220	150	70	250	300	95	9.10	715
14	220	150	70	250	300	95	9.10	715
15	220	150	70	250	300	95	9.10	715
16	220	150	70	250	300	95	9.10	715
17	220	150	70	250	300	95	9.10	715
18	220	150	70	250	300	95	9.10	715
19	220	150	70	250	300	95	9.10	715
20	220	150	70	250	300	95	9.10	715
21	220	150	70	250	300	95	9.10	715
22	220	150	70	250	300	95	9.10	715
23	220	150	70	250	300	95	9.10	715
24	220	150	70	250	300	95	9.10	715
25	220	150	70	250	300	95	9.10	715
26	220	150	70	250	300	95	9.10	715
27	220	150	70	250	300	95	9.10	715
28	220	150	70	250	300	95	9.10	715
29	220	150	70	250	300	95	9.10	715
30	220	150	70	250	300	95	9.10	715

JULY 77

DATE	TH	CA H	MG H	M-ALK	CL	SI	PH	TS
1	235	150	85	260	360	142	9.20	733
2	240	155	90	265	350	142	9.20	870
3	260	155	105	250	375	144	9.15	789
4	270	155	115	230	385	136	9.20	824
5	255	145	110	230	385	140	9.00	829
6	250	155	100	240	400	136	9.00	818
7	245	155	95	255	385	140	9.00	782
8	235	150	85	220	380	120	9.00	793
9	225	145	80	245	385	135	9.00	807
10	210	145	65	210	370	135	9.00	773
11	225	150	75	260	380	140	9.00	774
12	225	145	80	240	385	140	9.00	794
13	225	150	75	240	395	138	9.00	756
14	230	150	80	250	390	140	9.00	784
15	230	150	80	255	390	140	9.00	824
16	235	150	85	220	395	130	9.00	770
17	230	155	75	210	385	125	9.00	833
18	230	150	80	230	405	125	9.00	859
19	230	155	75	240	395	138	9.00	869
20	225	155	70	230	410	136	9.00	879
21	225	155	70	230	410	138	9.00	926
22	225	150	65	240	415	135	9.00	920
23	220	155	65	250	420	135	9.00	897
24	220	150	70	240	420	138	9.00	851
25	205	150	55	220	420	130	9.00	851

BIOGROWTH

Date	Biocount (colonies/ml)
11/21/76	46
11/24/76	2
11/26/76	2
11/28/76	Too numerous to count
12/04/76	150
12/08/76	31
12/09/76	115
1/23/77	1
1/24/77	3

Zero counts for the rest

MONTHLY AVERAGE COOLING TOWER WATER QUALITY

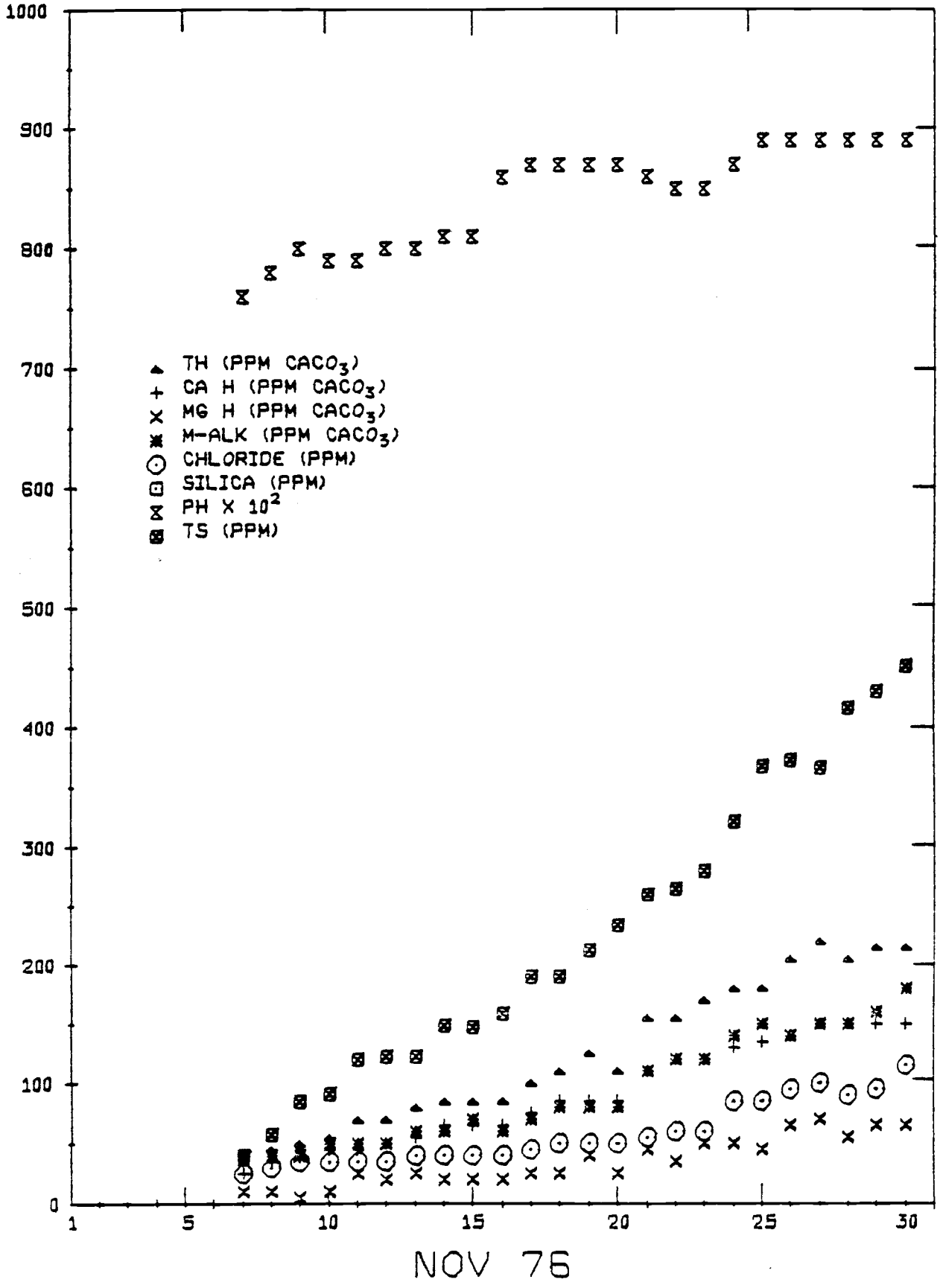
Month	TH	CaH	M-Alk	P-Alk	Cl	Si		pH	TS	Cond
						std method[1]	Hacks method			
Nov. 76	220	150	150	-----	100	-----	-----	8.9	367	----
Dec. 76	210 (13.2)	150 (4.6)	201 (14.7)	-----	165 (26.5)	-----	-----	8.92 (0.05)	499 (40)	----
Jan. 77	213 (14.7)	150 (3.9)	214 (12.5)	-----	204 (9.8)	-----	----	8.90 (0.06)	559 (28)	791 (63)
Feb. 77	221 (8.4)	152 (5.2)	209 (14.1)	21.4 (1.5)	219 (7.9)	79 (8.4)	----	8.86 (0.07)	584 (28)	826 (34)
March 77	218 (7.0)	151 (4.4)	187 (10.7)	25.1 (1.5)	276 (16.5)	81 (5.5)	----	9.02 (0.05)	664 (34)	950 (55)
April 77	217 (9.9)	147 (5.6)	217 (17.4)	279 (2.3)	306 (15.8)	89 (3.7)	----	9.03 (0.06)	678 (46)	1014 (24)
May 77	221 (9.4)	152 (4.6)	250 (13.5)	34.7 (1.5)	318 (11.7)	-----	137 (7.4)	9.09 (0.05)	743 (66)	1069 (74)
June 77	239 (10.9)	152 (4.0)	267 (10.6)	36.9 (1.3)	336 (16.6)	-----	139 (4.4)	9.14 (0.05)	751 (48)	1147 (62)
July	232 (14.7)	151 (3.8)	239 (15.2)	33.4 (3.2)	392 (17.3)	-----	135 6.0	9.11 (0.05)	824 (58)	1247 (83)

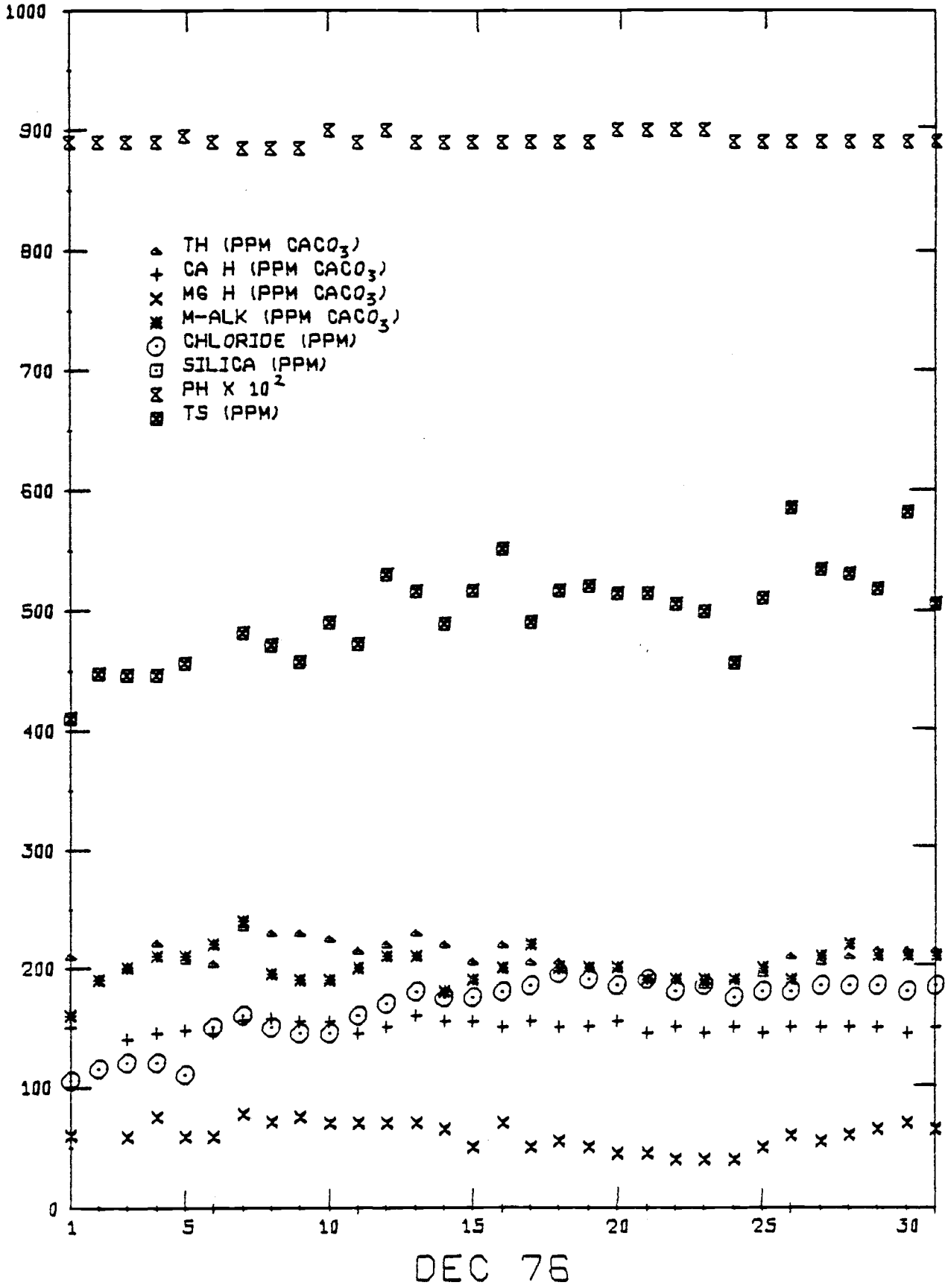
Notes: 1. Initial Conditions on November 27, 1976
2. Standard deviations in parenthesis

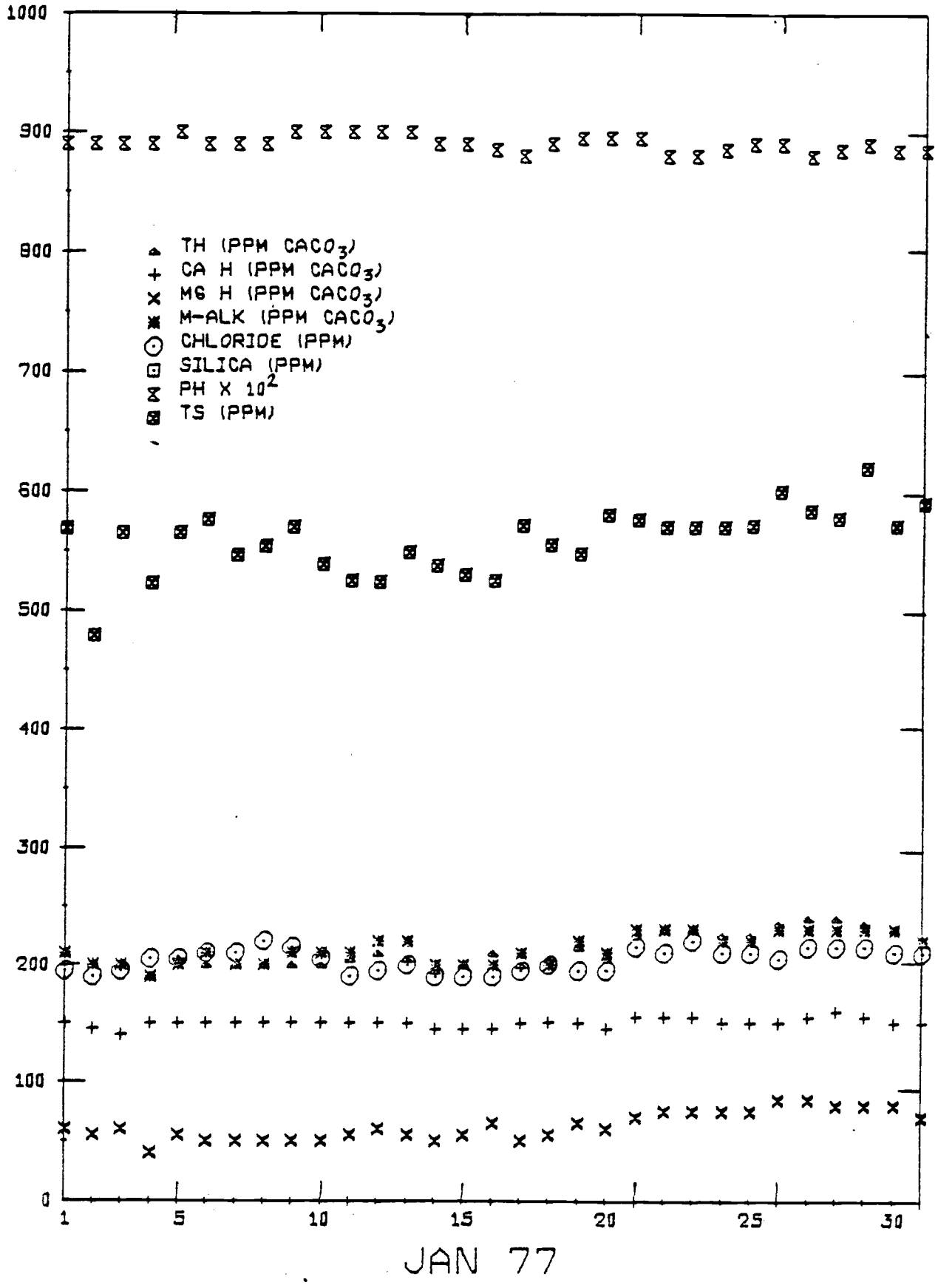
COOLING TOWER WATER HISTORY PLOTS

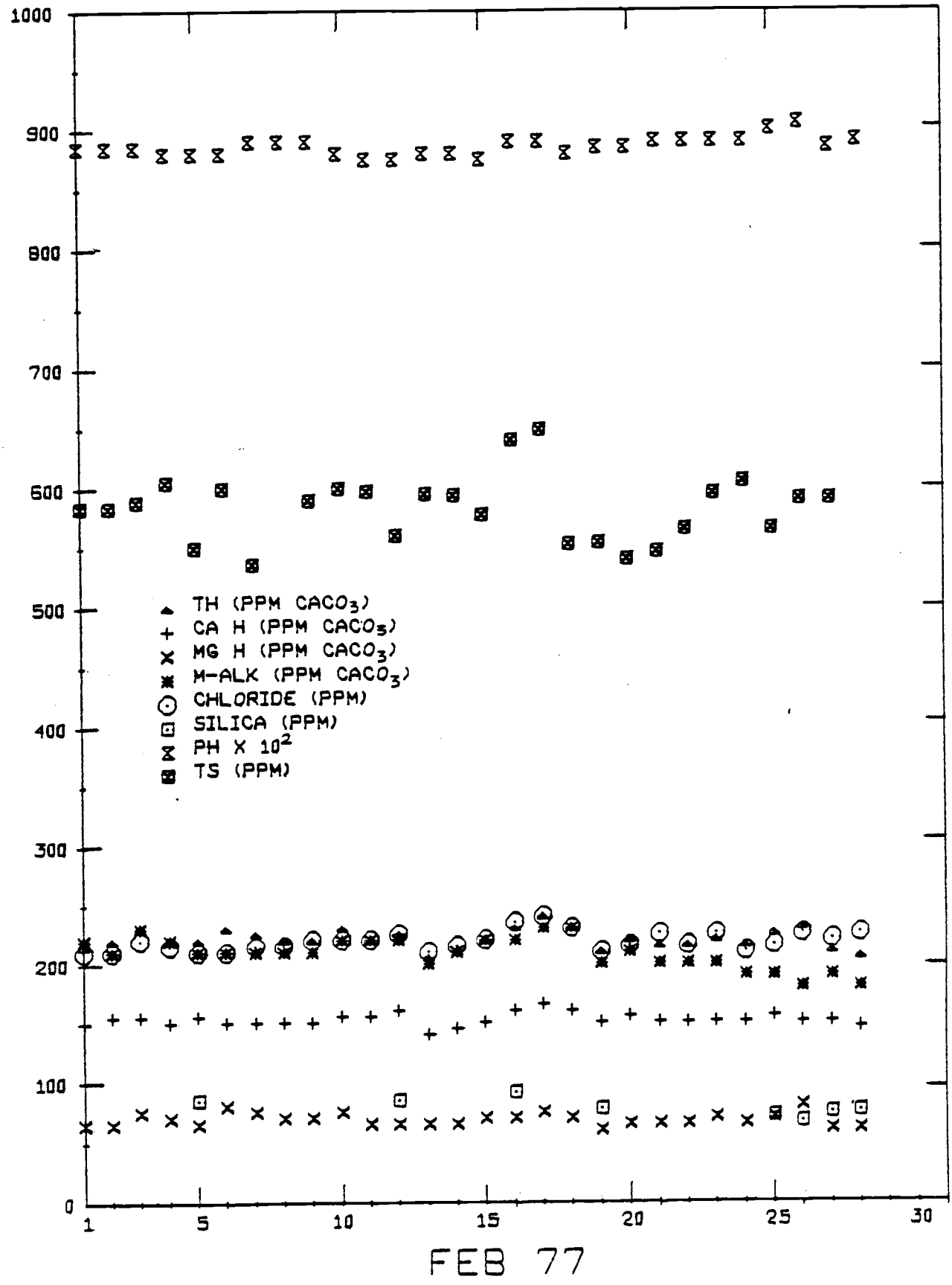
Nomenclature

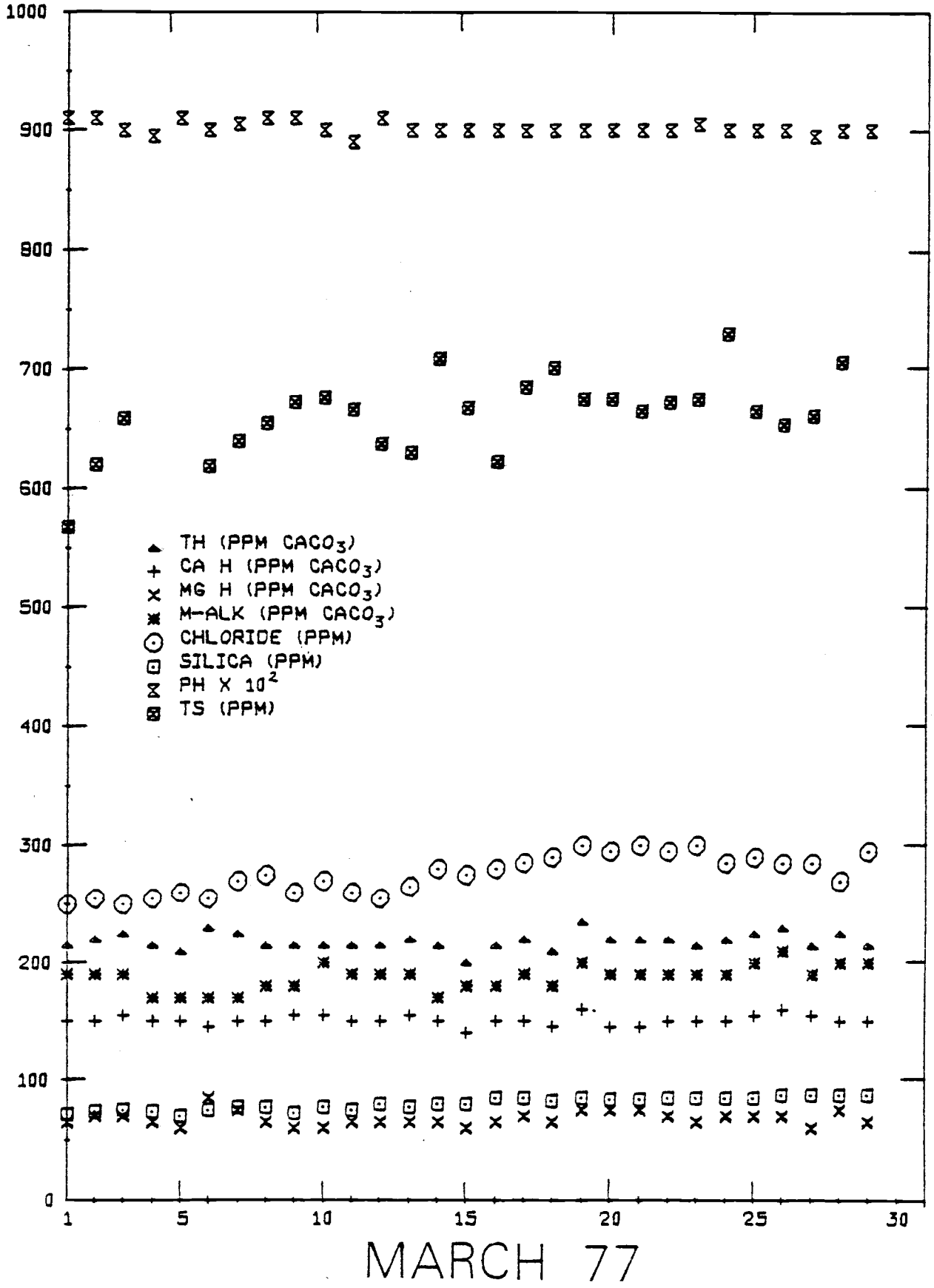
TH =	total hardness
CAH =	calcium hardness
MGH =	magnesium hardness
M-ALK =	methyl orange alkalinity
CL =	chloride
SI =	silica
TS =	total solids
PH =	acidity

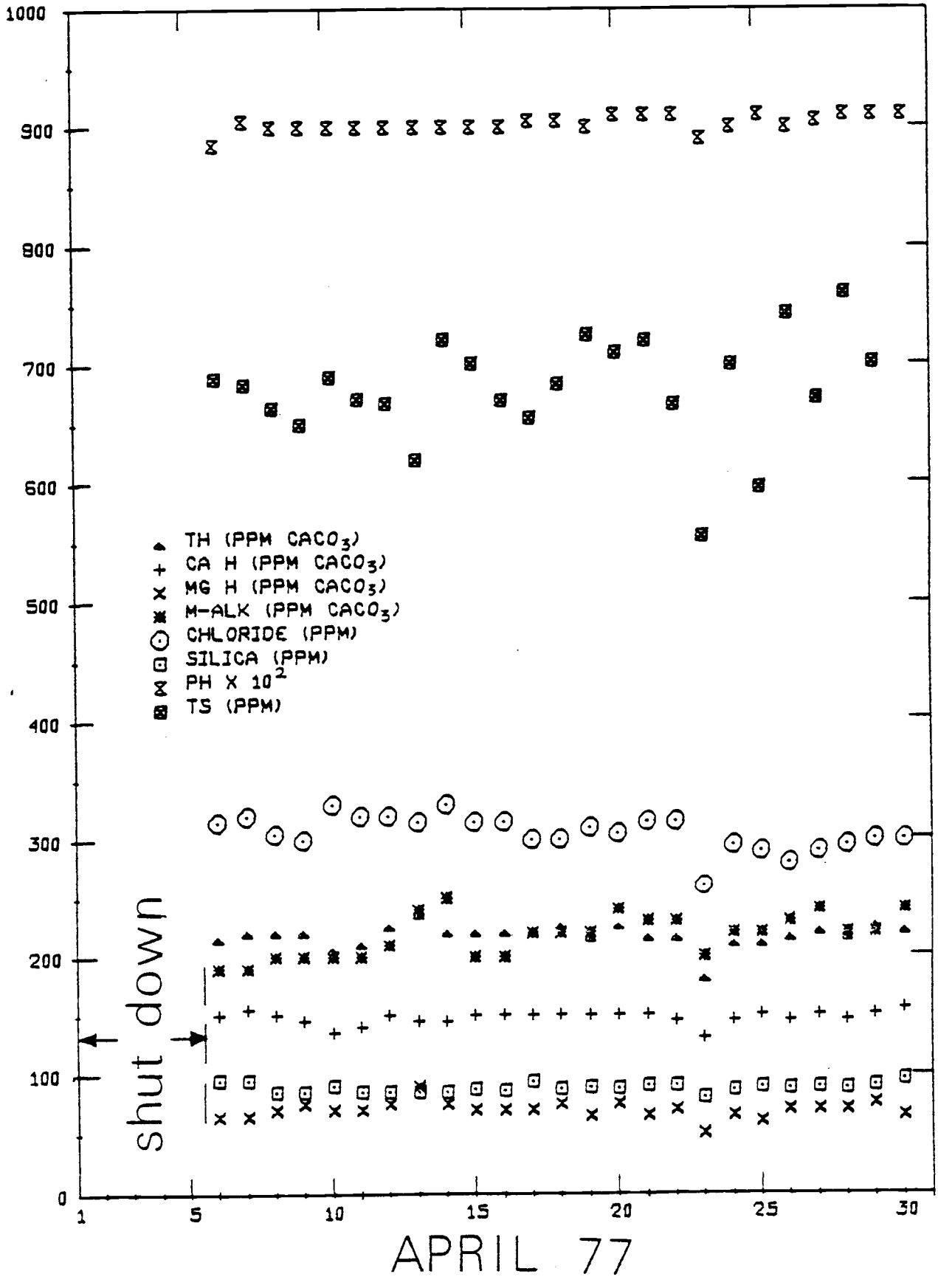

1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10^2
TS (PPM)
NOV 76

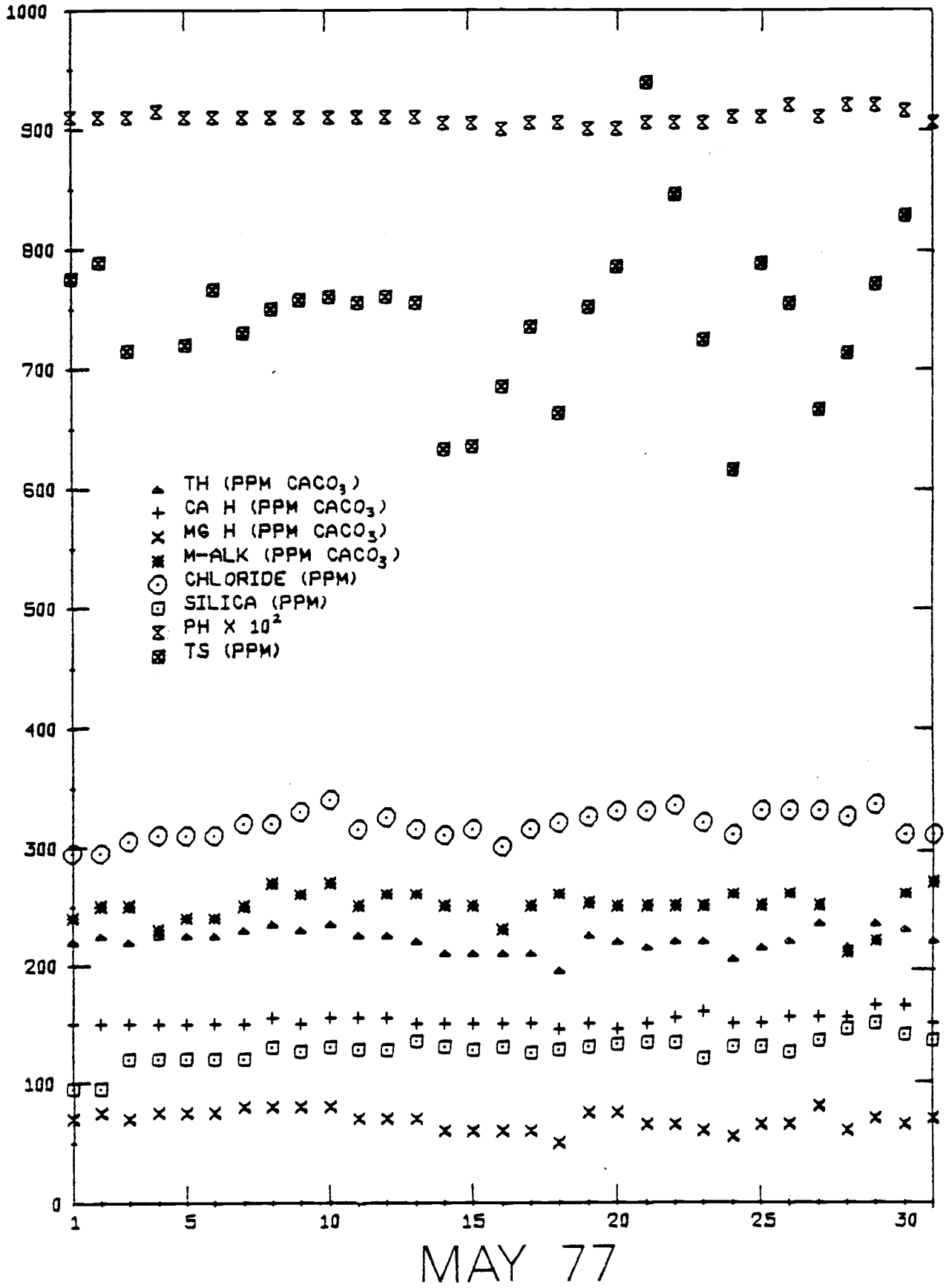

1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10 2
TS (PPM)
DEC 76

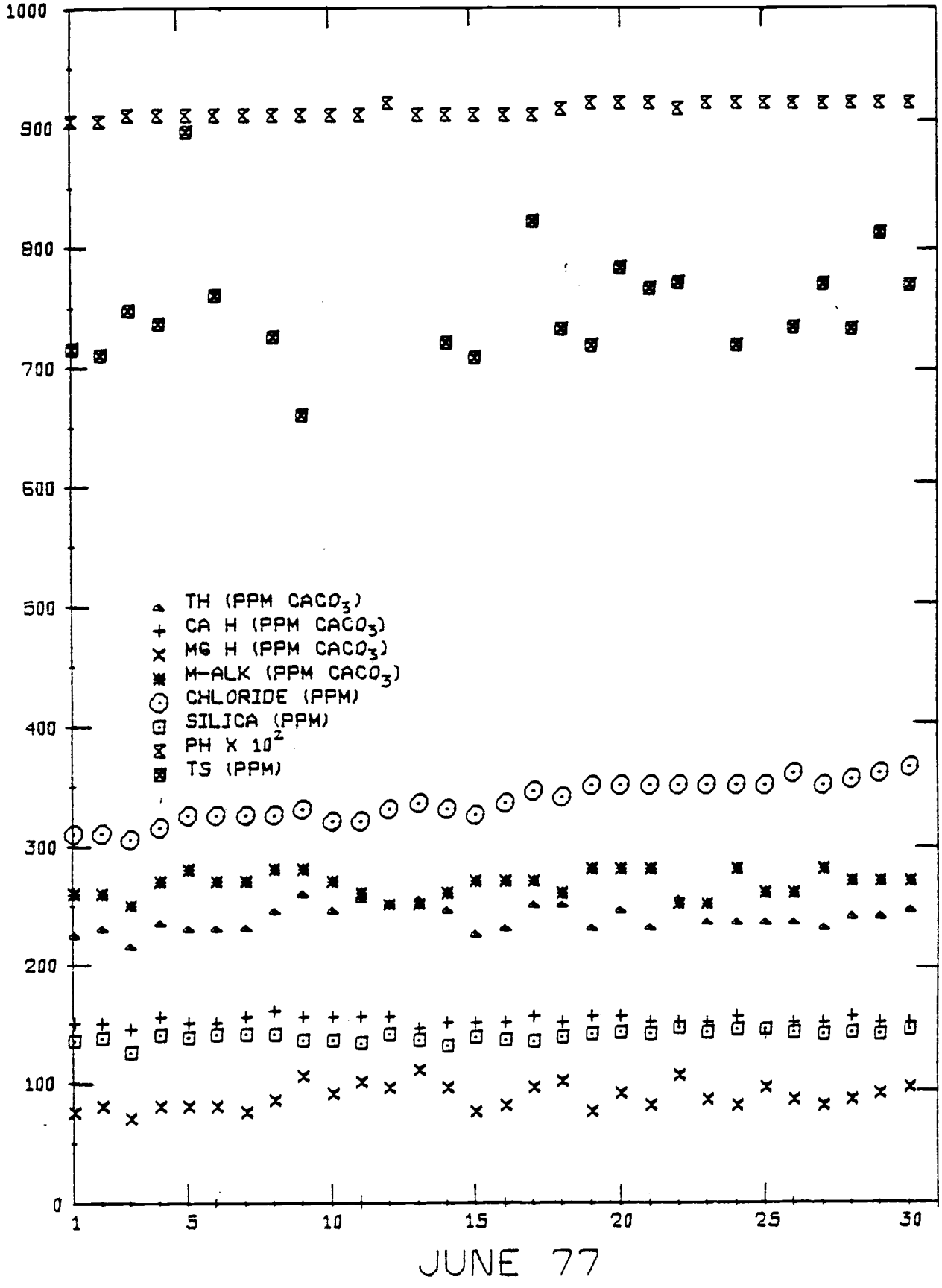

TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10^2
TS (PPM)
1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
JAN 77

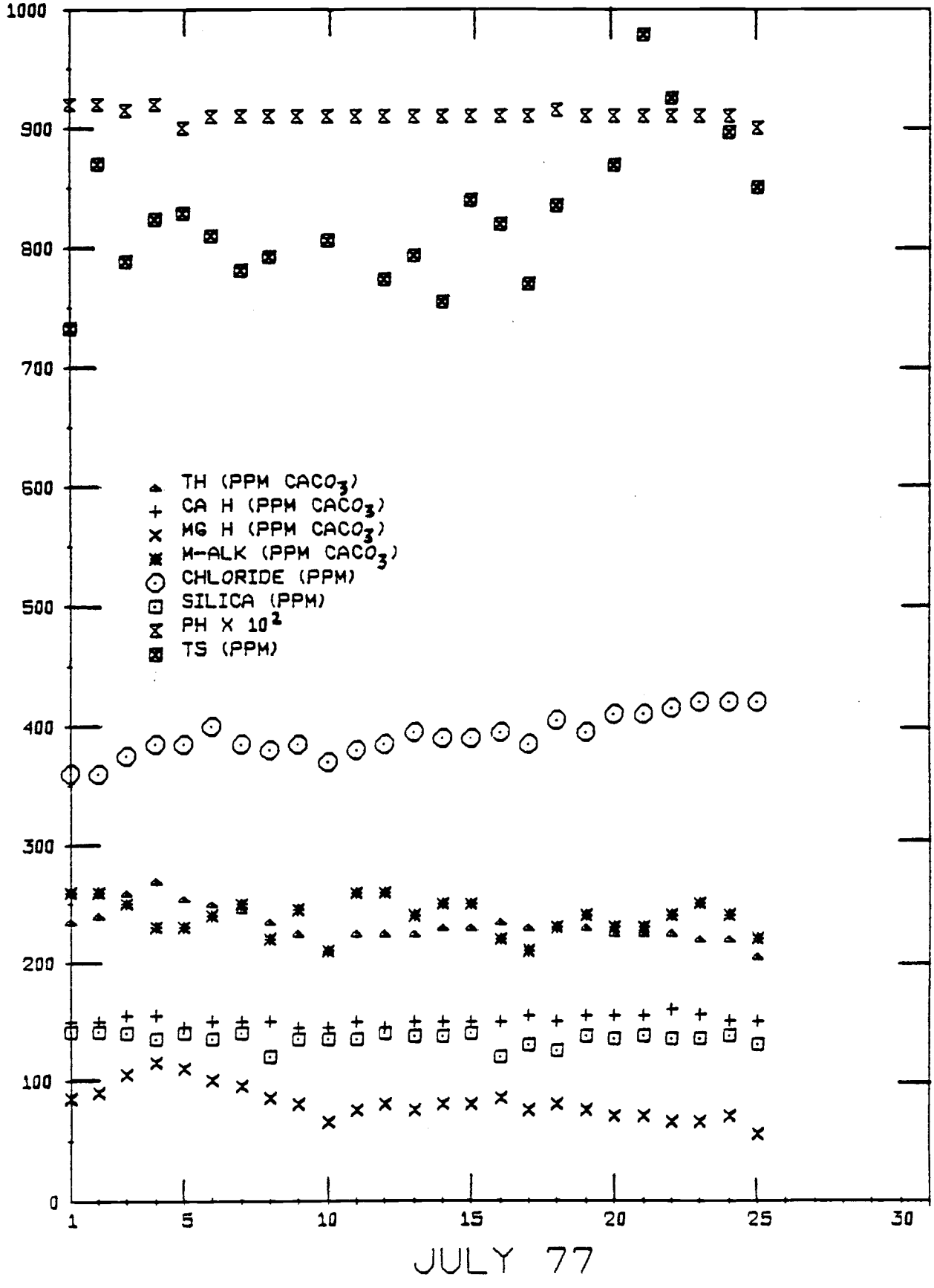

1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10^2
TS (PPM)
FEB 77


1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10^2
TS (PPM)
MARCH 77


1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10^2
TS (PPM)
shut down
APRIL 77


1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10²
TS (PPM)
MAY 77


1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10^2
TS (PPM)
JUNE 77


1000
900
800
700
600
500
400
300
200
100
0
1
5
10
15
20
25
30
TH (PPM CACO3)
CA H (PPM CACO3)
MG H (PPM CACO3)
M-ALK (PPM CACO3)
CHLORIDE (PPM)
SILICA (PPM)
PH X 10^2
TS (PPM)
JULY 77

APPENDIX F

CITY WATER QUALITY -

NOVEMBER 76 - JULY 77

COMPARISON OF COOLING WATER ANALYSIS

Date	Lab	TH	CaH	m-alk	Cl^-	pH	TS	Si	p-alk	cond
Nov. 29, 76	OSU	215	150	160	95	8.9	430	---	--	----
	NALCO[1]	189	120	204	67[3]	7.9	---	110	--	590
Dec. 10, 76	OSU	225	155	190	145	9.0	490	---	--	----
	NALCO	197	130	206	120[3]	8.7	---	100	26	720
Dec. 16, 76	OSU	220	150	200	180	8.9	552	---	--	----
	NALCO	172	110	195	140[3]	8.6	---	96	30	750
Jan. 31, 77	OSU	220	150	220	210	8.9	572	---	22	840
	CHEMAX[2]	---	145	225	180	8.8	---	122	48	760
May 13, 77	OSU	220	150	280	315	9.1	756	135	37	1050
	CHEMAX	203	130	---	320	8.8	---	93	--	1000
June 21, 77	OSU	230	150	260	350	9.2	765	140	39	1100
	NALCO	216	140	280	180[3]	---	---	130	92	----

1 NALCO Chemical Company, 6212 W. 66th Place, Chicago, Illinois 60636.
2 CHEMAX Incorporated Industrial Chemistry, 2106 N.W. 24th, Portland, Oregon 97210.
3 Reported as ppm Cl

CITY WATER HISTORY

DATE	TH	CaH	MgH	M-Alk	Cl	Si	pH	TS
Nov. 7, 76	35	25	10	40	--	--	7.6	41
Nov. 20, 76	35	25	10	40	25	--	7.5	68
Dec. 1, 76	50	31	19	30	25	--	7.6	49
Dec. 15, 76	50	30	20	40	30	--	7.7	72
Jan. 1, 77	45	35	10	50	25	--	8.2	89
Jan. 15, 77	40	30	10	40	30	--	8.1	53
Feb. 1, 77	40	30	10	40	30	--	8.85	62
Feb. 15, 77	50	35	15	40	35	--	8.75	60
March 1, 77	40	30	10	30	30	14	7.7	26
March 15, 77	40	30	10	40	35	13	7.6	66
April 6, 77	45	30	15	40	40	14.5	8.1	79
April 15, 77	30	30	0	40	40	15	7.6	66
May 1, 77	40	25	15	40	30	15	7.5	88
May 15, 77	35	25	10	40	30	16	8.0	29
June 1, 77	35	30	5	40	35	16	8.0	55
June 17, 77	50	35	15	40	35	15	8.0	81
July 4, 77	45	30	15	40	35	17	8.2	67
July 15, 77	45	35	10	40	40	17	8.2	64

Note: Refer to Appendix E for nomenclature.

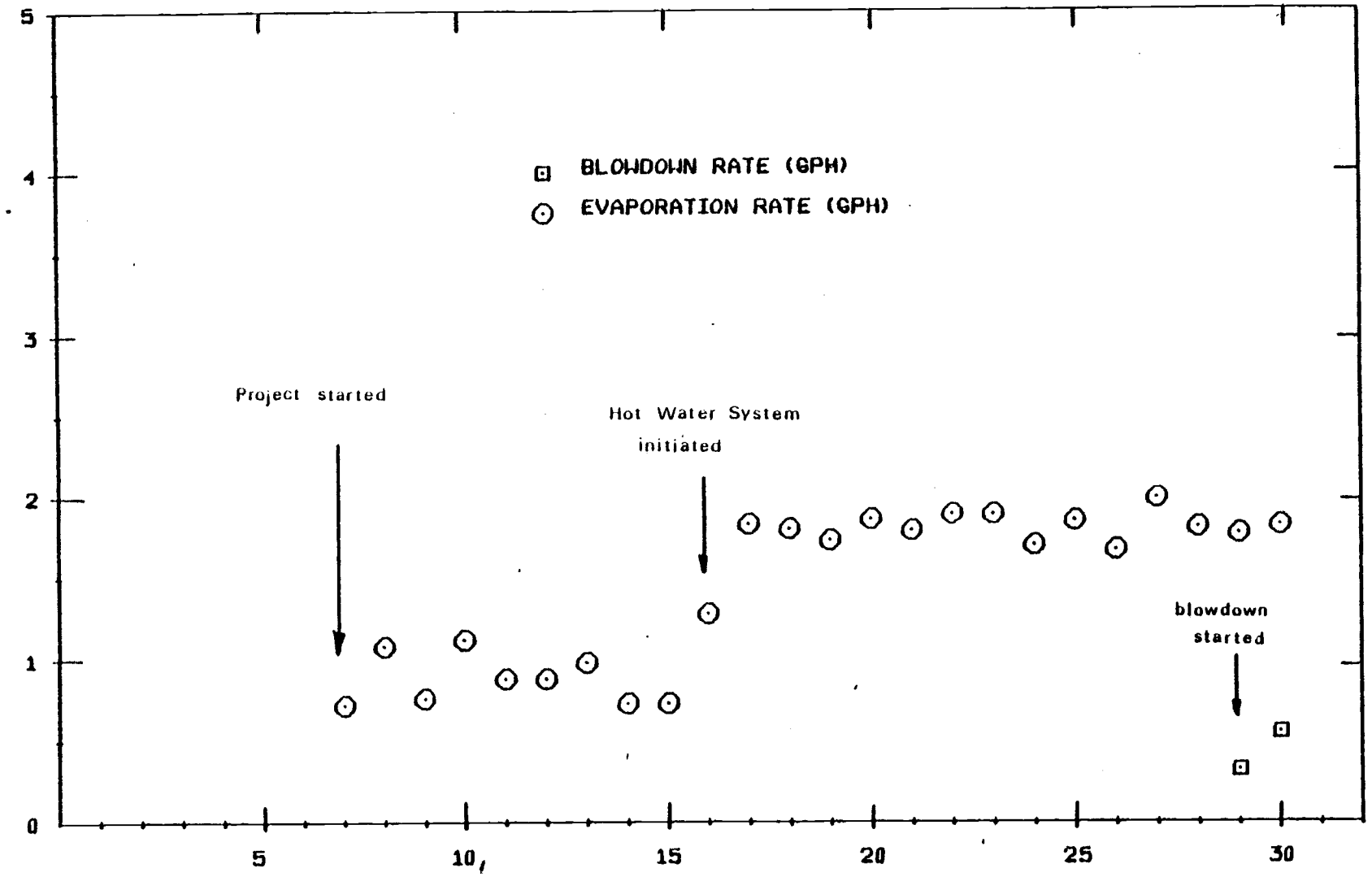
MONTHLY CITY WATER QUALITY

Month	TH	CaH	M-alk	Cl	Si		pH	TS	Cond
					Std method[1]	Hack's method			
Nov. 76	41 (5.8)	31 (5.0)	36 (5.0)	27 (2.8)	-----	-----	7.52 (0.16)	69 (17)	----
Dec. 76	47 (5.4)	32 (4.0)	44 (6.1)	30 (3.8)	-----	-----	7.95 (0.53)	67 (15)	----
Jan. 77	43 (3.0)	32 (3.4)	42 (4.0)	31 4.1	-----	-----	7.95 (0.37)	68 (18)	88 (11)
Feb. 77	44 (2.7)	31 (2.1)	41 (3.8)	33 (3.2)	14 (0.3)	-----	7.70 (0.34)	71 (20)	105 (10)
March 77	41 (1.9)	29 (2.8)	36 (5.3)	30 (3.9)	13 (9.8)	-----	7.72 0.20	53 (20)	87 (7)
April 77	39 (4.6)	27 (2.5)	40 (2.0)	32 (4.1)	15 (0.8)	-----	7.82 (0.21)	64 (21)	100 (12)
May 77	37 (2.5)	27 (2.5)	39 (2.5)	33 (2.8)	-----	18 (1.9)	7.81 0.21	65 (25)	97 (7.5)
June 77	44 (4.7)	31 (3.1)	42 (4.1)	36 (4.4)	-----	17 (1.2)	7.98 (0.15)	66 (16)	115 (15)
July 77	44 (2.6)	33 (3.6)	38 (3.7)	39 (2.5)	-----	17 (0.7)	8.14 (0.11)	77 (22)	119 (11)

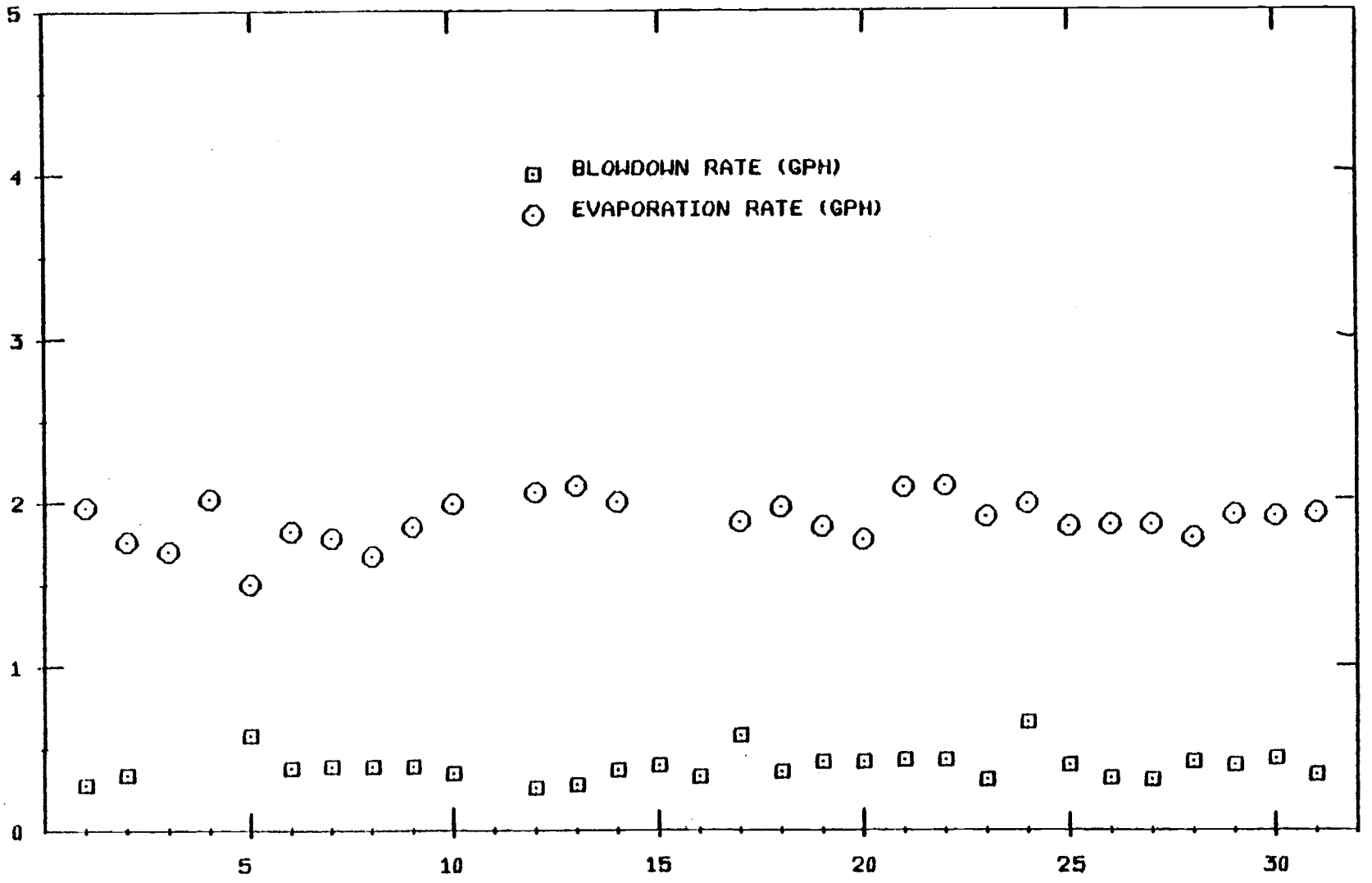
Notes: 1. Refer to Appendix E for nomenclature.
2. Standard deviations in parenthesis

APPENDIX G

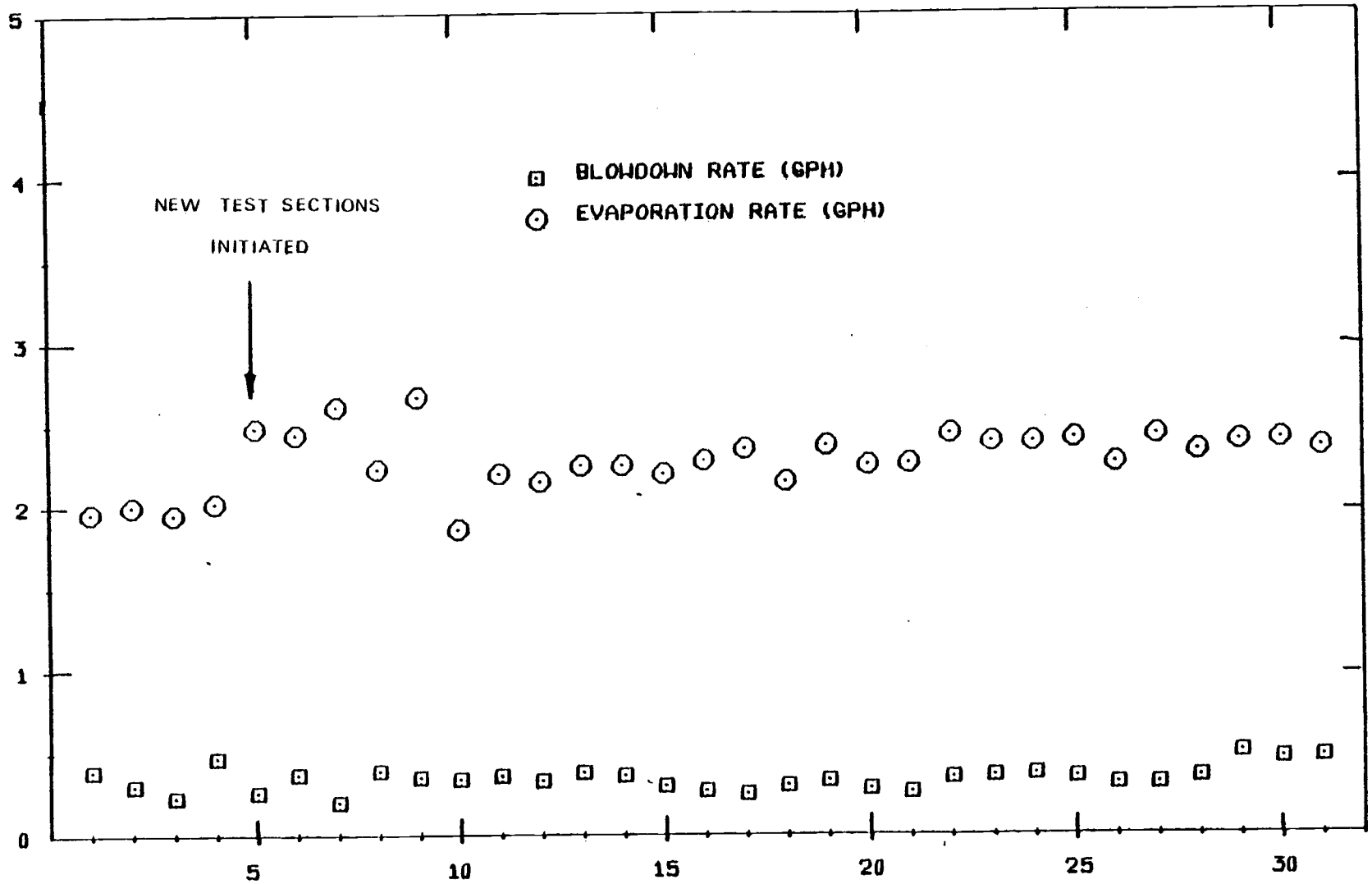
PLOTS OF BLOWDOWN RATE AND EVAPORATION RATE - NOVEMBER 76 THROUGH JULY 77


BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)
Project started
Hot Water System initiated
blowdown started
0
1
2
3
4
5
5
10
15
20
25
30

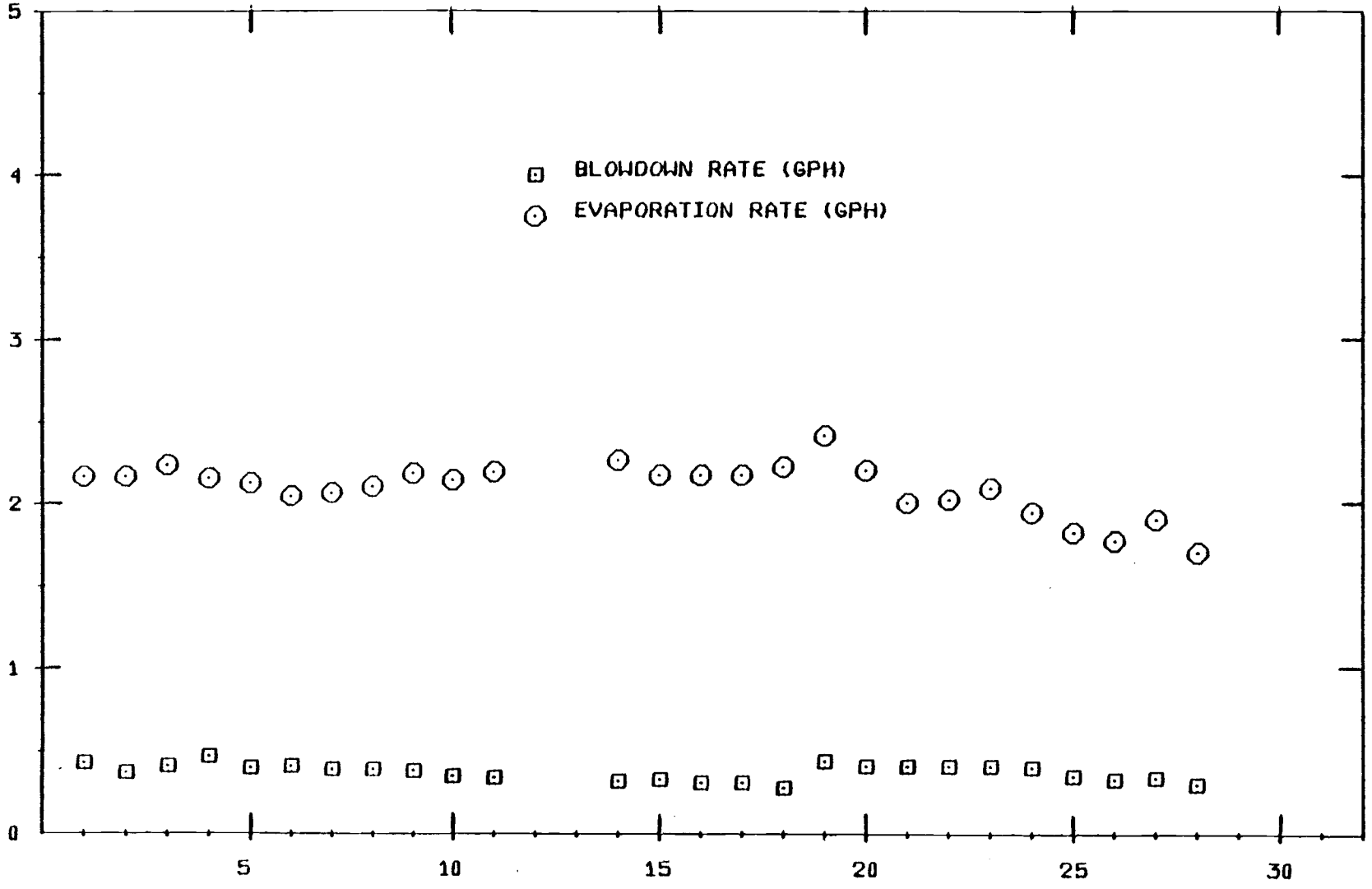
NOV 76


BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)
5
4
3
2
1
0
5
10
15
20
25
30

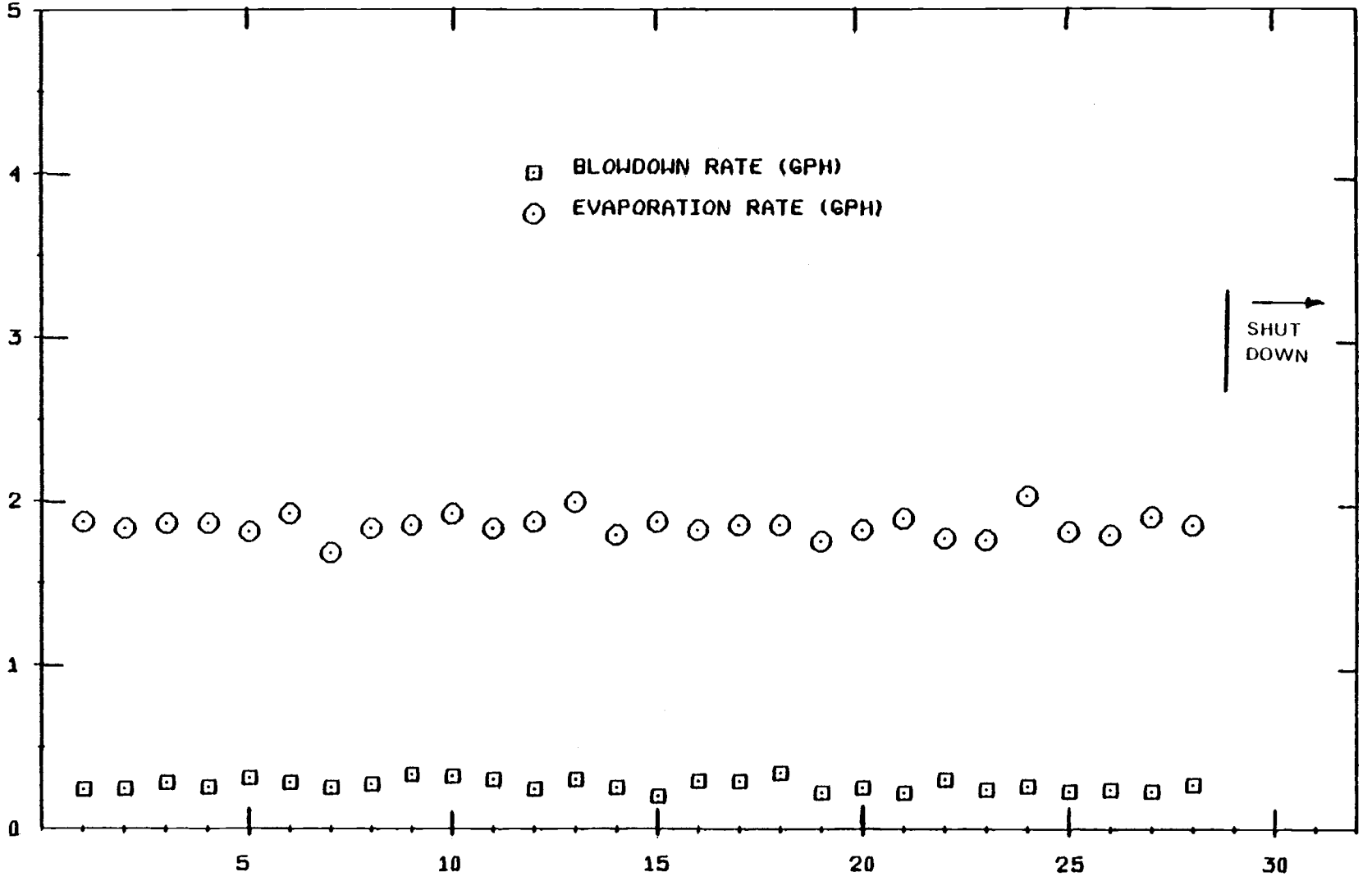
DEC 76


5
4
3
2
1
0
5
10
15
20
25
30
NEW TEST SECTIONS
INITIATED
BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)

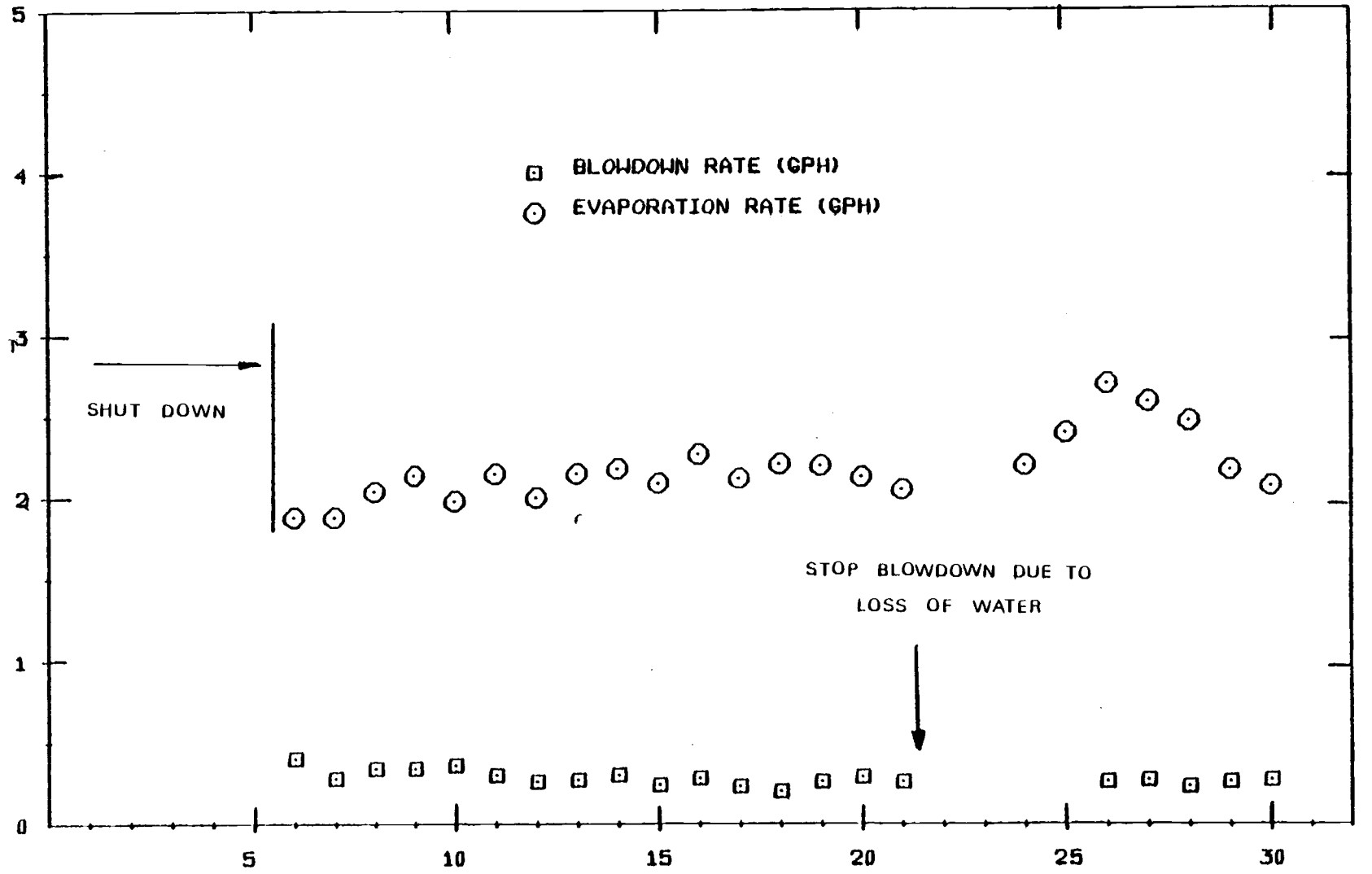
JAN 77


BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)
0
1
2
3
4
5
5
10
15
20
25
30

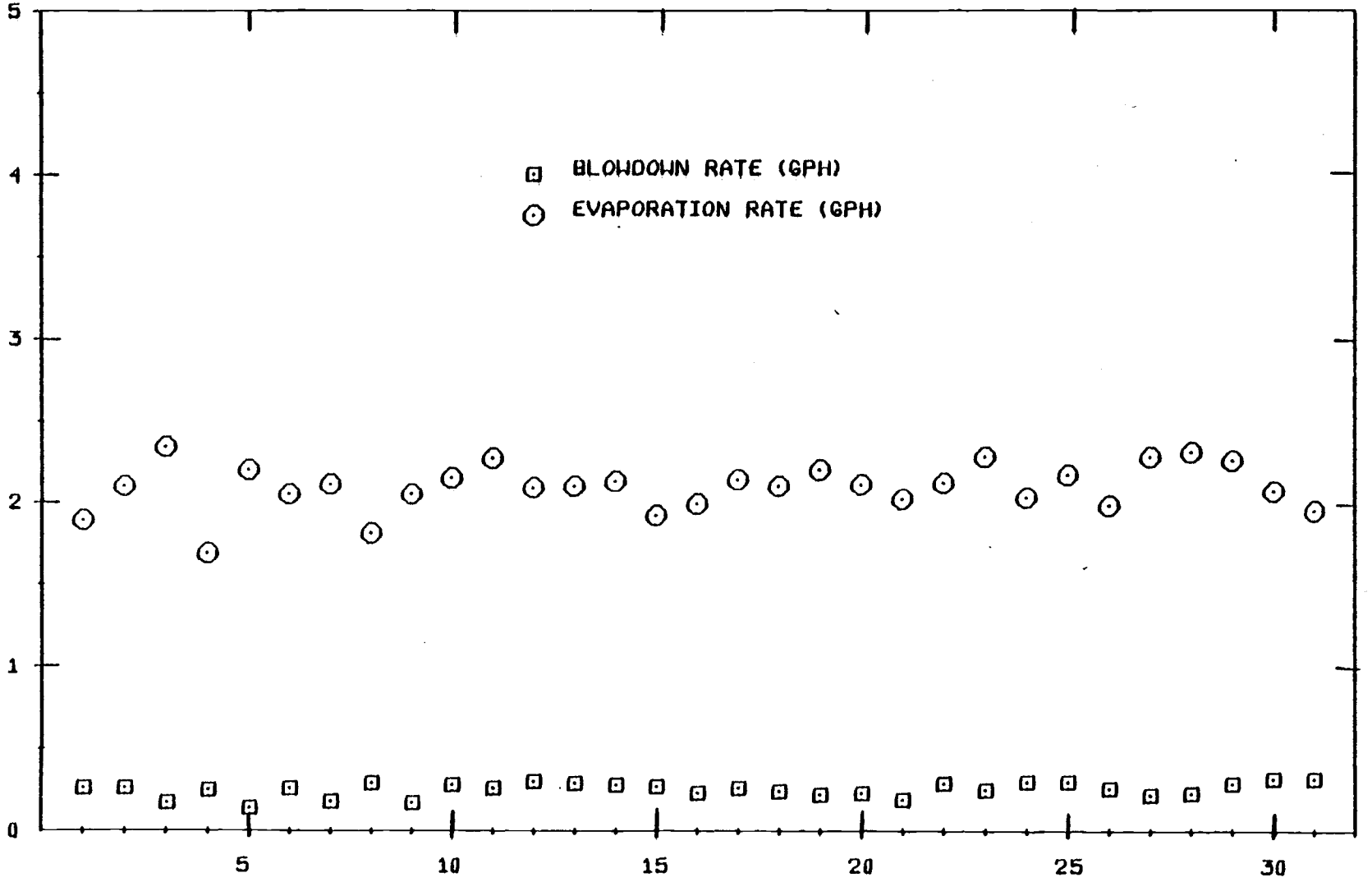
FEB 77


5
4
3
2
1
0
BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)
SHUT
DOWN
5
10
15
20
25
30

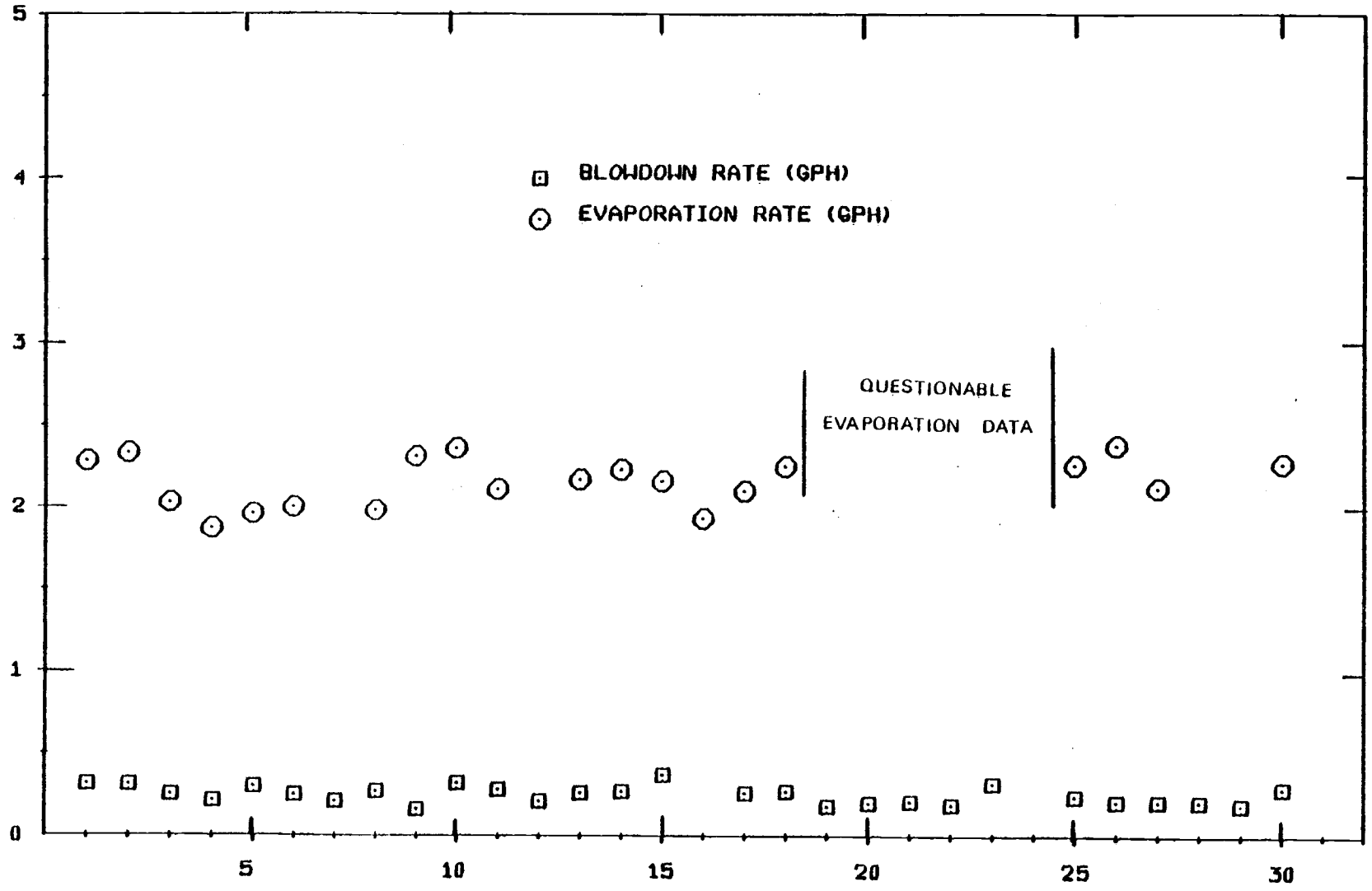
MARCH 77


BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)
SHUT DOWN
STOP BLOWDOWN DUE TO
LOSS OF WATER
0
1
2
3
4
5
5
10
15
20
25
30

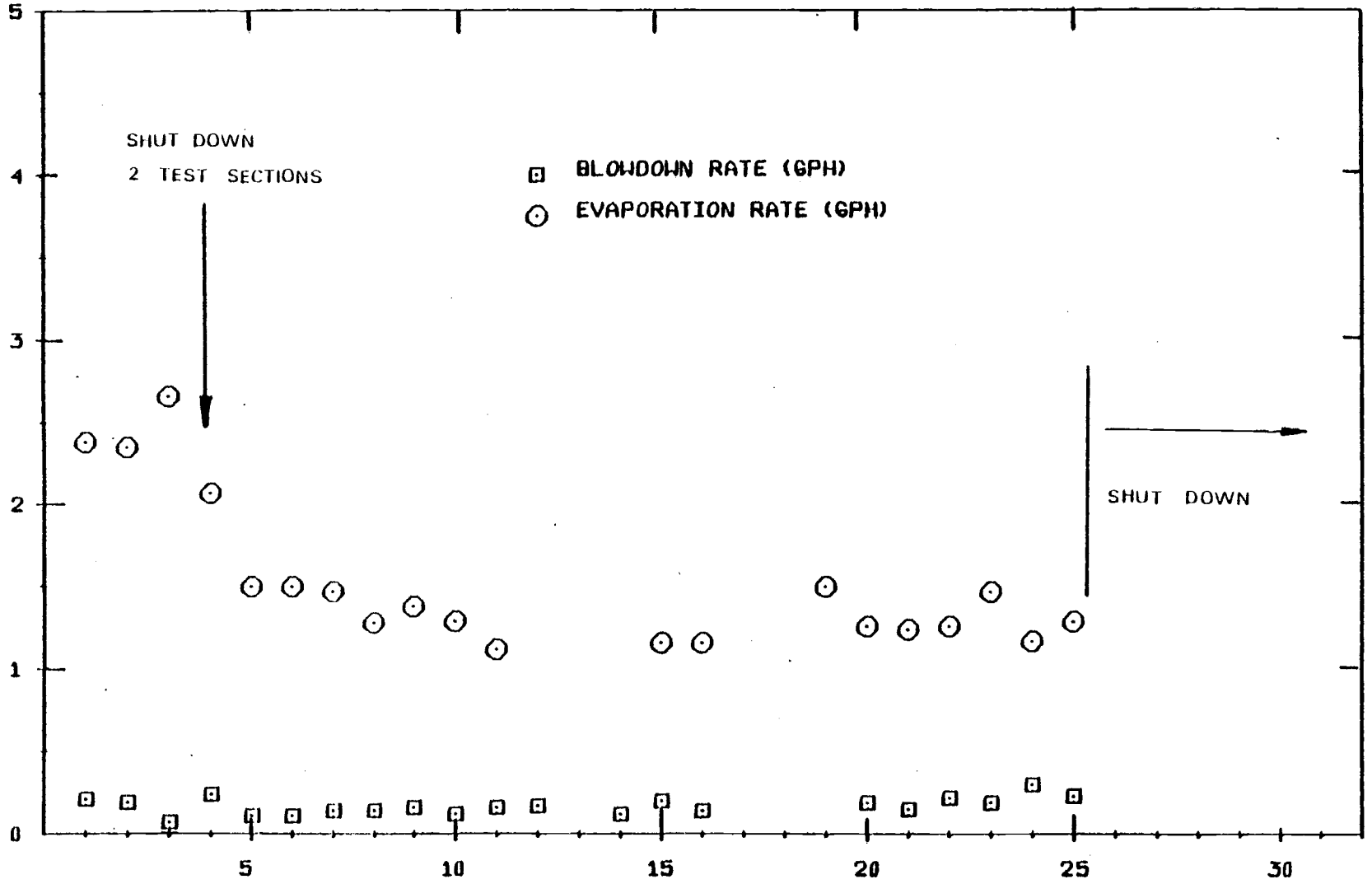
APRIL 77


BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)
0
1
2
3
4
5
5
10
15
20
25
30

MAY 77


5
4
3
2
1
0
BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)
QUESTIONABLE
EVAPORATION DATA
5
10
15
20
25
30

JUNE 77


SHUT DOWN
2 TEST SECTIONS
BLOWDOWN RATE (GPH)
EVAPORATION RATE (GPH)
SHUT DOWN
0
1
2
3
4
5
5
10
15
20
25
30

JULY 77

APPENDIX H

SAMPLE CALCULATIONS

A detailed calculation procedure for fouling resistance determination of location A, heater rod 169, Run 6 is outlined as follows. Specifications of heater rod, calibration equations and raw data can be found in Table 1, Appendix B and Appendix C respectively.

UNFOULED CONDITION - h_i/v_i^b CALCULATION

Date and Time: February 17, 1977, 10:10

Raw Data:

TC_{inlet} = 2.034 mv

TC_{outlet} = 2.091 mv

TC_{w_i} = 4.850 mv

Q = 1000 watts

Flow = 31.0% max. flow

Conversion of Data to Appropriate Units:

$$T_{inlet} = 32.583\ (2.034 + 0.979)^{0.949}$$
$$= 92.8^{o}F$$

$$T_{outlet} = 32.583\ (2.091 + 0.979)^{0.949}$$
$$= 94.5^{o}F$$

$$T_{w_i} = 38.529\ (4.85 + 0.679)^{0.8765}$$
$$= 172.3^{o}F$$

$$W'_{F_i} = 0.1613 \times 31.0$$
$$= 5.0\ gpm$$

$$v_i = W'_{F_i} \times 0.13368/((D_1/2)^2 - (D_2/2)^2) \times 60$$

$$= \frac{5.0 \times 0.13368 \times 4 \times 144}{3.1416 \times (0.75^2 - 0.435^2) \times 60}$$

$$= 5.5 \text{ ft/sec}$$

Local Bulk Temperature

From Eq. (5-1)

$$T_b = (T_{outlet} - T_{inlet}) \times (Y/L) + T_{inlet}$$

$$= (94.5 - 92.8) \times (3.0/3.95) + 92.8$$

$$= 94.1^{o}F$$

Local Surface Temperature

From Eq. (5-3)

$$T_{s_i} = T_{w_i} - (Q/A)(x/k)$$

$$= 172.5 - \left(\frac{1000 \times 491.62}{3.1416 \times 0.435 \times 3.95}\right)\left(\frac{1}{5081}\right)$$

$$= 154.6^{o}F$$

Local Film Coefficient

From Eq. (5-4)

$$h_i = (Q/A)(T_{s_i} - T_b)$$

$$= 91074/(154.6 - 94.1)$$

$$= 1506 \text{ Btu/ft}^2\text{-hr-}^{o}F$$

$$K_i = h_i/v_i^{r}$$

$$= 1506/(5.5)^{0.7}$$

$$= 458.3 \text{ (Btu/ft}^2\text{-hr-}^{o}F)\left(\frac{\text{sec}}{\text{ft}}\right)^{0.7}$$

The average value of 17 data points is

$$K_{avg} = \sum_{j=1}^{17} h_{ij}/v_{ij}^{r} \Big/ 17$$

$$= 466.9 \ (Btu/ft^2\text{-}hr\text{-}^oF)(sec/ft)^{0.7}$$

FOULED CONDITION - R_f CALCULATION

Date and Time: February 23, 1977, 10:35

Raw Data:

TC_{inlet} = 2.061 mv

TC_{outlet} = 2.117 mv

TC_w = 5.340 mv

Q = 999 watts

FLOW = 31.0% max. flow

Conversion of Data to Anpropriate Units

$$T_{inlet} = 32.583 \times (2.061 + 0.979)^{0.949}$$

$$= 9.36^oF$$

$$T_{outlet} = 32.583 \times (2.117 + 0.979)^{0.949}$$

$$= 95.2^oF$$

$$T_w = 38.529 \times (5.340 + 0.679)^{0.8765}$$

$$= 185.8^oF$$

$$W_F' = 0.1613 \times 31.0$$

$$= 5.0 \text{ gpm}$$

$$v = W_F' \times 0.13368/((D_1/2)^2 - (D_2/2)^2) \times 60$$

$$= \frac{5.0 \times 0.13368 \times 4 \times 144}{3.1416 \times (0.75^2 - 0.435^2) \times 60}$$

$$= 5.5 \text{ ft/sec}$$

Local Bulk Temperature

From Eq. (5-1)

$$T_b = (95.2 - 93.6) \times (3.0/3.95) + 95.6$$

$$= 94.8^{o}F$$

Local Film Coefficient

From Eq. (5-7)

$$h = K_{avg}\, v^{r}$$

$$= 466.9 \times (5.5)^{0.7}$$

$$= 1534 \text{ Btu/ft}^2\text{-hr-}^{o}\text{F}$$

Local Surface Temperature

From Eq. (5-8)

$$T_s = ((Q/A)/h) + T_b$$

$$= \left(\frac{999 \times 491.62}{3.1416 \times 0.435 \times 3.95 \times 1534}\right) + 94.8$$

$$= 154.2^{o}F$$

Local Fouling Resistance

From Eq. (5-9)

$$R_f = ((T_w - T_s)/(Q/A)) - x/k$$

$$= \frac{(185.8 - 154.2) \times 3.1416 \times 0.435 \times 3.95}{999 \times 491.62} - \frac{1}{5081}$$

$$= 1.51 \times 10^{-4} \text{ ft}^2\text{-hr-}^{o}\text{F/Btu}$$

ERROR ESTIMATION

From Eq. (5-17)

$$\frac{dT_{inlet}}{T_{inlet}} = \frac{0.949 \times 0.005}{2.034 + 0.979}$$

$$= 1.57 \times 10^{-3}$$

$$\frac{dT_{outlet}}{T_{outlet}} = \frac{0.949 \times 0.005}{2.091 + 0.979}$$

$$= 1.55 \times 10^{-3}$$

From Eq. (5-12)

$$Z_1 = (94.5 - 92.8) \times 3.0 + 92.8 \times 3.95$$

$$= 371.66$$

From Eq. (5-11), the relative error of bulk temperature is then

$$\frac{dT_{b_i}}{T_{b_i}} = \frac{(94.5)(3.0)}{371.66} \times 1.55 \times 10^{-3} \pm \frac{(3.0)(94.5 - 92.8)}{371.66} \times \frac{0.005}{3.0}$$

$$\pm \frac{(3.0)(94.5 - 92.8)}{371.66} \frac{0.005}{3.95} \pm \frac{(3.95 \pm 3.0)(92.8)}{371.66} \times 1.57 \times 10^{-3}$$

$$= \pm 3.95 \times 10^{-3}$$

From Eq. (5-18)

$$\frac{dT_{w_i}}{T_{w_i}} = \frac{(0.8765)(0.005)}{(4.85 + 0.679)}$$

$$= 7.93 \times 10^{-4}$$

From Eq. (5-16)

$$\frac{d(Q/A)_i}{(Q/A)_i} = \frac{2}{1000} \pm \frac{0.0005}{0.435} \pm \frac{0.005}{3.95}$$

$$= 4.42 \times 10^{-3}$$

From Eq. (5-15)

$$Z_2 = (172.5)(5081) - 91074$$

$$= 785400$$

From Eq. (5-13) the relative error of T_{s_i} is therefore

$$\frac{dT_{s_i}}{T_{s_i}} = \frac{(5081)(172.5)}{785400} \times 7.93 \times 10^{-4} \pm \frac{94074}{785400} \times 4.42 \times 10^{-3}$$

$$\pm \frac{91074}{785400} \times \frac{50}{5081}$$

$$= \pm 2.54 \times 10^{-3}$$

From Eq. (5-14)

$$\frac{dh_i}{h_i} = 4.42 \times 10^{-3} \pm \frac{154.6}{(154.6 - 94.1)} \times 2.54 \times 10^{-3}$$

$$\pm \frac{94.1}{(154.6 - 94.1)} \times 3.95 \times 10^{-3}$$

$$= \pm 1.71 \times 10^{-2}$$

From Eq. (5-20)

$$Z_3 = 91074 + (1534)(94.8)$$

$$= 236500$$

From Eq. (5-19), the relative error of the surface temperature is

$$\frac{dT_s}{T_s} = \frac{91074}{236500} \times 4.42 \times 10^{-3} \pm \frac{91074}{236500} \times 1.71 \times 10^{-2}$$

$$\pm \frac{(1534)(94.8)}{236500} \times 3.95 \times 10^{-3}$$

$$= \pm 1.07 \times 10^{-2}$$

From Eq. (5-24)

$$Z_4 = (5081)(185.8 - 154.2) - 90982$$

$$= 69577$$

From Eq. (5-18)

$$\frac{dT_w}{T_w} = \frac{(0.8765)(0.005)}{(5.34 + 0.679)}$$

$$= 7.28 \times 10^{-4}$$

From Eq. (5-23), the maximum relative error of the fouling resistance is

$$\frac{dR_f}{R_f} = \frac{(5081)(185.8)}{69577} \times 7.28 \times 10^{-4} \pm \frac{(5081)(154.2)}{69577} \times 1.07 \times 10^{-2}$$

$$\pm \frac{(5081)(185.8 - 154.2)}{69577} \times 4.42 \times 10^{-3} \pm \frac{90982}{69577} \times \frac{50}{5081}$$

$$= \pm 14.06\%$$

APPENDIX I

COMPUTER PROGRAMS IN FORTRAN IV

```
      PROGRAM FRPLOT
C
C     THIS PROGRAM IS TO CALCULATE THE FOULING RESISTANCE AS THE
C     SCALE IS FORMED ON THE HEAT EXCHANGER SURFACE.
C     FUNCTIONS INCLUDE:
C      1. CHRML-- CONVERSION OF TEMPERATURE FROM MV TO DEG F
C      2. FLOW-- CALCULATION OF (FLOW RATE)**N1,WHERE N1=0.7 WHEN
C                THE FLOW VELOCITY>4 FPS,AND N1=0.93 OTHERWISE
C      3. TSURF-- EVALUATION OF THE SURFACE TEMPERATURE
C      4. TBULK-- WATER BULK TEMPERATURE CALCULATION
C     SUBROUTINES INCLUDE:
C      1. AVGDEV-- CALCULATION OF THE MEAN AND THE STANDARD
C                  DEVIATION OF A SET OF DATA
C      2. PLOTRF-- DATA PLOTTING ROUTINE
C      3. SHIFT-- RAW DATA FORMAT MODIFICATION
C     PROGRAM OPTIONS:
C       IPRINT=1, DATA PRINT OUT ONLY
C       IPRINT=0, GRAPH PLOTTING ONLY
C       KOPT=0, LAST SET OF DATA
C     NOMENCLATURE
C      AQPA-- MEAN HEAT FLUX (BTU/HR FT**2)
C      ATB-- MEAN BULK TEMPERATURE (DEG F)
C      ATS-- MEAN SURFACE TEMPERATURE (DEG F)
C      AVEL-- MEAN FLOW VELOCITY (FT/SEC)
C      D-- RAW DATA MATRIX.  (D(I,J),J=1,10) REPRESENTS HOUR,
C          MINUTE,INLET TEMP (MV),OUTLET TEMP (MV),
C          WALL TEMP A (MV),WALL TEMP B (MV),WALL TEMP C (MV),
C          WALL TEMP D (MV),HEAT FLUX (KW),FLOW RATE
C          (%MAX FLOW FOR SECTION 3,MV FOR SECTION 1 AND 2)
C      FAC-- RATIO OF FILM COEF OF WATER WHEN HEATER ROD IS CLEAN,
C            TO VN: ENTER AS DATA
C      HDOD-- HEATER ROD OUTSIDE DIAMETER (IN)
C      HF-- FILM COEF OF WATER WHEN SCALE HAS BEEN FORMED
C           (BTU/FT**2 HR DEG F)
C      HW-- K/X OF HEATER ROD (BTU/FT **2 HR DEG F)
C      I-- SECTION 1,2 OR 3
C      KDAY-- DATE
C      KYR-- YEAR
C      KOE-- RUN TIME (DAY)
C      LHDNO-- HEATER ROD NUMBER
C      LSMIN,LSHR,LSDAY,LSMON,LYR-- STARTING MINUTE ,HOUR,DAY,
C                                   MONTH,YEAR,RESPECTIVELY
C      MON-- MONTH
C      N-- TOTAL NUMBER OF DATA POINTS FOR A SET OF DATA
C      NRUN-- RUN IDENTITY NUMBER
C      QPA-- HEAT FLUX (BTU/HR FT**2)
C      RF-- FOULING RESISTANCE (FT**2 HR DEG F/BTU)
C      SQPA-- STANDARD DEVIATION OF HEAT FLUX (BTU/HR FT**2)
C      SVEL-- STANDARD DEVIATION OF FLOW VELOCITY (FT/SEC)
C      STB-- STANDARD DEVIATION OF BULK TEMP (DEG F)
C      STS-- STANDARD DEVIATION OF SURFACE TEMP (DEG F)
C      TB-- BULK TEMP OF WATER (DEG F)
C      TC-- HEATER ROD WALL TEMP (DEG F)
C      TM-- TIME (HR)
C      TS-- SURFACE TEMP (DEG F)
C      V-- 4 FT/SEC IN MV FOR SECTION 1 AND 2, IN % MAX FLOW FOR 3
C      VEL-- FLOW VELOCITY (FT/SEC)
C      VFAC-- CONVERSION FACTOR FROM % MAX FLOW TO FPS FOR I=3
C      VN-- (FLOW RATE)**N1  (N1=0.7 IF VEL>4 FPS,OR N1=0.93)
C      XL-- LENGTH OF ENTIRE HEATER SECTION (IN)
C      XW-- POSITION OF CHARACTER OUTPUT IN X AXIS OF PLOTRF
C      YL-- LENGTH OF HEATER SECTION TO THE TIP OF THERMOCOUPLES
C           IN THE DIRECTION OF FLOW
C      YLL3-- POSITION OF CHARACTER OUTPUT IN Y AXIS OF PLOTRF
C
      DIMENSION FAC(3,4),HW(3,4),D(300,10),TS(300,4),TC(300,4),
     1  TB(300),QPA(300),VN(300),VEL(300),LSMON(3),LSDAY(3),
     2  LYR(3),XL(3),LHDNO(3),RF(300,4),ATS(4),STS(4),
     3  LSHR(3),LSMIN(3),TM(300),TTS(300),JDAY(300)
      COMMON I,V(3),HDOD(3),YL(3)
      COMMON /HXL/ XL
      COMMON/XYB/YLL3(10),XW
C
C     READ IN DATA
C
      READ (15,111) IPRINT,NRUN,XID,VFAC,YLL3(1),XW
  111 FORMAT (2I5,4F10.5)
      READ (15,100) (((HW(J,K),K=1,4),V(J)),J=1,3)
  100 FORMAT (5F10.2)
      READ (15,101) ((LSHR(J),LSMIN(J),LSMON(J),LSDAY(J),LYR(J),
     1   LHDNO(J),YL(J),XL(J),HDOD(J)),J=1,3)
  101 FORMAT (6I5,3F7.3)
      READ (15,104) ((FAC(J,K),K=1,4),J=1,3)
```

```
  104 FORMAT (4F7.3)
      CALL SHIFT
      REWIND 10
      NPP=0
 2000 CONTINUE
      READ (10,102) MON,KDAY,KYR,KDE,KOPT,I,N
  102 FORMAT (7I5)
      NP=NPP+1
      NPP=NPP+N
      READ (10,103) ((D(J,K),K=1,10),J=NP,NPP)
      IF (EOF(10)) GO TO 195
  103 FORMAT (F5.0,F2.0,6F7.3,F7.4,F7.2)
C
CCC   DATA REDUCTION
C
      DO 15 K5=NP,NPP
      TM(K5)=24.*FLOAT(KDE)-FLOAT(LSHR(I))-(FLOAT(LSMIN(I))/60.)
     1   +D(K5,1)+D(K5,2)/60.
   15 JDAY(K5)=KDE
      DO 1 I1=NP,NPP
      DO 1 I3=5,8
      I4=I3-4
      TC(I1,I4)=CHRML(D(I1,I3))
    1 IF (D(I1,I3).EQ.0.) TC(I1,I4)=0.
      IF (I.EQ.3) GO TO 60
      DO 2 I2=NP,NPP
      QPA(I2)=D(I2,9)*100.*(491.62/(3.1415*HOOD(I)*XL(I)))
      VEL(I2)=D(I2,10)**0.5*10./20.**0.5
      TB(I2)=TBULK(VEL(I2),QPA(I2))+CHRML(D(I2,3))
      VN(I2)=FLOW(VEL(I2))
    2 CONTINUE
      GO TO 90
   60 DO 5 I5=NP,NPP
      TB(I5)=((CHRML(D(I5,4))-CHRML(D(I5,3)))*YL(I)/XL(I))+CHRML
     1   (D(I5,3))
      QPA(I5)=D(I5, 9)*1000.*491.62/(3.1416*HOOD(I)*XL(I))
      VEL(I5)=VFAC*D(I5,10)
    5 VN(I5)=FLOW(VEL(I5))
   90 DO 10 J=NP,NPP
      DO 10 J1=1,4
      IF (TC(J,J1).EQ.0.) GO  TO 91
      HF=-VN(J)*FAC(I,J1)
      TS(J,J1)=TSURF(QPA(J),HF,TB(J))
      RF(J,J1)=((TC(J,J1)-TS(J,J1))/QPA(J)-1./HW(I,J1))*10000.
      GO TO 10
   91 RF(J,J1)=0.
      TS(J,J1)=0.
   10 CONTINUE
      IF(KOPT.NE.0) GO TO 2000
      GO TO 200
  195 WRITE (61,500)
  500 FORMAT (1H1, *DATA INCOMPLETE*)
      GO TO 202
  200 CONTINUE
      DO 16 K6=1,NPP
   16 VEL(K6)=(VEL(K6)*0.13368/60.)/(3.1416*(XID**2-(HOOD(I))**2)
     1   /576.)
      CALL AVGDEV(VEL,NPP,AVEL,SVEL)
      CALL AVGDEV(TB,NPP,ATB,STB)
      CALL AVGDEV(QPA,NPP,AQPA,SQPA)
      DO 17 K7=1,4
      IF (FAC(I,K7).EQ.0.) GO TO 17
      DO 18 K8=1,NPP
   18 TTS(K8)=TS(K8,K7)
      CALL AVGDEV(TTS,NPP,ATS(K7),STS(K7))
   17 CONTINUE
      REWIND 26
      WRITE(26,112) NRUN,LHONO(I),AVEL
  112 FORMAT (2I8,F8.2)
      DO 24 J24=1,4
      IF (ATS(J24).EQ.0.) GO TO 25
      WRITE (26,113) ATS(J24)
  113 FORMAT (F8.1)
      GO TO 24
   25 WRITE (26,114)
  114 FORMAT(*            *)
   24 CONTINUE
      IF (IPRINT.EQ.0)GO TO 201
C
CCC   PRINTOUT FORMAT OF RESULTS
C
      WRITE(61,110) NRUN
  110 FORMAT (1H1,*RUN*,25X,I5)
      WRITE(61,119) I
```

```
  115 FORMAT (1H0,≠TEST SECTION≠,16X,I5)
      WRITE(61,120) LMONO(I)
  120 FORMAT (1H0,≠HEATER ROD NUMBER≠,11X,I5)
      WRITE(61,125) LSMON(I),LSDAY(I),LYR(I)
  125 FORMAT (1H0,≠STARTING DATE≠,12X,I2,≠/≠,I2,≠/≠,I2)
      WRITE(61,130) KDE
  130 FORMAT (1H0,≠RUN TIME (DAYS)≠,13X,I5)
      WRITE(61,135)
  135 FORMAT (/ 1H0,≠RUN STATISTICS≠,15X,≠MEAN≠,6X,≠STD. DEV.≠)
      WRITE(61,140) AVEL,SVEL
  140 FORMAT (1H0,≠WATER VELOCITY (FPS)≠,8X,F5.3,10X,F5.3)
      WRITE(61,145) AQPA,SQPA
  145 FORMAT (1H0,≠HEAT FLUX (BTU/HR)≠,7X,F8.0,7X,F8.1)
      WRITE(61,150) ATB,STB
  150 FORMAT (1H0,≠WATER BULK TEMP (DEG F)≠,4X,F6.1,9X,F6.2)
      WRITE (61,151)
  151 FORMAT (1H0,≠SURFACE TEMP (DEG F)≠)
      IF (ATS(1 ).EQ.0.) GO TO 600
      WRITE(61,155) ATS(1 ),STS(1 )
  155 FORMAT (1H0,≠  LOCATION A≠,15X,F6.1,9X,F6.2)
  600 IF (ATS(2 ).EQ.0.) GO TO 601
      WRITE(61,156) ATS(2 ),STS(2 )
  156 FORMAT (1H0,≠  LOCATION B≠,15X,F6.1,9X,F6.2)
  601 IF (ATS(3 ).EQ.0.) GO TO 603
      WRITE(61,157) ATS(3 ),STS(3)
  157 FORMAT (1H0,≠  LOCATION C≠,15X,F6.1,9X,F6.2)
  603 IF (ATS(4 ).EQ.0.) GO TO 19
      WRITE(61,158) ATS(4 ),STS(4)
  158 FORMAT (1H0,≠  LOCATION D≠,15X,F6.1,9X,F6.2)
   19 CONTINUE
      WRITE(61,160) NRUN
  160 FORMAT(1H1,24X,≠RAW DATA--RUN≠,I3)
      WRITE(61,165)
  165 FORMAT (//1H0,≠DAY  TIME    TIN    TOUT    TWA    TWB    ≠
     1   ≠TWC    TWD    HEAT   FLOW≠/)
      DO 20 JO=1,NPP
      WRITE(61,170) JDAY(JO),(O(JO,K),K=1,10)
  170 FORMAT (1X,I3,F4.0,F2.0,8F7.3 )
   20 CONTINUE
      WRITE(61,175) NRUN
  175 FORMAT(1H1,55X,≠RESULTS--RUN≠,I3)
      WRITE(61,180)
  180 FORMAT(//1H0,5X,≠DAY≠,4X,≠TIME≠,4X,≠VEL≠,5X,≠Q/A≠,
     1   5X,≠TBA≠,4X,≠TWA≠,4X,≠TSA≠,4X,≠RFA≠,4X,≠TWB≠,4X,
     2   ≠TSB≠,4X,≠RFB≠,4X,≠TWC≠,4X,≠TSC≠,4X,≠RFC≠,4X,
     3   ≠TWD≠,4X,≠TSD≠,4X,≠RFD≠/)
      DO 21 JR=1,NPP
      WRITE(61,185) JDAY(JR),TM(JR),VEL(JR),QPA(JR),TB(JR),
     1   (TC(JR,K),TS(JR,K),RF(JR,K),K=1,4)
  185 FORMAT (7X,I2,F8.1,F7.2,F8.0,F7.1,4(F7.1,F7.1,F7.2))
   21 CONTINUE
      IF (IPRINT.EQ.1) GO TO 202
  201 CONTINUE
      CALL PLOTRF(NPP,TM,RF)
  202 CONTINUE
      END



      SUBROUTINE AVGDEV(A,NP,AVG,SIGMA)
C
C     THIS SUBROUTINE IS TO CALC. THE AVERAGE VALUE AND STD
C     DEVIATION OF A SET OF DATA
C     NOMENCLATURE:
C       A       SET OF DATA
C       NP      NUMBER OF DATA
C       AVG     MEAN OF DATA
C       SIGMA   STANDARD DEVIATION OF DATA
C
      DIMENSION A(300)
      SUMA=0.
      SUMSQ=0.
      NC=NP
      DO 1 J=1,NP
      IF (A(J).EQ.0.) NC=NC-1
    1 SUMA=SUMA+A(J)
      AVG=SUMA/(FLOAT(NC))
      DO 2 K=1,NP
      IF(A(K).EQ.0.) GO TO 2
      SUMSQ=SUMSQ+(ABS((A(K)-AVG)))**2
    2 CONTINUE
      SIGMA=(SUMSQ/(FLOAT(NC-1)))**0.5
      RETURN
      END
```

```
      FUNCTION TSURF(X,Y,Z)
C
C     THIS FUNCTION IS TO CALCULATE THE SURFACE
C     TEMP OF THE HEATER ROD
C
      TSURF=-X/Y+Z
      RETURN
      END



      FUNCTION TBULK(X,Y)
C
C     THIS FUNCTION IS TO CALCULATE THE BULK
C     TEMPERATURE OF WATER
C
      COMMON I,V(3),HDOD(3),YL(3)
      TBULK=Y*3.1416*HDOD(I)*YL(I)*7.481/
     1   (144.*62.37*X*60.)
      RETURN
      END



      FUNCTION CHRML(T)
C
C     THIS FUNCTION IS TO CONVERT MV TO
C     DEG F
C
      COMMON I,V(3),HDOD(3),YL(3)
      IF (I.NE.3) GO TO 10
      IF (T.GT.3.041) GO TO 5
      CHRML=32.583*(T+0.979)**0.949
      RETURN
    5 CHRML=38.529*(T+0.679)**0.9765
      RETURN
   10 IF (T.GT.-1.) GO TO 15
      CHRML=32.583*(T+5.02)**0.949
      RETURN
   15 CHRML=38.529*(T+4.72)**0.8765
      RETURN
      END



      FUNCTION FLOW(A)
C
C     THIS FUNCTION IS TO CALCULATE THE VALUE OF
C     VEL**N1,WHERE N1=0.7 OR 0.93
C
      COMMON I,V(3),HDOD(3),YL(3)
      IF (I.NE.3) GO TO 1
      IF (A.GE.V(3)) GO TO 4
      GO TO 3
    1 IF (I.EQ.2) GO TO 2
      IF (A.GE.V(1)) GO TO 4
      GO TO 3
    2 IF (A.GE.V(2)) GO TO 4
    3 FLOW=A**0.93
      RETURN
    4 FLOW=A**0.7
      RETURN
      END
```

```
      PROGRAM FP
C
C     THIS PROGRAM IS TO CALC THE RATIO OF THE FILM COEF
C     OF WATER TO (FLOW RATE)**N1 WHEN THE HEATER ROD
C     IS CLEAN
C     NOMENCLATURE:
C      HC== FILM COEF OF WATER WHEN HEATER ROD IS CLEAN
C           (BTU/HR FT**2 DEG F)
C      SQ== SET POINT HEAT FLUX (KW)
C      STVEL== SET POINT FLOW RATE (% MAX FLOW FOR
C              SECTION 3,GPM FOR SECTION 1,2)
C     FOR DEFINITION OF OTHER IMPORTANT VARIABLES,
C     PLEASE REFER TO PROGRAM FRPLOT
C
      DIMENSION FAC(3,4),HW(3,4),D(50,9 ),TS(50,4),TC(50,4),
     1  T3(50),QPA(50),VN(50),VEL(50),NC(4),LSMON(3),LSDAY(3),
     2  LYR(3),XL(3),SQ(3),SVEL(3),LHONC(3),HC(50,4),PF(50,4),
     3  HCT(4),LSHR(3),LSMIN(3)
      COMMON I,V(3),HDOD(3),YL(3)
C
C     INPUT DATA
C
      READ (15,100) (((HW(J,K),K=1,4),V(J)),J=1,3)
  100 FORMAT (5F10.2)
      READ (15,101) ((LSHR(J),LSMIN(J),LSMON(J),LSDAY(J),LYR(J),
     1  LHONC(J),YL(J),XL(J),HDOD(J),SQ(J),SVEL(J)),J=1,3)
  101 FORMAT (6I5,5F7.3)
 2000 CONTINUE
      READ (10,102) MON,KDAY,KYR,KOE,KOPT,I,N
      IF (ECF(10)) GO TO 200
  102 FORMAT (7I5)
      READ (10,103) ((D(J,K),K=1,9 ),J=1,N)
      IF (ECF(10)) GO TO 199
  103 FORMAT (F7.0,6F7.3,F7.4,F5.2)
C
C     WRITE OUT DATA
C
      WRITE (61,105) I,MON,KDAY,KYR,KOE,MON,KDAY,KYR,KOE
  105 FORMAT (1H1,5X,#TEST SECTION NUMBER#,1X,I2,15X,#DATE#,5X,
     1  I2,#/#,I2,#/#,I2,5X,#DAYS ELAPSED#,I5,
     2  /30X,#DATE#,5X,I2,#/#,I2,#/#,I2,3X,I2)
      WRITE (61,110) LHONC(I),LSMON(I),LSDAY(I),LYR(I),LSHR(I),
     1  LSMIN(I)
  110 FORMAT (/// 1H0,#HEATER ROD NUMBER:#,I5,5X,#DATE #,
     1  #STARTED:#,I5,#/#,I2,#/#,I2,5X,#   TIME:#,I5,#:#,I2)
      WRITE (61,120) SQ(I),SVEL(I)
  120 FORMAT (/ 1H0,#SET POINT HEAT FLUX:#,F6.3,1X,#KW#,5X,#SET#
     1  #POINT VELOCITY:#,F6.3,1X,#MV OR % FLOW#)
      WRITE (61,130) (HW(I,J),J=1,4)
  130 FORMAT (/ 1H0,#K/X OF 4 TCS:# / 1H0,14X,#A#,14X,#B#,14X,
     1  #C#,14X,#D# / 1H ,4(5X,F10.1))
      WRITE (61,140)
  140 FORMAT (///1H ,9X,#TIME      TCIN      TCOUT       TW4     #
     1  #    TW8       TWC       TWO       HEAT      FLOW#)
      WRITE (61,150) ((D(J,K),K=1,9 ),J=1,N)
  150 FORMAT (1H ,6X,F7.3,8F10.3)
C
C     DATA REDUCTION
C
      DO 1 I1=1,N
      DO 1 I3=4,7
      I4=I3-3
      TC(I1,I4)=CHRML(D(I1,I3))
    1 IF (D(I1,I3).EQ.0.) TC(I1,I4)=0.
      IF (I.EQ.3) GO TO 60
      DO 2 I2=1,N
      QPA(I2)=D(I2,8 )*100.*(491.62/(3.1416*HDOD(I)*XL(I)))
      VEL(I2)=D(I2, 9)**.5*10./20.**.5
      T3(I2)=TBULK(VEL(I2),QPA(I2))+CHRML(D(I2,2))
      VN(I2)=FLOW(VEL(I2))
    2 CONTINUE
      GO TO 70
   60 DO 5 I5=1,N
      T3(I5)=((CHRML(D(I5,3))-CHRML(D(I5,2)))*YL(I)/XL(I))
     1  +CHRML(D(I5,2))
      QPA(I5)=D(I5, 8)*100.*491.62/(3.1416*HDOD(I)*XL(I))
      VEL(I5)=0.1b13*D(I5,9)
    5 VN(I5)=FLOW(D(I5, 8))
   70 CONTINUE
      DO 6 I6=1,4
      FAC(I,I6)=0.
      NC(I6)=N
      HCT(I6)=0.
```

```
    6 CONTINUE
      DO 7 I7=1,N
      DO 7 I8=1,4
      TS(I7,I8)=TSURF(QPA(I7),HW(I,I8),TC(I7,I8))
      HC(I7,I8)=QPA(I7)/(TS(I7,I8)-TB(I7))
      IF (TC(I7,I8).NE.0.) GO TO 81
      TS(I7,I8)=0.
      HC(I7,I8)=0.
      NC(I8)=NC(I8)-1
   81 FAC(I,I8)=FAC(I,I8)+HC(I7,I8)/VN(I7)
    7 HCT(I8)=HCT(I8)+HC(I7,I8)
      DO 9 I9=1,4
      FAC(I,I9)=FAC(I,I9)/FLOAT(NC(I9))
      HCT(I9)=HCT(I9)/FLOAT(NC(I9))
    9 CONTINUE
      WRITE (61,160) (HCT(J),J=1,4)
  160 FORMAT (/// 1H ,*AVERAGE CONVECTIVE VALUE FOR EACH TC*//
     1   1H ,10X,*A*,10X,*B*,10X,*C*,10X,*C*/1H ,4(5X,F6.1))
      WRITE (61,190) (FAC(I,J),J=1,4)
  190 FORMAT (/ 1H ,*VALUES OF HC/V**N*// 1H ,10X,*A*,10X,
     1   *B*,10X,*C*,10X,*D*/ 1H ,4(4X,F7.3))
      WRITE (61,165)
  165 FORMAT (1H1,*   TIME    FLOW        Q/A        TB       TWA   *
     1   *     TSA       HCA       TWB       TSB       HCB       TWC       *
     2   *TSC       HCC       TWD       TSD       HCD*)
      WRITE (61,166) ((D(K,1),VEL(K),QPA(K),TE(K),TC(K,1),
     1   TS(K,1),HC(K,1),TC(K,2),TS(K,2),HC(K,2),TC(K,3),
     2   TS(K,3),HC(K,3),TC(K,4),TS(K,4),HC(K,4)),K=1,N)
  166 FORMAT (1H ,F7.3,F7.2,F11.1,13F8.2)
      GO TO 2000
  195 WRITE (61,153)
  153 FORMAT (1H1,*DATA INCOMPLETE*)
  200 CONTINUE
      END
```

```
      SUBROUTINE PLOTRF(NP,X,Y)
C
C     THIS SUBROUTINE IS TO PLOT THE FOULING RESISTANCE
C     (FT**2 HR F/BTU) VS TIME (HR)
C     FOR FURTHER INFORMATION OF THE PLOTTER ROUTINE,
C     PLEASE REFER TO COMPLOT BY L. HUBBLE AND
C     J. BALLANCE OF OSU COMPUTER CENTER
C     TWO VERSIONS OF THIS PROGRAM ARE AVAILABLE
C     TO ACCOUNT FOR THE CHANGE IN THE X-Y AXIS
C
      DIMENSION YA(5),XA(2),HEATP(2),VELP(3),SURFP(3),
     1  XLOCA(2),XLOCB(2),XLOCC(2),XLOCD(2),NUM(15),X(300),
     2  Y(300,4),SUB(2),SURF(4)
      COMMON/XYB/YLL3(10),XW
C
C     READ IN CHARACTERS TO BE APPEARED IN GRAPH
C
      READ (30,100) (NUM(N),N=1,14)
  100 FORMAT (14A4)
      READ (30,101) (YA(N),N=1,5),(XA(M),M=1,2)
  101 FORMAT (7A4)
      READ (30,102) RUNP,(HEATP(N1),N1=1,2),(VELP(N2),N2=1,3),
     1   (SURFP(N4),N4=1,3)
  102 FORMAT (9A4)
      READ(30,103) (XLOCA(N1),N1=1,2),(XLOCB(N2),N2=1,2),
     1   (XLOCC(N3),N3=1,2),(XLOCD(N4),N4=1,2)
  103 FORMAT (8A4)
      READ (30,104) F,(SUB(J),J=1,2)
  104 FORMAT (3A4)
      REWIND 25
      READ (25,105) RUN,HEAT,VEL
  105 FORMAT (3A4)
      READ (25,106) (SURF(J),J=1,4)
  106 FORMAT (4A4)
      CALL PLOTLUN(50)
      CALL SIZE(27.0,23.5)
      CALL SCALE(0.02778,1.,4.,4.,0.,-1.7)
      CALL AXIS(0.,0.,0.,0.,-1.0,15.,-1.0,100.,2.,1.,1)
      CALL SYMBOL(-45.0,1.0,.35,0.,32,39,YA)
      CALL SYMBOL(-42.,3.175,.08,0.,16,1,F)
      CALL SYMBOL(-53.6,9.5,.08,0.,16,1,NUM(5))
      CALL SYMBOL(-53.6,10.3,.08,0.,16,1,SUB(1))
      CALL SYMBOL(-53.6,12.06,.08,0.,16,1,SUB(2))
      CALL SYMBOL(-17.28,-0.16,.08,0.,32,1,NUM(1))
      YLL=1.34
      DO 1 J=3,12,2
      CALL SYMBOL(-17.28,YLL,.08,0.,32,1,NUM(J))
    1 YLL=YLL+2.
      YLL=9.84
      DO 10 JI=11,13
      CALL SYMBOL(-24.75,YLL,.08,0.,32,2,NUM(JI))
   10 YLL=YLL+2.
      CALL SYMBOL(350.,-2.07,.08,0.,32,10,XA)
      CALL SYMBOL(0.,-1.57,.08,0.,32,1,NUM(1))
      CALL SYMBOL(94.25,-1.57,.08,0.,32,1,NUM(2))
      CALL SYMBOL(94.24,-1.57,.08,0.,32,2,NUM(2))
      YLL1=181.
      XLL2=194.24
      DO 2 K=3,9
      CALL SYMBOL(YLL1,-1.57,.08,0.,32,1,NUM(K))
      CALL SYMBOL(XLL2,-1.57,.08,0.,32,2,NUM(K))
      XLL1=XLL1+100.
      XLL2=XLL2+100.
    2 CONTINUE
      XWW=XW+200.
      XWC=XW+135.
      DO 11 K1=1,9
      K2=K1+1
   11 YLL3(K2)=YLL3(K1)-0.48
      YLLD=YLL3(4)+0.16
      CALL SYMBOL(XW,YLL3(1),.08,0.24,3,RUNP)
      CALL SYMBOL(XWW,YLL3(1),.08,0.24,3,RUN)
      CALL SYMBOL(XW,YLL3(2),.08,0.24,10,HEATP)
      CALL SYMBOL(XWW,YLL3(2),.08,0.24,3,HEAT)
      CALL SYMBOL(XW,YLL3(3),.08,0.24,20,VELP)
      CALL SYMBOL(XWW,YLL3(3),.08,0.24,3,VEL)
      CALL SYMBOL(XW,YLL3(4),.08,0.24,17,SURFP)
      CALL SYMBOL(XWC,YLL3(3),.08,0.16,1,SUB(2))
      CALL SYMBOL(XW,YLL3(5),.08,0.24,12,XLOCA)
      CALL SYMBOL(XWW,YLL3(5),.08,0.24,3,SURF(1))
      CALL SYMBOL(XW,YLL3(6),.08,0.24,12,XLOCB)
      CALL SYMBOL(XWW,YLL3(6),.08,0.24,3,SURF(2))
      CALL SYMBOL(XW,YLL3(7),.08,0.24,12,XLOCC)
```

```
      CALL SYMBOL(XWW,YLL3(7),.1,24,.0,SURF(3))
      CALL SYMBOL(XW,YLL3(9),.1,24,12,XLOOO)
      CALL SYMBOL(XWW,YLL3(8),.1,24,.0,SURF(4))
      CALL PLOT(0.,15.,0,0)
      CALL PLOT(830.,15.,1,0)
      CALL PLOT(800.,-1.,1,0)
      CALL PLOT(0.,3.,0,0)
      DO 3 M=1,4
C
CC    DATA PLOTTING
C
      IF (M.EQ.1) NSYM=19
      IF (M.EQ.2) NSYM=20
      IF (M.EQ.3) NSYM=2
      IF (M.EQ.4) NSYM=4
      MY=M+4
      CALL POINTS
      CALL PLOT(XW,YLL3(MY),1,NSYM)
      XP=0.
      DO 3 N=1,NO
      IF (Y(N,M).EQ.0.) GO TO 3
      XDIF=X(N)-XP
      IF (YDIF.LT.3..AND.XDIF.NE.0.) GO TO 3
      XP=X(N)
      IF (X(N).GT.800.) XP=X(N)-800.
      CALL POINTS
      CALL PLOT(XP,Y(N,M),1,NSYM)
      XP=X(N)
    3 CONTINUE
      CALL PLOTEND
      RETURN
      END
```

```
      SUBROUTINE SHIFT
      DIMENSION DIN(50,9),IRUN(7)
      REWIND 10
 1000 READ (60,100) (IRUN(J),J=1,7)
  100 FORMAT(7I5)
      REWIND 25
      XE=0.
      N=IRUN(7)
      NC=IRUN(7)
      DO 1 J=1,N
      READ (60,300) (DIN(J,K),K=1,9)
  300 FORMAT(F7.0,6F7.3,F7.4,F7.2)
      XDIF=DIN(J,1)-X
      IF (XDIF.LT.300..AND.DIN(J,1).NE.0.) GO TO 2
      X=DIN(J,1)
      GO TO 3
    2 IF(DIN(J,6).EQ.0..AND.DIN(J,7).EQ.0.) GO TO 4
    3 WRITE (25,400) (DIN(J,K),K=1,9)
  400 FORMAT(F7.0,6F7.3,F7.4,F7.2)
      GO TO 1
    4 NC=NC-1
    1 CONTINUE
      REWIND 25
      IRUN(7)=NC
      READ (25,500) ((DIN(J,K),K=1,9),J=1,NC)
  500 FORMAT (F7.0,6F7.3,F7.4,F7.2)
      WRITE (10,600) (IRUN(J),J=1,7)
  600 FORMAT(7I5)
      WRITE(10,700) ((DIN(J,K),K=1,9),J=1,NC)
  700 FORMAT (F7.0,6F7.3,F7.4,F7.2)
      IF (IRUN(6).NE.0) GO TO 1000
      REWIND 10
      RETURN
      END
```

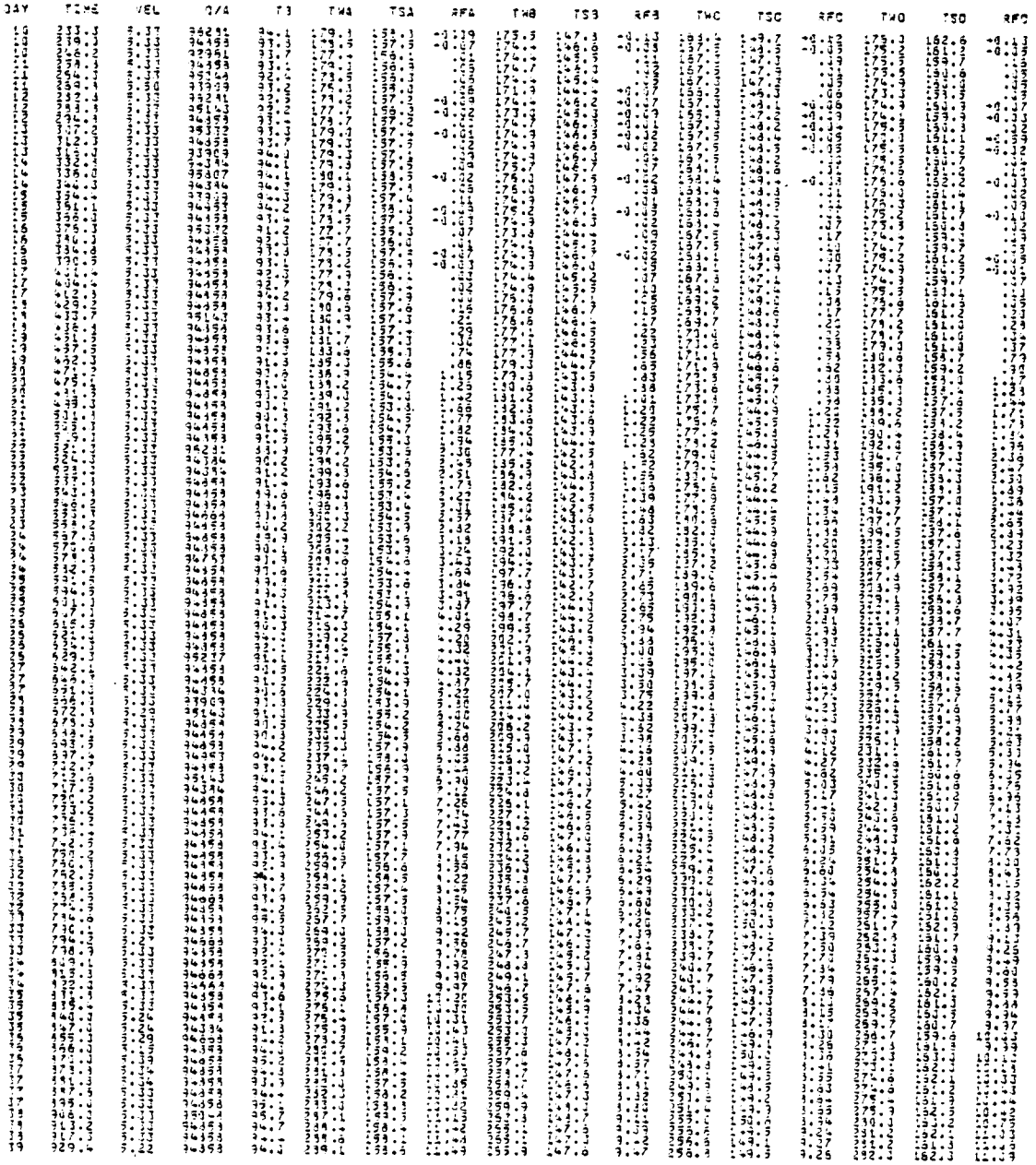
APPENDIX J

LISTING OF FOULING RESISTANCE VS TIME, RUNS 1 - 24

NOMENCLATURE

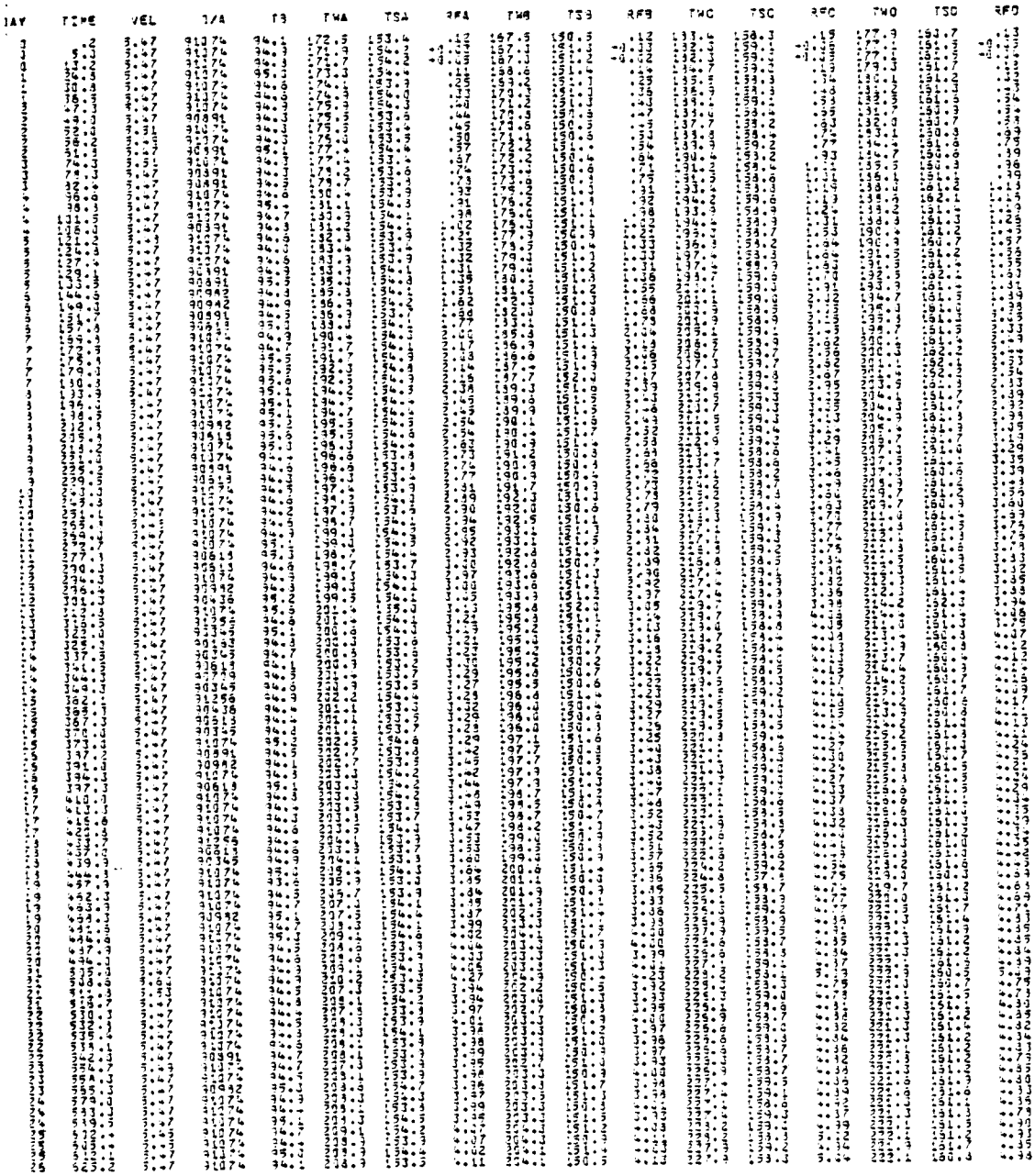
DAY:	days elapsed (days)
TIME:	total hours elapsed (hrs)
VEL:	flow velocity (ft/sec)
Q/A:	heat flux (Btu/ft^2-hr)
TB:	local bulk temperature
TWA, TWB, TWC, TWD:	wall temperatures at locations A, B, C, D
TSA, TSB, TSC, TSD:	local surface temperatures at locations A, B, C, D
RFA, RFB, RFC, RFD:	local fouling resistances at locations A, B, C, D

Note: zero denotes no data


RESULTS → RUN 1

RESULTS--RUN 2

RESULTS--RUN 6



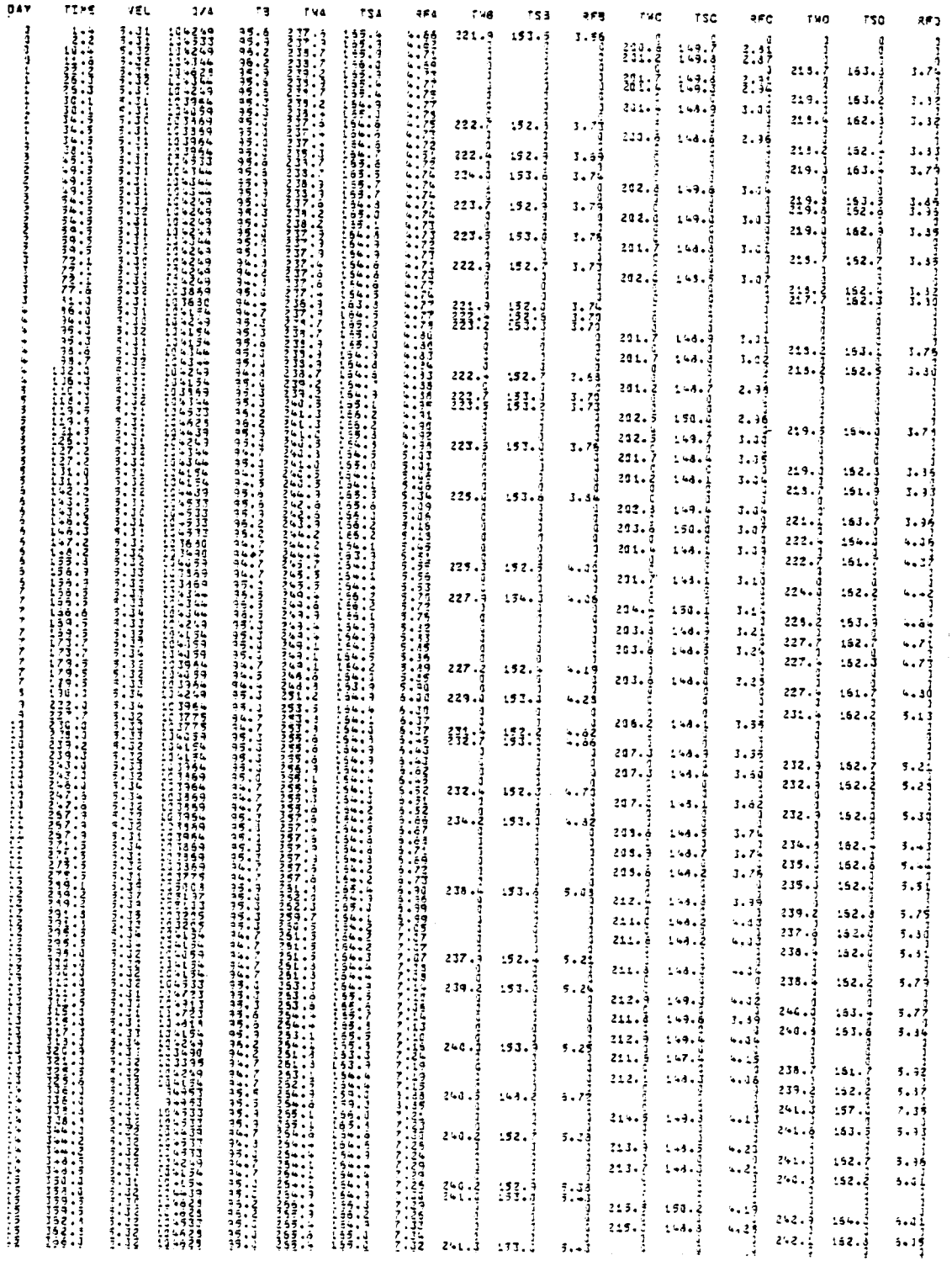
RESULTS--RUN 3

DAY	TIME	VEL	T/A	FR	TWA	TSA	FFA	TWB	TSB	FFB	TWC	TSC	FFC	TWD	TSD	FFD
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

RESULTS--RUN 15

DAY	TIME	VEL	D/A	TB	TWA	TSA	RFA	TWB	TSB	RFB	TWC	TSC	RFC
9	.2	5.34	911355	95.2	174.4	153.6	-0.01	173.0	154.1	-0.32	154.2	153.8	-0.12
9	4.7	5.34	911355	95.2	175.1	152.9	.01	173.0	153.4	.02	154.2	153.2	.02
9	9.2	5.34	911355	95.2	174.1	153.0	.02	172.7	153.5	.02	154.2	153.3	.02
9	13.7	5.34	911355	95.2	175.1	153.7	.02	174.3	154.2	.02	154.2	153.7	.02
9	18.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	22.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	27.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	31.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	36.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	40.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	45.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	49.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	54.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
9	58.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	3.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	7.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	12.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	16.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	21.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	25.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	30.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	34.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	39.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	43.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	48.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	52.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
10	57.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	1.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	6.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	10.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	15.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	19.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	24.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	28.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	33.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	37.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	42.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	46.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	51.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
11	55.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	0.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	4.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	9.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	13.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	18.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	22.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	27.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	31.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	36.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	40.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	45.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	49.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	54.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
12	58.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	3.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	7.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	12.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	16.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	21.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	25.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	30.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	34.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	39.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	43.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	48.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	52.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
13	57.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	1.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	6.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	10.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	15.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	19.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	24.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	28.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	33.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	37.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	42.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	46.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	51.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
14	55.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	0.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	4.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	9.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	13.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	18.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	22.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	27.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	31.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	36.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	40.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	45.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	49.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	54.2	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02
15	58.7	5.34	911355	95.2	174.4	153.4	.02	173.6	153.9	.02	154.2	153.4	.02

RESULTS--RUN 19



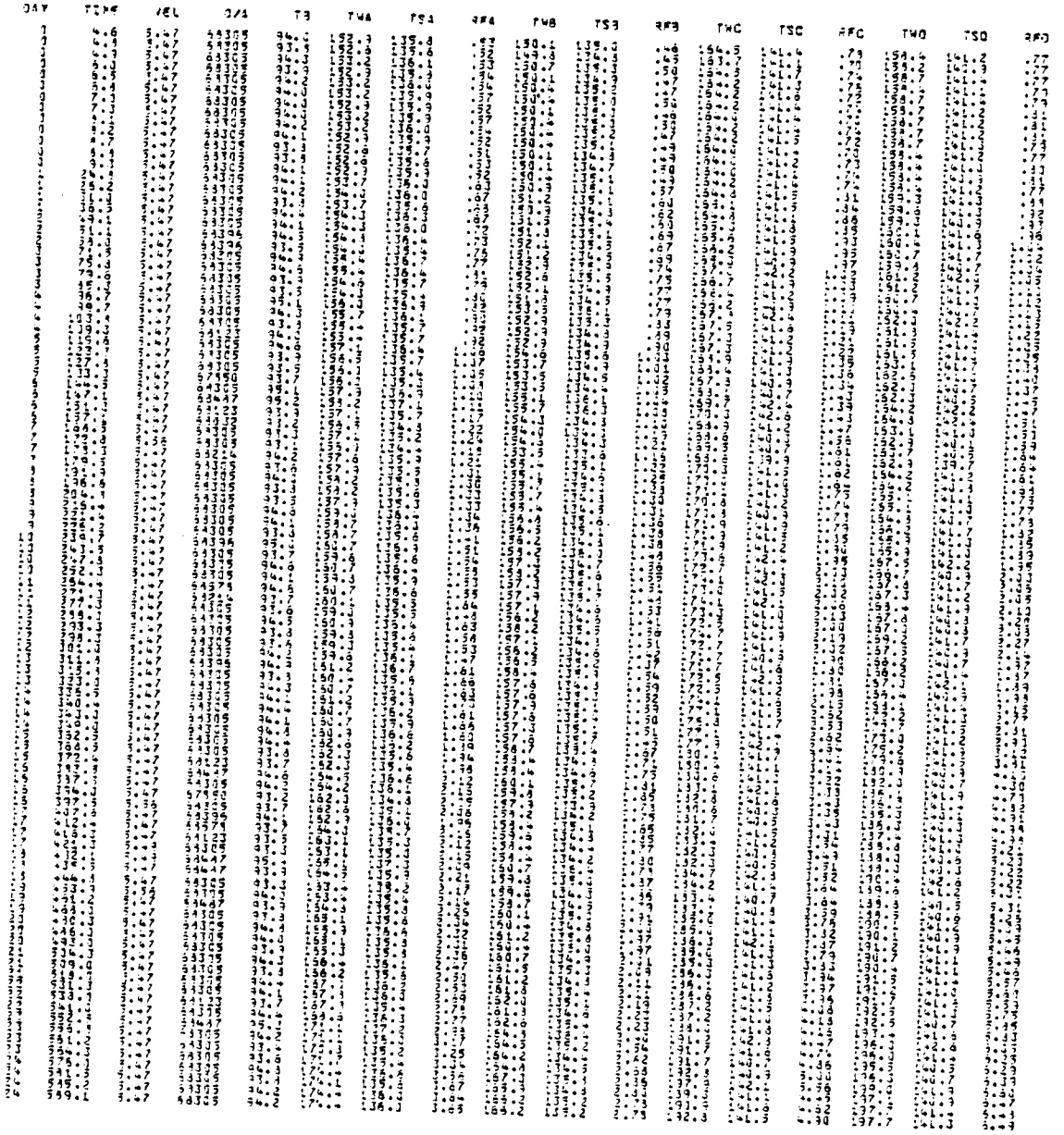
RESULTS--RUN 20

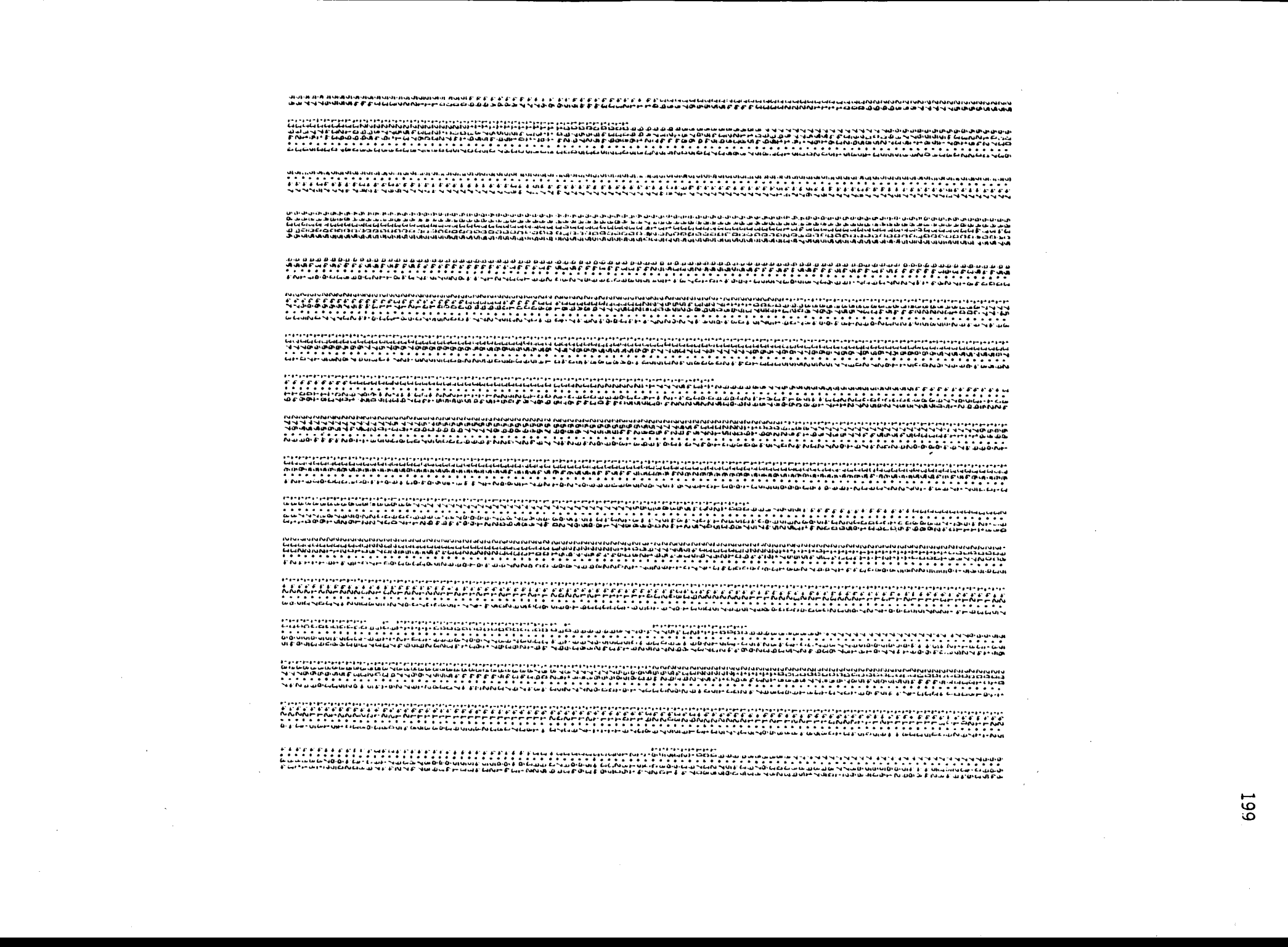
DAY	TIME	VEL	O/A	TB	TWA	TSA	RFA	TWB	TSB	RFB	TWC	TSC	RFC	TWD	TSD	RFD
0	.5	5.47	50090	94.9	135.8	126.0	-0.01	134.4	125.7	-0.02	143.4	130.5	-0.02	138.6	130.0	-0.04
0	5.0	5.47	50090	93.2	133.8	124.2	-0.05	132.7	123.9	-0.01	141.7	128.7	-0.01	136.9	128.3	-0.03
0	12.6	5.47	50182	94.7	135.8	125.8	.03	134.7	125.5	.07	143.7	130.3	.06	138.9	129.8	.05
1	24.4	5.47	50273	94.8	136.1	125.9	.05	134.9	125.6	.10	144.0	130.4	.08	139.2	130.0	.07
1	27.1	5.47	50090	94.1	135.5	125.2	.10	134.4	124.9	.14	143.4	129.7	.14	138.6	129.2	.12
1	31.3	5.47	50090	94.0	135.5	125.1	.12	134.1	124.8	.11	143.4	129.6	.15	138.3	129.1	.08
1	35.5	5.47	49908	93.8	134.9	124.7	.09	133.8	124.4	.13	142.8	129.2	.13	138.1	128.7	.12
2	46.8	5.47	50455	94.4	136.1	125.7	.10	134.9	125.4	.15	144.0	130.2	.12	139.2	129.7	.12
2	50.6	5.47	49635	94.8	136.1	125.5	.16	134.9	125.2	.21	144.0	130.0	.21	139.2	129.5	.19
2	54.5	5.47	50364	93.9	135.5	125.1	.11	134.1	124.8	.10	143.1	129.6	.08	138.6	129.1	.13
2	59.6	5.47	50090	93.8	135.2	124.8	.10	134.1	124.6	.15	143.1	129.4	.14	138.3	128.9	.13
3	72.3	5.47	50090	93.1	134.7	124.1	.14	133.5	123.8	.19	142.6	128.6	.18	137.9	128.1	.16
3	77.7	5.47	50090	92.9	134.4	123.9	.12	132.7	123.6	.05	142.3	128.4	.16	137.2	128.0	.09
3	79.5	5.47	50090	93.4	134.7	124.4	.07	133.2	124.1	.06	142.3	128.9	.06	137.8	128.5	.10
3	85.0	5.47	50090	93.6	134.7	124.6	.04	133.2	124.3	.03	142.3	129.1	.02	137.8	128.6	.07
4	96.2	5.47	50090	93.8	134.9	124.9	.04	133.8	124.6	.09	142.8	129.4	.08	138.1	128.9	.07
4	99.8	5.47	50090	93.7	135.2	124.7	.13	134.1	124.4	.18	143.1	129.2	.17	138.6	128.7	.21
4	107.3	5.47	50090	93.7	135.2	124.7	.13	134.1	124.4	.18	143.1	129.2	.17	138.3	128.7	.16
5	120.4	5.47	50090	94.2	136.1	125.2	.19	134.7	125.0	.18	144.2	129.8	.29	139.2	129.3	.22
5	122.4	5.47	50090	93.9	135.5	125.0	.14	134.1	124.7	.13	143.7	129.5	.23	138.6	129.0	.16
5	128.2	5.47	50090	91.8	133.5	122.8	.17	132.4	122.5	.22	141.4	127.3	.21	136.6	126.9	.19
5	132.0	5.47	50090	93.5	134.9	124.5	.12	133.8	124.2	.16	143.1	129.0	.21	138.3	128.6	.20
6	143.3	5.47	50090	94.5	136.4	125.5	.20	134.9	125.2	.19	144.2	130.0	.23	139.7	129.6	.28
6	147.2	5.47	50090	95.0	136.9	126.0	.21	135.5	125.8	.20	145.1	130.5	.30	140.0	130.1	.23
6	152.0	5.47	49635	93.7	135.8	124.4	.32	134.4	124.2	.31	143.7	128.9	.37	139.2	128.4	.41
6	156.4	5.47	49908	93.8	135.8	124.7	.25	134.7	124.4	.30	144.2	129.2	.41	139.2	128.7	.34
7	167.6	5.47	50364	95.3	137.5	126.5	.21	136.4	126.2	.26	145.9	131.0	.35	140.9	130.6	.29
7	170.5	5.47	50090	94.2	136.4	125.3	.25	135.2	125.0	.29	144.8	129.8	.39	140.0	129.3	.39
7	174.7	5.47	50090	93.9	136.1	124.9	.26	134.9	124.6	.31	144.5	129.4	.41	139.5	129.0	.34
7	178.6	5.47	50364	93.4	135.8	124.6	.26	134.4	124.3	.25	144.2	129.1	.40	139.2	128.6	.34
7	180.5	5.47	50090	93.5	135.5	124.5	.23	134.4	124.2	.28	144.0	129.0	.38	138.9	128.5	.31
8	191.9	5.47	50090	94.7	136.9	125.8	.26	135.8	125.5	.31	145.1	130.3	.35	140.6	129.8	.40
8	194.5	5.47	50090	93.8	136.1	124.8	.28	134.9	124.5	.33	144.5	129.3	.43	139.7	128.9	.42
8	200.0	5.47	50090	93.3	135.5	124.3	.27	134.4	124.0	.31	144.0	128.8	.42	139.2	128.4	.40
8	203.1	5.47	49908	93.6	135.8	124.6	.28	134.7	124.3	.33	144.2	129.1	.44	139.2	128.6	.37
9	216.8	5.47	50273	94.1	136.6	125.2	.31	135.5	124.9	.36	145.4	129.7	.51	140.3	129.3	.44
9	218.8	5.47	50182	94.5	136.9	125.6	.29	135.8	125.3	.33	145.6	130.1	.49	140.6	129.7	.42
9	223.0	5.47	50090	93.7	136.1	124.8	.29	134.9	124.5	.33	144.8	129.3	.49	139.7	128.8	.42
9	228.7	5.47	49635	93.7	136.1	124.4	.38	134.9	124.2	.42	144.8	128.9	.60	139.7	128.5	.52
10	244.0	5.47	49908	93.9	136.4	124.8	.35	135.2	124.5	.39	145.1	129.3	.56	140.3	128.8	.54
10	248.6	5.47	49726	93.6	136.1	124.4	.38	134.9	124.1	.43	144.8	128.9	.60	139.7	128.4	.53
10	250.3	5.47	49908	94.0	136.6	125.0	.37	135.5	124.7	.42	145.4	129.5	.58	140.3	129.0	.51
11	268.9	5.47	50364	94.3	137.2	125.4	.37	136.1	125.2	.41	145.9	130.0	.56	140.9	129.5	.50
11	272.5	5.47	50090	94.2	136.6	125.2	.31	135.8	125.0	.41	145.6	129.8	.57	140.3	129.3	.44
11	276.5	5.47	50090	93.6	136.4	124.7	.37	135.2	124.4	.41	145.4	129.2	.63	140.0	128.7	.50
12	289.3	5.47	51183	94.6	138.6	126.3	.44	137.5	126.0	.49	147.3	130.9	.60	142.3	130.4	.56
12	291.7	5.49	49453	94.9	136.4	125.4	.24	135.2	125.1	.29	144.5	129.9	.36	140.0	129.4	.39
12	296.0	5.47	49726	93.6	135.5	124.3	.28	134.4	124.1	.32	144.0	128.8	.44	139.2	128.4	.42
12	300.9	5.47	49908	93.7	135.5	124.6	.22	134.1	124.3	.21	143.4	129.1	.26	138.9	128.6	.30
13	311.5	5.47	50364	94.1	136.6	125.3	.29	134.7	125.0	.17	144.0	129.8	.21	140.0	129.3	.37
13	315.0	5.47	50090	94.7	136.9	125.7	.28	135.2	125.4	.21	144.2	130.2	.20	140.3	129.7	.36

RESULTS--RUN 21

DAY	TIME	VEL	O/A	TB	TWA	TSA	REA	TWB	TSB	REB	TWC	TSC	REC	TWD	TSD	RED
0	0	5.47	59289	94.9	144.5	131.5	.23	142.3	130.6	.22	153.2	136.0	.30	148.4	136.0	.34
0	.4	5.47	59380	95.1	145.1	131.8	.28	142.6	130.9	.22	153.2	136.2	.25	148.7	136.3	.34
0	1.0	5.47	59198	94.8	144.5	131.3	.26	142.3	130.4	.25	152.9	135.8	.29	148.4	135.9	.38
0	1.3	5.47	59198	94.7	144.5	131.2	.28	142.3	130.3	.27	152.6	135.7	.26	148.2	135.7	.35
0	1.9	5.47	59199	94.9	144.8	131.4	.29	142.6	130.5	.26	152.9	135.9	.27	148.7	135.9	.41
0	2.3	5.47	59198	94.8	144.5	131.3	.26	142.3	130.4	.25	152.9	135.8	.29	148.4	135.8	.37
0	2.9	5.47	59198	94.6	144.5	131.1	.29	142.0	130.3	.23	152.6	135.6	.27	148.2	135.6	.36
0	3.5	5.47	59198	94.4	144.2	130.9	.28	141.7	130.0	.22	152.6	135.4	.31	147.9	135.4	.39
0	3.8	5.47	59198	93.9	143.7	130.3	.29	141.4	129.4	.27	152.1	134.8	.31	147.6	134.8	.40
0	4.9	5.47	59199	93.2	143.1	129.7	.30	140.6	128.8	.24	151.5	134.1	.33	146.8	134.2	.37
0	6.5	5.47	59198	93.7	143.1	130.2	.21	141.2	129.3	.25	152.1	134.7	.33	147.3	134.7	.37
0	7.3	5.47	59198	93.7	143.4	130.2	.25	141.2	129.4	.24	151.8	134.7	.28	147.3	134.7	.37
0	9.5	5.47	59198	93.5	142.8	130.0	.20	140.6	129.1	.19	151.8	134.4	.33	147.0	134.5	.37
1	20.0	5.47	59380	94.9	144.5	131.5	.23	142.3	130.6	.21	152.9	136.0	.25	148.4	136.0	.34
1	22.8	5.47	59198	94.7	144.2	131.2	.23	142.0	130.3	.22	152.3	135.7	.21	148.2	135.7	.35
1	27.5	5.47	59198	94.0	143.7	130.5	.26	141.4	129.6	.25	151.8	134.9	.24	147.6	135.0	.38
1	32.5	5.47	59199	93.9	143.7	130.4	.27	141.2	129.6	.21	151.8	134.9	.25	147.3	134.9	.33
2	43.5	5.47	59198	94.1	144.5	131.3	.26	142.3	130.4	.25	152.3	135.8	.20	148.4	135.8	.38
2	46.8	5.47	59198	93.9	144.0	130.4	.32	141.7	129.5	.31	151.8	134.9	.25	147.9	134.9	.43
2	50.7	5.47	59198	93.7	144.0	130.2	.35	141.4	129.3	.29	152.1	134.7	.33	147.6	134.7	.42
2	56.8	5.47	59198	93.7	143.7	130.3	.30	141.4	129.4	.28	152.1	134.7	.32	147.6	134.8	.41
3	68.2	5.49	59198	94.9	144.8	131.3	.31	142.3	130.4	.25	153.2	135.8	.34	148.7	135.8	.43
3	71.3	5.47	59198	94.6	144.5	131.1	.30	142.3	130.2	.29	152.9	135.5	.33	148.7	135.6	.46
3	75.8	5.47	59198	93.9	144.0	130.3	.34	141.4	129.4	.27	152.1	134.8	.31	147.6	134.8	.40
3	77.6	5.47	59016	93.8	143.7	130.2	.32	141.4	129.3	.30	152.1	134.7	.35	147.9	134.7	.44
3	81.0	5.47	59198	93.6	143.7	130.1	.32	141.2	129.2	.26	152.1	134.6	.35	147.6	134.6	.44
4	93.8	5.47	59016	93.9	144.0	130.3	.34	141.4	129.4	.28	152.1	134.8	.33	147.9	134.8	.46
4	96.4	5.47	59198	93.8	144.0	130.3	.34	141.7	129.4	.32	152.3	134.8	.36	147.9	134.8	.45
4	100.9	5.47	59198	93.6	144.0	130.1	.37	141.4	129.2	.31	152.3	134.6	.40	147.9	134.6	.49
4	104.8	5.47	59198	94.0	144.2	130.5	.36	141.7	129.6	.30	152.6	134.9	.38	148.2	135.0	.47
5	116.0	5.47	59198	94.2	144.8	130.8	.40	142.6	129.9	.39	153.5	135.2	.48	148.8	135.3	.56
5	120.0	5.47	59198	94.0	144.8	130.5	.45	142.3	129.6	.39	153.2	135.0	.47	148.8	135.0	.51
5	123.8	5.47	59198	93.8	144.5	130.3	.44	142.3	129.4	.43	153.2	134.7	.51	148.7	134.8	.50
5	127.4	5.47	59198	93.9	144.8	130.4	.46	142.3	129.6	.40	153.2	134.9	.48	148.7	134.9	.57
6	139.3	5.47	59380	94.6	145.6	131.2	.46	143.4	130.3	.45	154.6	135.7	.57	149.8	135.7	.52
6	143.5	5.47	59198	94.9	146.2	131.4	.52	143.7	130.6	.46	154.8	135.9	.59	150.4	135.9	.58
6	147.7	5.47	59198	93.5	144.8	130.0	.53	142.6	129.1	.52	153.7	134.5	.65	149.0	134.5	.59
6	151.5	5.47	59198	93.5	144.8	130.1	.52	142.3	129.2	.46	153.7	134.5	.64	149.0	134.6	.58
7	162.9	5.47	59198	94.5	145.9	131.0	.55	143.7	130.1	.53	154.8	135.5	.66	150.1	135.5	.75
7	166.3	5.47	59198	94.4	145.9	130.9	.57	143.4	130.0	.51	154.8	135.4	.68	150.1	135.4	.77
7	170.4	5.47	59198	94.1	145.6	130.6	.57	143.4	129.7	.56	154.6	135.0	.69	150.1	135.1	.78
7	175.7	5.47	59198	93.6	145.4	130.1	.61	142.8	129.2	.55	154.0	134.6	.68	149.8	134.6	.92
8	187.0	5.47	59198	93.9	145.4	130.3	.58	142.9	129.4	.52	154.6	134.7	.75	149.8	134.9	.79
8	191.5	5.47	59198	94.2	145.9	130.7	.60	143.4	129.9	.54	154.8	135.2	.71	150.4	135.2	.80
8	196.0	5.47	59198	93.6	145.4	130.1	.60	142.8	129.3	.54	154.3	134.6	.72	149.8	134.6	.91
8	200.0	5.47	59198	93.6	145.1	130.2	.55	142.9	129.3	.54	154.6	134.8	.77	149.8	134.7	.91
9	211.5	5.47	59198	94.7	145.9	131.2	.52	143.7	130.3	.50	155.7	135.7	.77	150.9	135.7	.82
9	214.9	5.47	59198	93.9	145.6	130.4	.60	143.1	129.5	.54	155.1	134.9	.81	150.4	134.9	.96
9	220.1	5.47	59289	94.6	146.9	131.2	.66	144.2	130.3	.60	156.2	135.6	.87	151.5	135.7	.91
9	224.7	5.47	58742	93.5	144.5	129.8	.54	142.3	128.9	.53	154.0	134.2	.77	149.3	134.2	.81
10	235.5	5.47	59289	93.7	145.4	130.2	.58	142.8	129.4	.52	154.6	134.7	.75	150.1	134.7	.94
10	238.9	5.47	59198	94.8	145.9	131.3	.61	143.4	130.4	.45	155.1	135.7	.67	150.7	135.8	.76
10	244.7	5.47	59107	93.2	144.8	129.6	.60	142.0	128.7	.49	154.0	134.1	.77	149.3	134.1	.81
10	248.7	5.47	59016	93.5	144.5	129.9	.58	142.0	129.0	.44	153.7	134.4	.67	149.6	134.4	.71
11	260.9	5.47	59198	94.2	145.4	130.7	.51	143.1	129.8	.49	155.1	135.2	.77	150.4	135.2	.81
11	264.4	5.47	59198	93.6	144.8	130.2	.51	142.6	129.3	.49	154.6	134.6	.77	149.8	134.7	.91

RESULTS--RUN 22





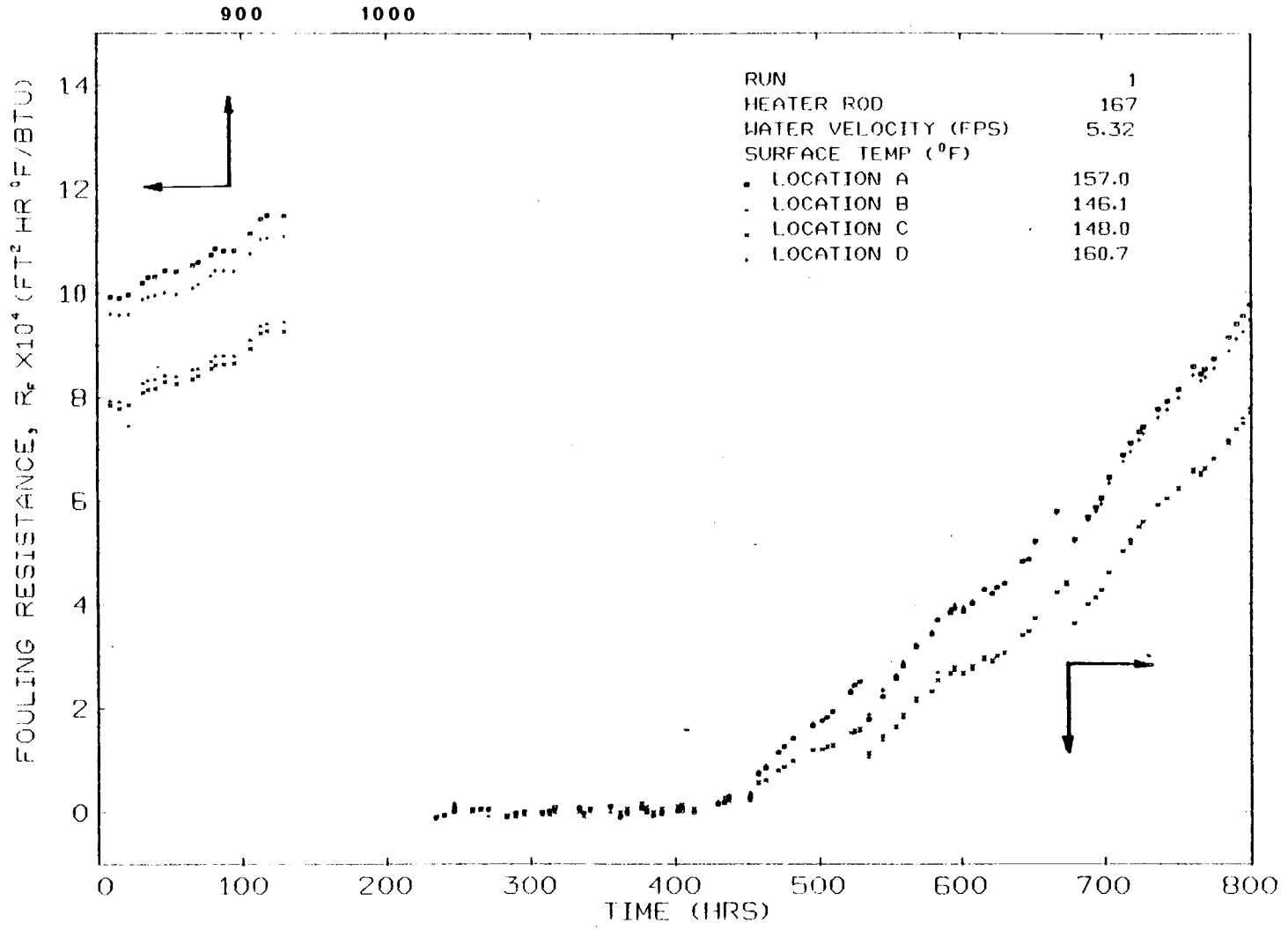
RESULTS--RUN 24

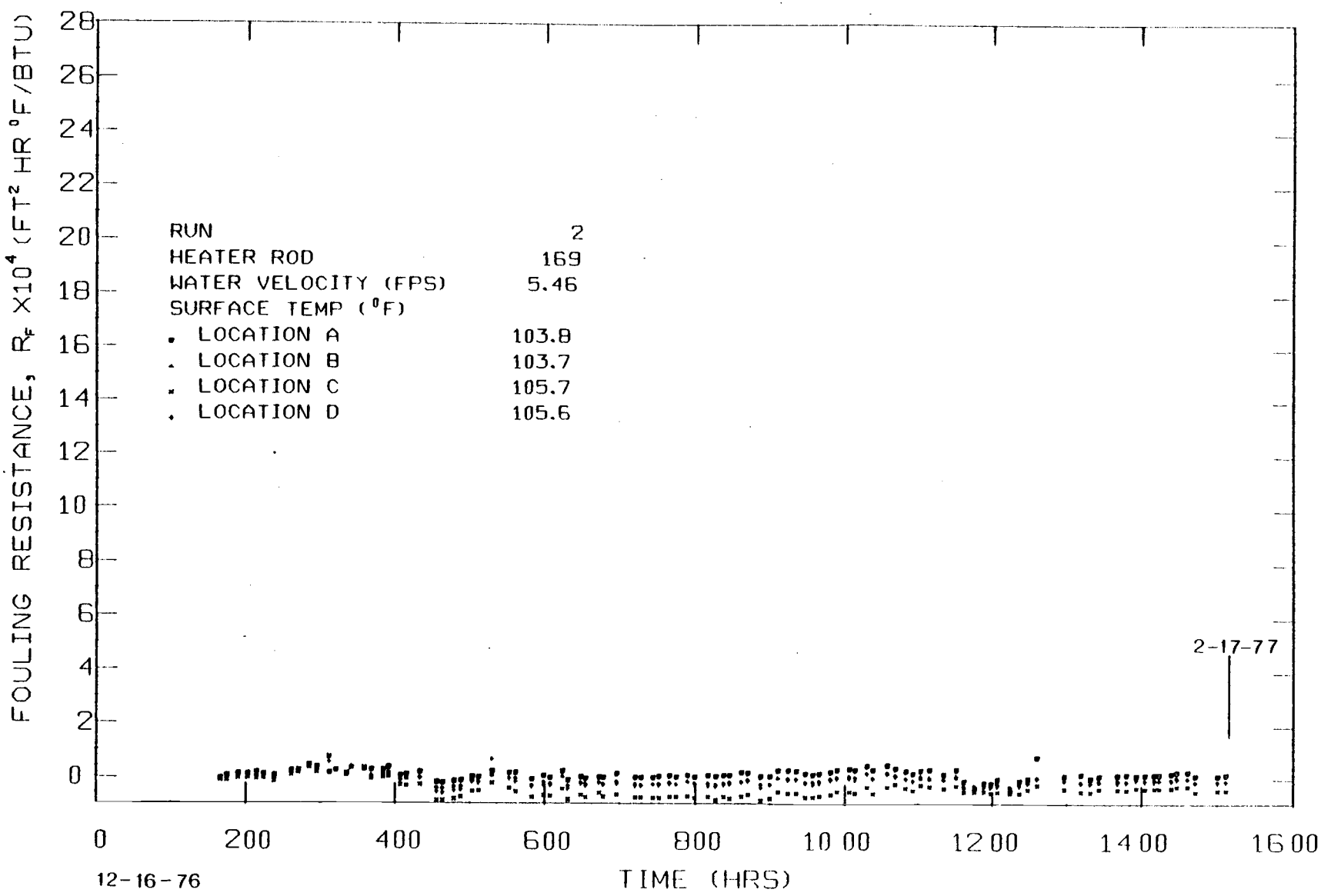
DAY	TIME	VEL	DZA	TA	THA	TSA	RFA	TWB	TSB	RFB	TWC	TSC	RFC	TWD	TSD	RFD
0	.0	4.52	95332	95.1	180.7	159.3	-0.03	176.3	147.7	-0.00	0	0	0	0	0	0
0	.0	4.54	95237	94.8	180.7	158.7	.03	0	0	0	164.5	144.8	.01	0	0	0
0	.0	4.54	95237	94.8	180.9	158.7	.06	0	0	0	0	0	0	171.4	156.7	.01
0	7.5	4.51	94479	95.1	180.4	158.9	.01	0	0	0	164.6	145.0	-0.15	0	0	0
0	7.5	4.51	94479	95.1	179.6	158.8	-0.07	0	0	0	0	0	0	171.1	156.8	-0.01
1	17.6	4.49	94953	95.4	180.3	159.6	-0.03	176.3	148.1	-0.02	0	0	0	0	0	0
1	17.6	4.50	94953	95.4	181.2	159.5	.01	0	0	0	164.5	146.6	-0.06	0	0	0
1	17.6	4.50	94953	95.4	180.4	159.5	-0.08	0	0	0	0	0	0	171.7	157.6	-0.04
1	26.2	4.49	94573	94.9	180.3	158.8	.07	176.6	147.3	.04	0	0	0	0	0	0
1	26.2	4.49	94573	94.8	180.9	158.8	.07	0	0	0	164.5	144.9	.02	0	0	0
1	26.2	4.49	94668	94.8	181.7	159.0	.03	0	0	0	0	0	0	171.7	156.9	.04
1	31.1	4.50	94763	94.5	180.9	158.5	.09	0	0	0	164.8	144.6	.07	0	0	0
2	42.0	4.51	95048	97.2	181.4	161.1	.05	178.8	149.9	.05	0	0	0	0	0	0
2	42.0	4.52	95143	97.2	181.4	161.2	.03	0	0	0	167.6	147.5	-0.00	0	0	0
2	42.0	4.52	95048	97.2	181.4	161.2	.06	0	0	0	0	0	0	174.1	159.2	.05
2	45.5	4.51	94953	95.1	182.5	159.2	.22	0	0	0	165.6	145.3	.09	0	0	0
2	45.5	4.51	94953	95.1	182.6	159.2	.19	0	0	0	0	0	0	172.8	157.2	.11
2	50.0	4.51	94858	94.8	182.3	158.8	.21	177.1	147.3	.15	0	0	0	0	0	0
2	50.0	4.51	94953	94.8	182.3	158.8	.28	0	0	0	0	0	0	172.5	156.8	.12
2	54.9	4.51	94858	95.1	183.1	159.1	.26	0	0	0	165.4	145.2	.07	0	0	0
2	54.9	4.51	94953	95.1	182.8	159.2	.22	0	0	0	0	0	0	173.0	157.2	.14
3	62.0	4.49	94668	94.9	183.4	158.9	.31	0	0	0	0	0	0	173.6	156.9	.21
3	63.9	4.49	94763	95.4	184.2	159.5	.33	0	0	0	0	0	0	173.6	157.5	.17
3	64.9	4.51	94763	95.4	184.5	159.4	.38	0	0	0	165.4	145.5	.05	0	0	0
3	71.2	4.51	95048	95.1	184.7	159.3	.41	178.2	147.7	.21	0	0	0	0	0	0
3	71.2	4.51	95048	95.1	184.7	159.3	.41	0	0	0	165.9	145.3	.11	0	0	0
3	71.2	4.51	95143	95.1	185.3	159.3	.45	0	0	0	0	0	0	174.1	157.3	.24
3	78.0	4.50	94858	95.1	185.6	159.2	.51	0	0	0	165.4	145.3	.06	0	0	0
3	78.1	4.51	94858	94.8	185.3	158.8	.51	0	0	0	0	0	0	174.1	156.9	.29
4	90.3	4.49	95048	96.3	186.5	160.6	.67	181.2	149.8	.39	0	0	0	0	0	0
4	90.3	4.49	95048	96.0	186.4	160.3	.73	0	0	0	167.3	146.3	.15	0	0	0
4	90.3	4.49	95143	96.0	186.8	160.3	.72	0	0	0	0	0	0	176.9	158.3	.42
4	96.0	4.50	94763	95.4	186.9	159.4	.94	0	0	0	166.7	145.5	.10	0	0	0
4	96.0	4.49	94763	95.4	186.5	159.5	.79	0	0	0	0	0	0	176.6	157.5	.43
4	101.0	4.51	94763	94.8	187.1	158.8	.92	180.7	147.3	.52	0	0	0	0	0	0
4	103.0	4.50	94668	95.1	189.6	159.1	.95	0	0	0	167.8	145.2	.25	0	0	0
4	103.1	4.50	94668	95.1	189.6	159.1	.95	0	0	0	0	0	0	177.1	157.1	.59
5	114.3	4.53	94858	95.1	192.3	159.1	1.23	182.3	147.5	.66	0	0	0	0	0	0
5	114.3	4.51	94953	95.4	191.6	159.4	1.33	0	0	0	0	0	0	179.6	157.6	.91
5	119.0	4.52	94953	95.4	194.7	159.4	1.45	0	0	0	169.1	145.8	.33	0	0	0
5	119.0	4.52	94953	95.4	194.7	159.4	1.45	0	0	0	169.1	145.5	.33	0	0	0
6	128.0	4.52	94763	95.7	200.1	159.5	2.01	184.7	148.0	.97	0	0	0	0	0	0
6	141.0	4.51	94668	95.7	211.0	159.6	3.16	186.9	148.1	1.80	0	0	0	0	0	0
6	142.1	4.51	94763	95.4	212.6	159.4	3.35	0	0	0	170.6	145.5	.54	0	0	0
6	148.2	4.50	94668	95.1	221.1	159.1	4.20	0	0	0	170.3	145.2	.60	0	0	0
6	148.3	4.50	94763	94.8	221.6	158.8	4.35	0	0	0	0	0	0	186.4	156.9	1.59
6	148.0	4.50	94668	95.1	222.4	159.1	4.42	189.1	147.5	1.38	0	0	0	0	0	0
6	151.0	4.50	94763	95.7	226.5	159.7	4.98	0	0	0	172.0	145.8	.70	0	0	0
6	151.0	4.49	94763	95.7	226.2	159.8	4.95	0	0	0	0	0	0	189.1	157.8	1.77
7	162.5	4.50	94953	96.6	251.6	160.7	7.28	202.0	149.2	2.56	0	0	0	0	0	0
7	162.5	4.50	94953	96.6	251.4	160.7	7.28	0	0	0	174.7	146.0	.98	0	0	0
7	166.3	4.51	94953	95.4	258.7	159.5	8.17	0	0	0	175.0	145.6	1.04	0	0	0
7	171.2	4.50	94573	94.9	265.4	158.7	9.01	213.1	147.2	3.97	0	0	0	0	0	0
7	171.2	4.51	94573	94.9	265.6	158.6	9.04	0	0	0	175.2	144.8	1.14	0	0	0
7	171.2	4.51	94668	94.8	265.1	158.7	8.97	0	0	0	0	0	0	216.1	156.7	4.74
7	174.3	4.52	94953	94.5	271.0	158.9	9.55	0	0	0	176.3	145.0	1.25	0	0	0
7	174.3	4.50	94858	94.5	270.8	158.6	9.56	0	0	0	0	0	0	221.6	156.6	5.32
8	190.3	4.50	95048	96.3	288.9	160.5	11.34	236.6	148.9	6.22	0	0	0	0	0	0
8	190.3	4.51	94953	96.3	289.3	160.4	11.37	0	0	0	181.8	146.4	1.66	0	0	0
8	190.3	4.50	95048	96.0	290.7	160.2	11.46	0	0	0	0	0	0	241.0	159.2	7.13
8	193.7	4.52	94953	94.5	319.5	158.5	14.69	0	0	0	191.4	144.6	3.08	0	0	0
8	193.7	4.54	94953	94.7	319.0	158.7	14.92	0	0	0	0	0	0	260.5	153.8	9.71
8	199.1	4.52	94763	93.1	321.5	159.1	14.46	265.1	147.6	9.60	0	0	0	0	0	0
8	199.1	4.51	94763	95.1	322.4	159.1	14.91	0	0	0	199.3	145.2	2.50	0	0	0
8	199.1	4.50	94953	93.1	320.5	159.2	14.73	0	0	0	0	0	0	264.9	157.2	9.42
9	210.6	4.48	94953	96.3	327.7	160.5	15.35	279.2	149.3	10.73	0	0	0	0	0	0
9	210.6	4.48	94953	96.3	327.7	160.5	15.34	0	0	0	199.7	146.5	3.44	0	0	0
9	211.6	4.49	94763	96.0	327.2	160.1	15.36	0	0	0	0	0	0	277.9	158.1	11.12
9	213.3	4.48	95048	97.7	330.2	160.0	15.64	0	0	0	202.2	146.6	3.96	0	0	0
9	213.3	4.47	95048	97.4	329.7	159.7	15.61	0	0	0	0	0	0	291.5	157.7	11.50
9	219.2	4.49	94858	95.1	330.0	159.2	15.73	284.7	147.7	11.86	0	0	0	0	0	0
9	219.5	4.51	94953	95.1	330.3	159.3	15.77	0	0	0	221.0	145.3	5.91	0	0	0
9	219.5	4.51	94953	95.1	330.2	159.2	15.76	0	0	0	0	0	0	298.4	157.2	12.29
9	222.0	4.50	94858	94.8	331.7	158.9	15.94	0	0	0	227.0	145.0	6.69	0	0	0
9	222.1	4.51	94858	94.8	332.2	158.8	16.00	0	0	0	0	0	0	302.5	156.9	12.77
10	234.0	4.52	95522	96.6	337.4	161.1	16.18	338.9	149.5	13.69	0	0	0	0	0	0
10	234.0	4.49	95522	96.6	338.2	161.2	16.26	0	0	0	268.2	147.1	9.78	0	0	0

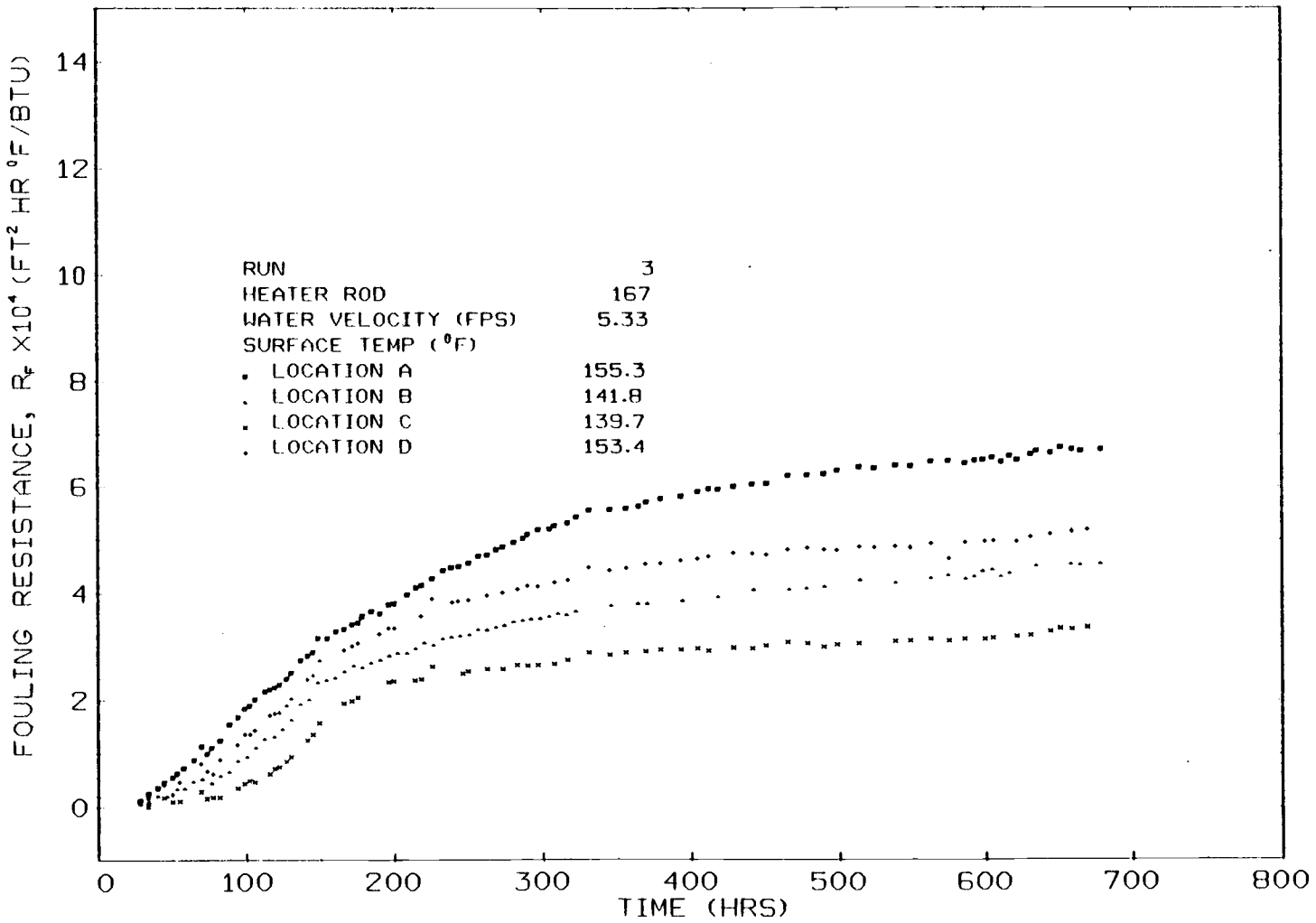
10	238.2	4.51	95997	94.9	346.2	159.5	16.59	0	0	0	269.2	145.4	10.76	0	0	0	0	0	0
10	242.0	4.49	95522	94.6	342.2	159.2	16.88	318.2	147.6	14.46	0	0	0	0	0	0	0	0	0
10	242.0	4.51	95617	94.6	342.4	159.1	16.89	0	0	0	275.1	145.1	11.54	0	0	0	0	0	0
10	242.0	4.50	95617	94.6	341.7	159.1	16.82	0	0	0	0	0	0	0	0	0	0	0	0
10	246.0	4.49	95712	94.8	342.9	159.5	16.88	0	0	0	283.8	145.5	12.08	0	0	0	315.2	157.1	15.3
10	246.0	4.50	95712	94.8	342.6	159.5	16.86	0	0	0	0	0	0	0	0	0	0	0	0
11	257.8	4.50	96176	96.6	347.4	161.7	16.99	330.7	150.6	15.75	0	0	0	0	0	0	315.4	157.5	14.9
11	257.9	4.45	96176	96.9	347.6	161.1	16.97	0	0	0	292.5	147.9	12.94	0	0	0	0	0	0
11	261.4	4.49	96565	96.6	349.6	159.9	17.27	0	0	0	292.5	145.7	13.14	0	0	0	0	0	0
11	265.5	4.48	96565	95.4	350.1	160.8	17.33	0	0	0	0	0	0	0	0	0	316.4	158.8	13.9
11	271.2	4.47	96573	95.4	351.3	159.5	18.00	0	0	0	0	0	0	0	0	0	333.1	157.6	13.96
11	271.2	4.47	96669	95.7	351.6	160.0	17.96	0	0	0	294.6	146.6	13.58	0	0	0	0	0	0
12	280.0	4.47	94763	95.4	352.1	159.7	18.03	333.9	148.1	16.61	0	0	0	0	0	0	0	0	0
12	281.9	4.47	94858	95.7	353.1	160.1	18.07	0	0	0	294.7	146.1	13.61	0	0	0	0	0	0
12	285.9	4.47	94858	95.1	353.1	159.4	18.14	0	0	0	294.5	145.5	13.65	0	0	0	0	0	0
12	285.9	4.47	94763	94.9	352.9	159.2	18.16	0	0	0	0	0	0	0	0	0	329.2	157.2	16.52
12	293.5	4.49	94573	95.1	351.5	159.2	18.25	335.4	147.7	16.95	0	0	0	0	0	0	0	0	0
12	293.5	4.47	94669	95.1	351.5	159.4	18.24	0	0	0	295.1	145.4	13.77	0	0	0	0	0	0
13	297.6	4.48	94669	94.9	354.3	159.0	18.36	0	0	0	0	0	0	0	0	0	331.2	157.0	16.44
13	307.5	4.46	94668	96.9	357.0	161.2	19.41	338.9	149.6	16.99	0	0	0	0	0	0	0	0	0
13	307.5	4.47	94763	96.9	356.5	161.2	19.34	0	0	0	299.2	147.2	13.96	0	0	0	0	0	0
13	312.5	4.47	94668	95.6	357.0	160.8	18.45	0	0	0	0	0	0	0	0	0	334.2	158.9	16.39
14	312.5	4.47	94763	95.1	356.5	159.4	18.53	0	0	0	297.6	145.5	14.00	0	0	0	334.2	157.4	17.13
14	312.5	4.47	94859	95.1	356.5	159.5	18.49	0	0	0	297.5	145.7	14.00	0	0	0	0	0	0
14	312.5	4.47	94573	95.4	356.3	159.6	18.47	338.2	148.1	17.10	0	0	0	0	0	0	334.4	157.6	17.14
14	318.1	4.46	94668	95.4	355.8	159.7	18.46	0	0	0	286.9	139.5	13.46	0	0	0	0	0	0
15	315.5	4.46	94951	95.4	355.5	159.7	18.43	0	0	0	287.1	140.3	13.42	0	0	0	329.0	158.0	16.95
15	315.5	4.47	94951	94.9	348.8	151.9	18.47	329.0	141.6	16.73	0	0	0	0	0	0	0	0	0
15	315.5	4.47	94951	94.9	343.1	151.9	18.49	0	0	0	289.4	141.6	13.48	0	0	0	317.9	156.6	16.13
15	315.5	4.36	95048	94.9	344.8	151.7	18.46	0	0	0	287.4	139.8	13.51	0	0	0	327.7	152.1	16.93
15	342.5	4.31	94859	95.5	349.9	152.7	18.40	0	0	0	0	0	0	0	0	0	326.2	150.3	16.99
15	342.5	4.31	94763	95.5	349.8	152.7	18.48	330.0	142.5	16.74	300.8	145.7	14.25	0	0	0	0	0	0
15	342.0	4.31	94953	95.8	350.1	152.4	18.51	0	0	0	301.6	146.3	14.24	0	0	0	334.7	154.5	17.50
15	353.1	4.34	95143	97.0	351.3	152.8	18.46	0	0	0	0	0	0	0	0	0	0	0	0
15	353.1	4.35	95143	97.0	350.6	153.9	18.40	0	0	0	304.9	147.5	14.52	0	0	0	342.9	159.4	17.32
15	356.5	4.33	94859	95.2	349.8	152.1	18.57	0	0	0	0	0	0	0	0	0	341.7	158.4	17.79
15	356.6	4.34	94951	95.2	349.8	152.1	18.55	0	0	0	310.7	145.4	15.40	0	0	0	0	0	0
15	361.0	4.46	95044	95.4	359.0	160.1	18.65	338.7	144.4	17.01	0	0	0	0	0	0	346.6	157.6	18.44
15	361.0	4.49	94951	95.4	359.5	159.7	18.77	0	0	0	0	0	0	0	0	0	352.1	157.9	19.32
15	366.2	4.47	94668	96.0	360.7	160.3	18.90	0	0	0	0	0	0	0	0	0	0	0	0
16	366.2	4.44	94668	96.0	360.9	160.5	18.98	0	0	0	0	0	0	0	0	0	0	0	0
16	377.1	4.46	94858	97.2	364.9	161.7	19.15	344.4	150.1	17.48	0	0	0	0	0	0	359.4	159.1	19.65
16	377.1	4.47	94953	96.9	365.6	161.5	19.22	0	0	0	0	0	0	0	0	0	0	0	0
16	377.1	4.46	94858	96.9	363.4	161.4	19.02	0	0	0	0	0	0	0	0	0	0	0	0
16	380.9	4.49	94953	96.1	364.6	160.4	19.25	0	0	0	0	0	0	0	0	0	0	0	0
16	386.0	4.48	94573	95.7	372.0	159.5	20.17	346.9	148.2	18.00	0	0	0	0	0	0	0	0	0
16	390.4	4.51	94668	95.4	371.3	159.3	20.12	0	0	0	0	0	0	0	0	0	0	0	0
16	390.5	4.48	94668	93.4	370.8	159.5	20.04	0	0	0	310.7	145.4	15.40	0	0	0	0	0	0
16	391.1	4.46	94479	95.7	377.6	159.9	20.77	0	0	0	0	0	0	0	0	0	0	0	0
17	392.0	4.47	94384	96.0	379.4	160.0	20.86	348.4	148.5	18.17	0	0	0	0	0	0	346.6	157.6	18.44
17	400.0	4.47	94573	96.9	391.8	161.1	22.12	359.7	149.5	19.22	0	0	0	0	0	0	352.1	157.9	19.32
17	401.1	4.47	94573	96.9	393.8	161.1	22.33	0	0	0	0	0	0	0	0	0	0	0	0
17	403.3	4.46	94573	96.9	394.5	161.1	22.40	0	0	0	339.4	147.1	18.17	0	0	0	0	0	0
17	405.3	4.47	94763	95.4	402.5	159.7	23.35	0	0	0	347.1	145.7	19.20	0	0	0	359.7	159.1	19.69
17	408.0	4.47	94669	95.4	410.7	159.7	24.25	382.5	148.1	21.76	0	0	0	0	0	0	0	0	0
17	409.6	4.45	94668	95.4	414.4	159.7	24.62	0	0	0	357.2	145.8	20.28	0	0	0	0	0	0
17	414.5	4.46	94289	95.4	423.1	159.5	25.70	0	0	0	367.3	145.6	21.46	0	0	0	0	0	0
17	414.5	4.46	94289	95.4	424.7	159.5	25.85	0	0	0	0	0	0	0	0	0	372.5	157.6	23.39
18	425.6	4.44	94573	96.0	447.1	160.5	28.03	420.8	148.9	26.60	389.6	146.4	23.64	0	0	0	0	0	0
18	425.5	4.46	94669	96.0	447.1	160.4	28.01	0	0	0	395.7	146.9	24.25	0	0	0	395.3	158.5	24.27
18	428.7	4.46	94669	96.0	447.1	160.5	27.97	0	0	0	0	0	0	0	0	0	0	0	0
18	428.9	4.46	94573	96.6	454.0	160.9	29.72	0	0	0	403.2	146.8	25.11	0	0	0	397.4	158.6	24.56
18	428.9	4.45	94479	96.3	453.7	160.6	29.75	0	0	0	0	0	0	0	0	0	0	0	0
18	431.6	4.46	94384	96.6	460.7	160.9	29.58	0	0	0	412.2	146.7	26.16	0	0	0	0	0	0
18	434.0	4.46	94194	96.3	460.4	160.7	29.56	435.3	149.1	27.39	0	0	0	0	0	0	0	0	0
18	438.5	4.46	94099	96.6	469.0	160.6	30.49	0	0	0	0	0	0	0	0	0	416.7	158.5	28.70
18	438.5	4.46	94004	96.6	469.0	160.5	30.54	0	0	0	429.1	146.8	27.93	0	0	0	0	0	0
19	449.1	4.45	94194	96.6	486.3	160.7	32.29	461.6	149.2	30.17	0	0	0	0	0	0	0	0	0
19	449.1	4.47	94194	96.6	487.2	160.5	32.41	0	0	0	0	0	0	0	0	0	462.6	158.8	30.69
19	449.1	4.45	94289	96.6	486.7	160.4	32.38	469.2	149.2	31.11	0	0	0	0	0	0	462.6	157.7	30.87
19	455.5	4.49	94099	96.0	495.0	159.7	33.36	491.5	148.7	32.48	0	0	0	0	0	0	0	0	0
19	464.0	4.47	93815	96.6	507.9	160.1	34.66	0	0	0	441.7	146.2	30.3	0	0	0	0	0	0
19	466.0	4.47	93815	96.3	506.1	159.9	34.62	502.8	148.3	34.44	0	0	0	0	0	0	0	0	0
20	470.3	4.51	94668	96.6	528.5	159.8	36.68	0	0	0	472.8	145.9	32.44	0	0	0	0	0	0
20	479.4	4.52	94763	95.0	528.5	159.7	36.64	0	0	0	0	0	0	0	0	0	504.7	159.1	35.05
20	479.4	4.51	94668	96.3	529.3	160.1	36.62	0	0	0	487.4	146.4	34.14	0	0	0	0	0	0
20	486.5	4.51	94099	96.9	543.5	160.1	38.67	0	0	0	0	0	0	0	0	0	540.0	158.1	39.10
21	490.5	4.48	94668	93.4	570.6	157.5	41.36	543.5	146.9	38.99	503.9	139.7	36.06	0	0	0	0	0	0
22	526.3	4.46	94763	89.3	573.4	153.7	42.01	0	0	0	0	0	0	0	0	0	0	0	0

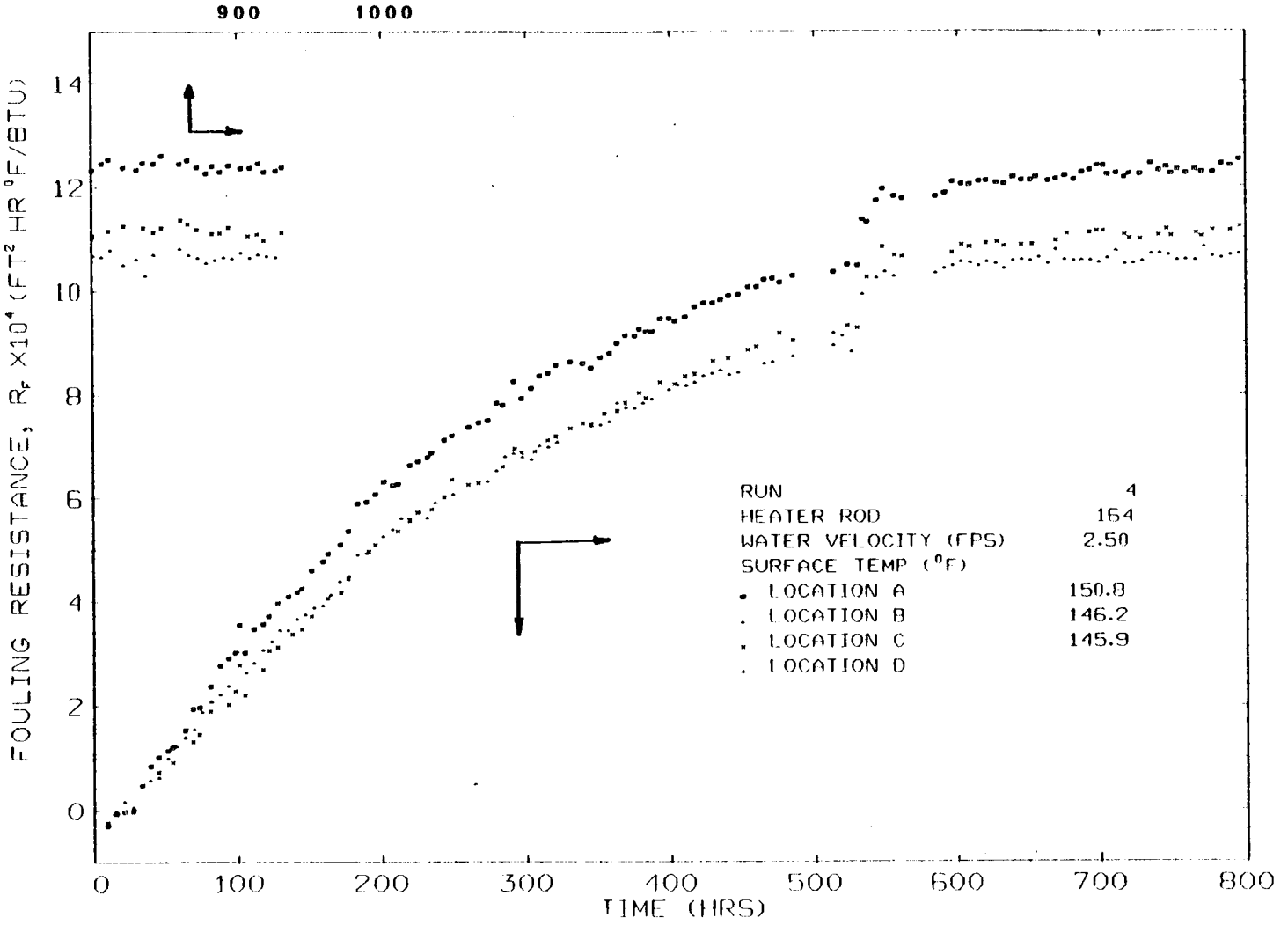
APPENDIX K

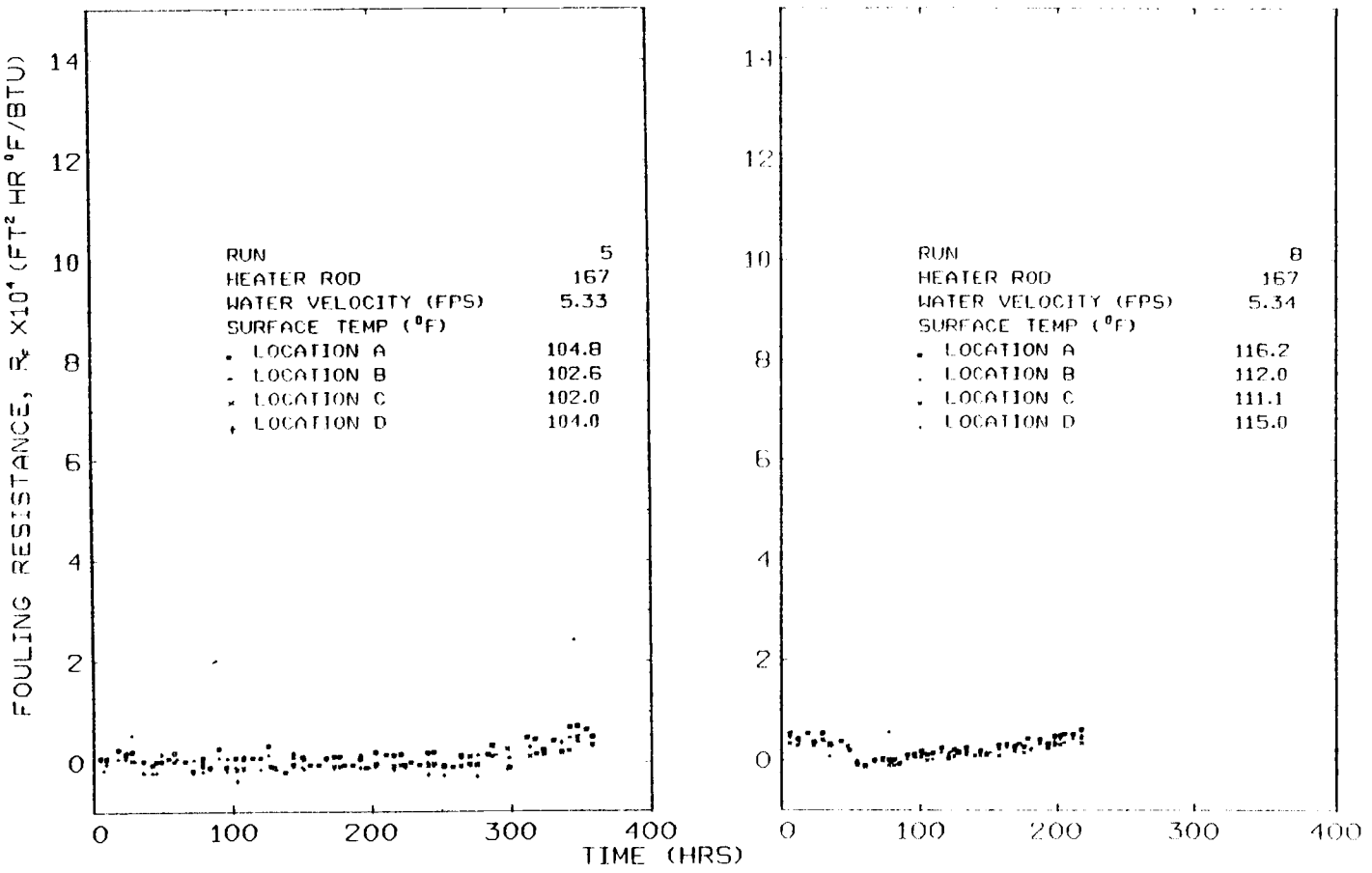
PLOTS OF FOULING RESISTANCE VS TIME, RUNS 1 - 24

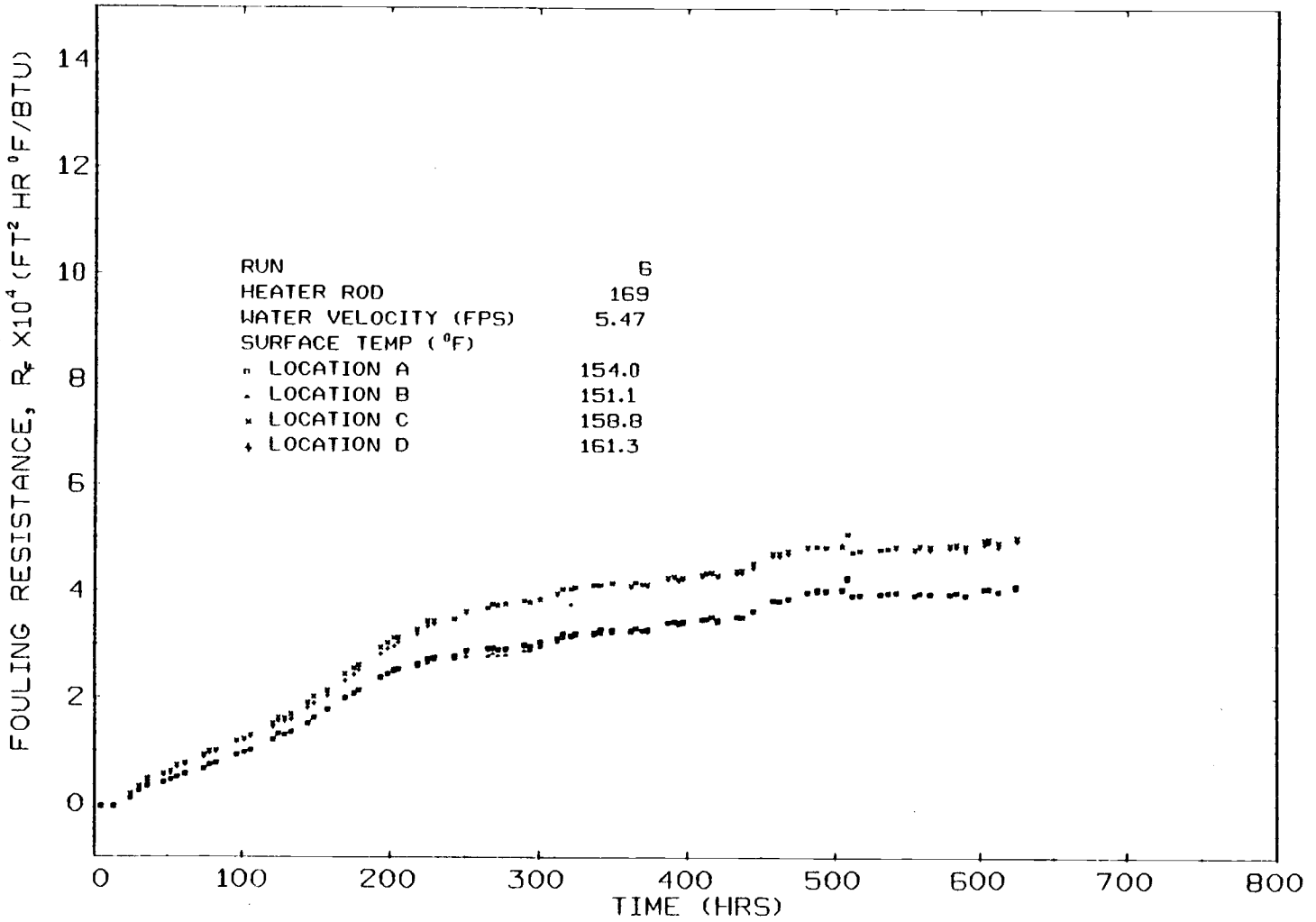

900
1000
RUN 1
HEATER ROD 167
WATER VELOCITY (FPS) 5.32
SURFACE TEMP (°F)
LOCATION A 157.0
LOCATION B 146.1
LOCATION C 148.0
LOCATION D 160.7
FOULING RESISTANCE, R_f X10⁴ (FT² HR °F/BTU)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
TIME (HRS)

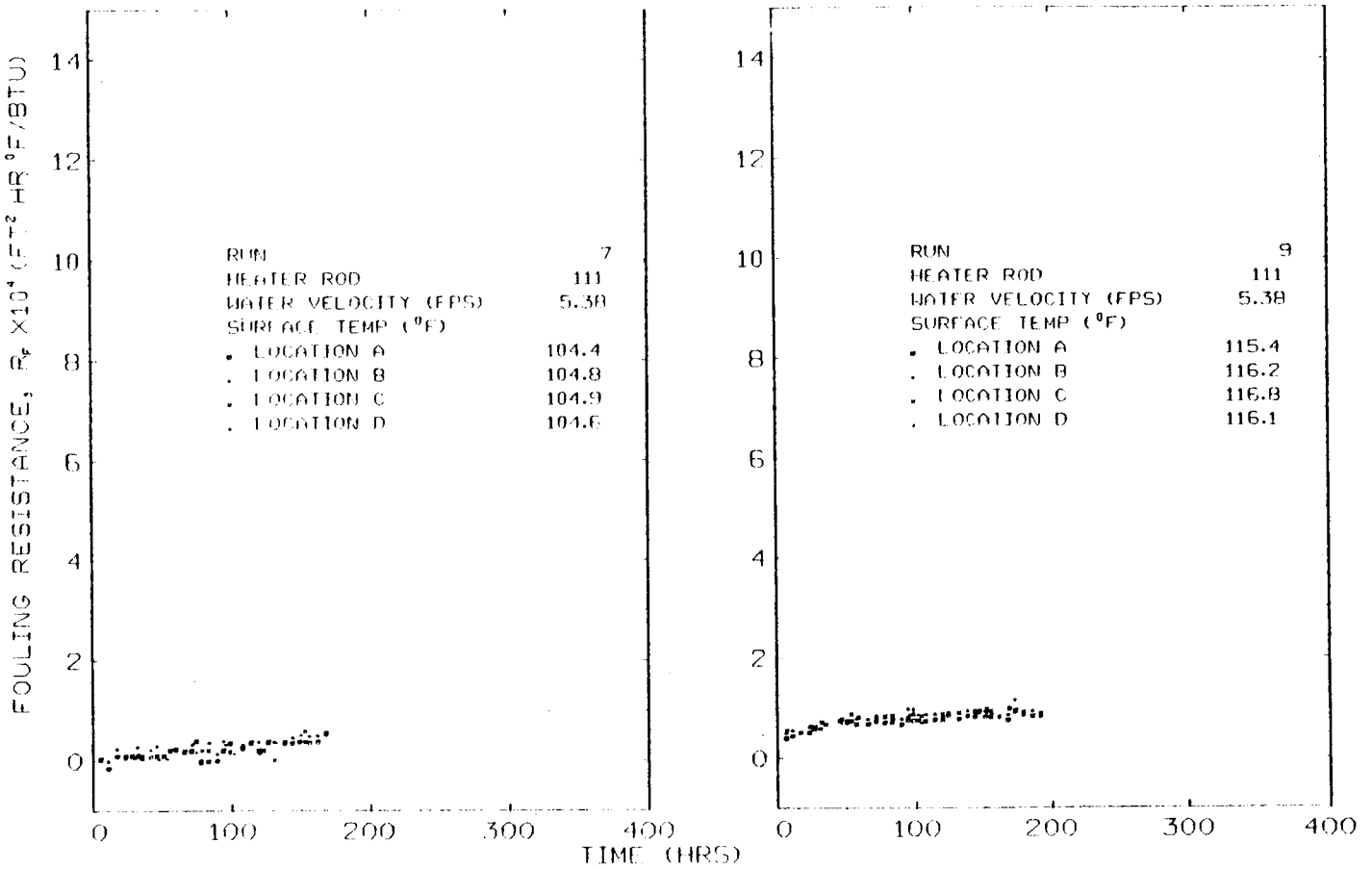

FOULING RESISTANCE, R_f X10^4 (FT^2 HR °F/BTU)
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
RUN 2
HEATER ROD 169
WATER VELOCITY (FPS) 5.46
SURFACE TEMP (°F)
• LOCATION A 103.8
. LOCATION B 103.7
. LOCATION C 105.7
. LOCATION D 105.6
2-17-77
0
200
400
600
800
10 00
12 00
14 00
16 00
12-16-76
TIME (HRS)

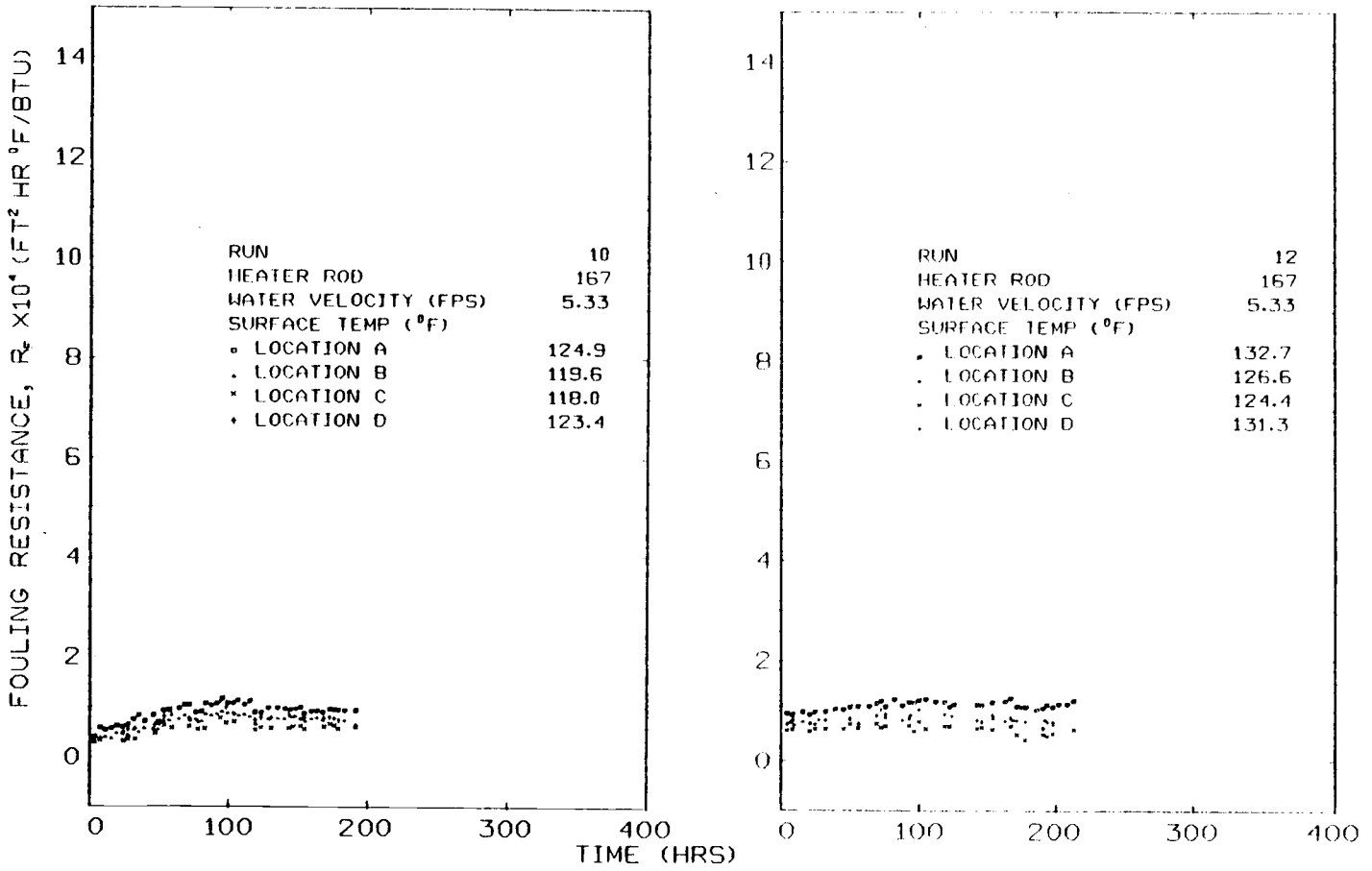

FOULING RESISTANCE, R_f X10^4 (FT^2 HR °F/BTU)
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
TIME (HRS)
RUN 3
HEATER ROD 167
WATER VELOCITY (FPS) 5.33
SURFACE TEMP (°F)
. LOCATION A 155.3
. LOCATION B 141.8
. LOCATION C 139.7
. LOCATION D 153.4

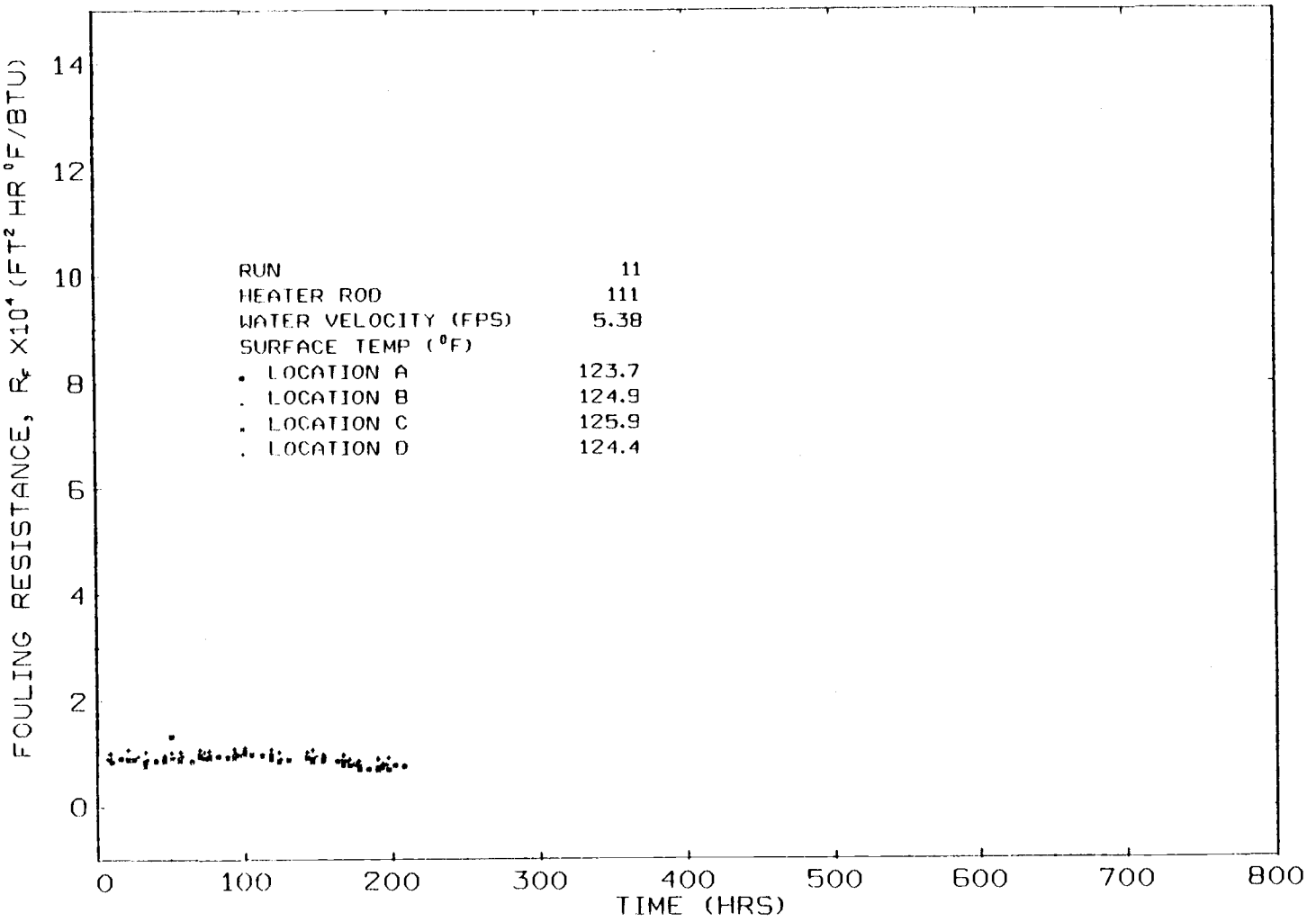

900
1000
FOULING RESISTANCE, R_f X10^4 (FT^2 HR °F/BTU)
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
TIME (HRS)
RUN 4
HEATER ROD 164
WATER VELOCITY (FPS) 2.50
SURFACE TEMP (°F)
• LOCATION A 150.8
. LOCATION B 146.2
x LOCATION C 145.9
. LOCATION D

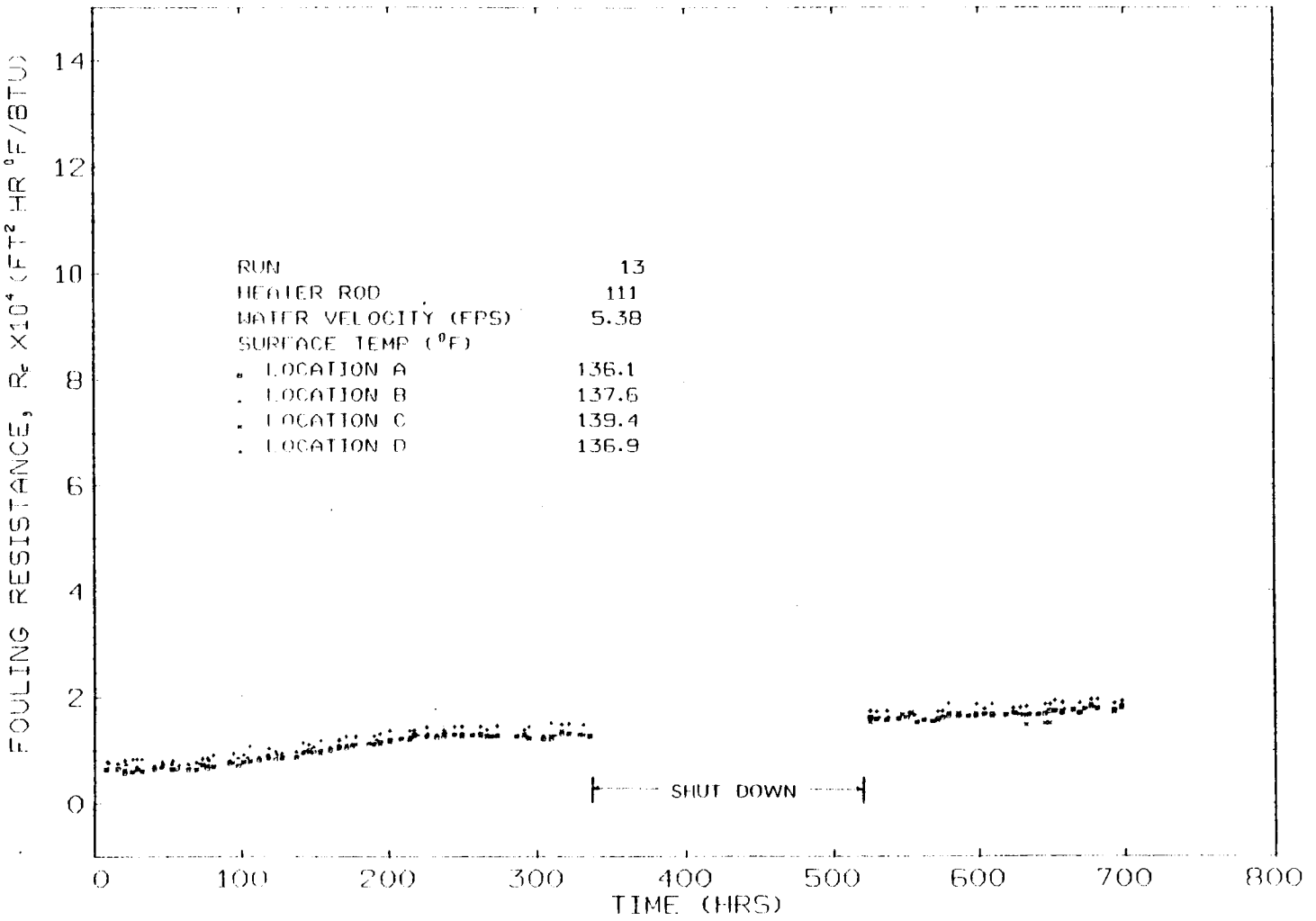

FOULING RESISTANCE, R_f X10^4 (FT^2 HR °F/BTU)
TIME (HRS)
RUN 5
HEATER ROD 167
WATER VELOCITY (FPS) 5.33
SURFACE TEMP (°F)
LOCATION A 104.8
LOCATION B 102.6
LOCATION C 102.0
LOCATION D 104.0
RUN 8
HEATER ROD 167
WATER VELOCITY (FPS) 5.34
SURFACE TEMP (°F)
LOCATION A 116.2
LOCATION B 112.0
LOCATION C 111.1
LOCATION D 115.0

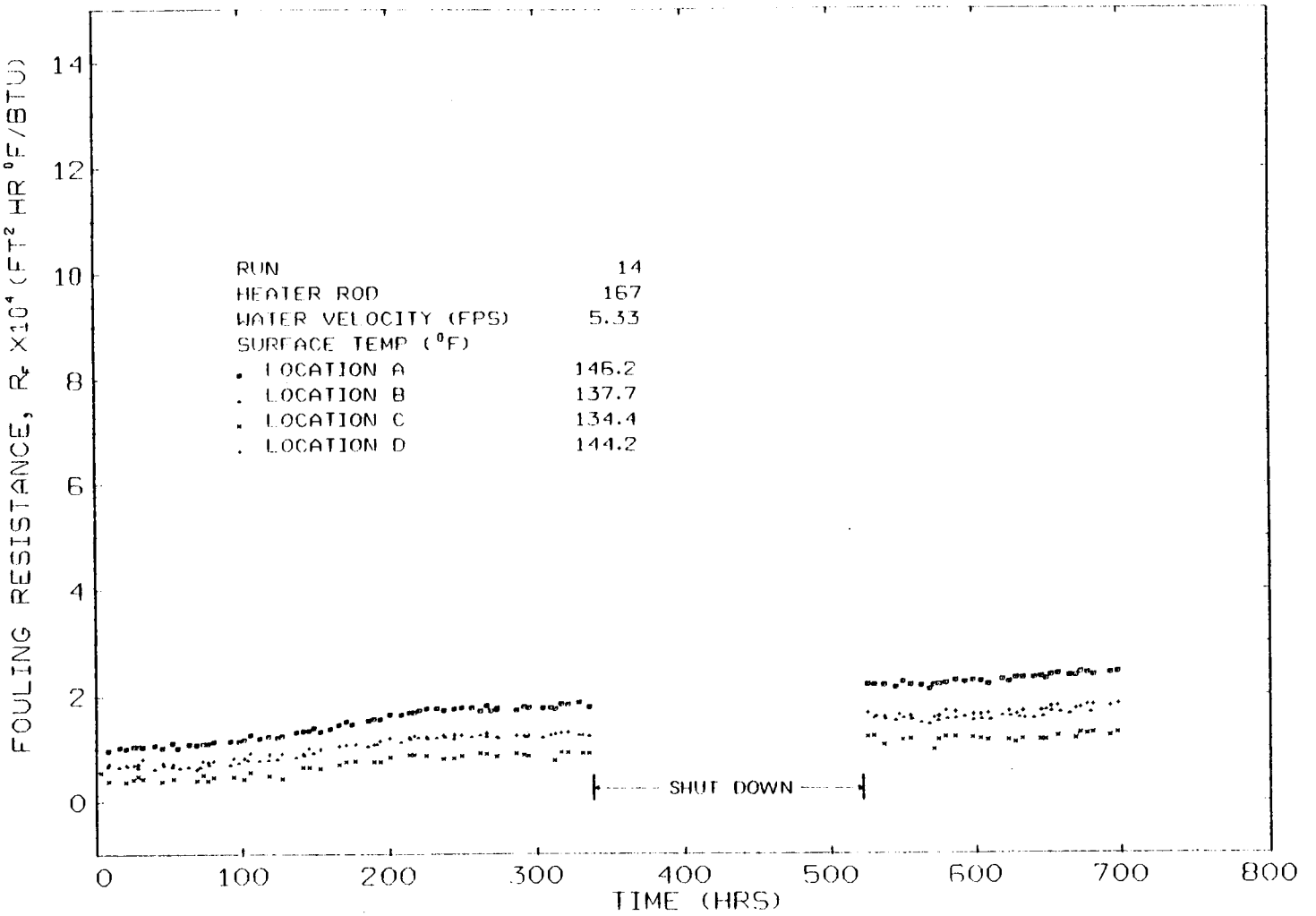

FOULING RESISTANCE, R_f X10^4 (FT^2 HR ^{0}F/BTU)
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
TIME (HRS)
RUN 6
HEATER ROD 169
WATER VELOCITY (FPS) 5.47
SURFACE TEMP (^{0}F)
▫ LOCATION A 154.0
· LOCATION B 151.1
× LOCATION C 158.8
+ LOCATION D 161.3

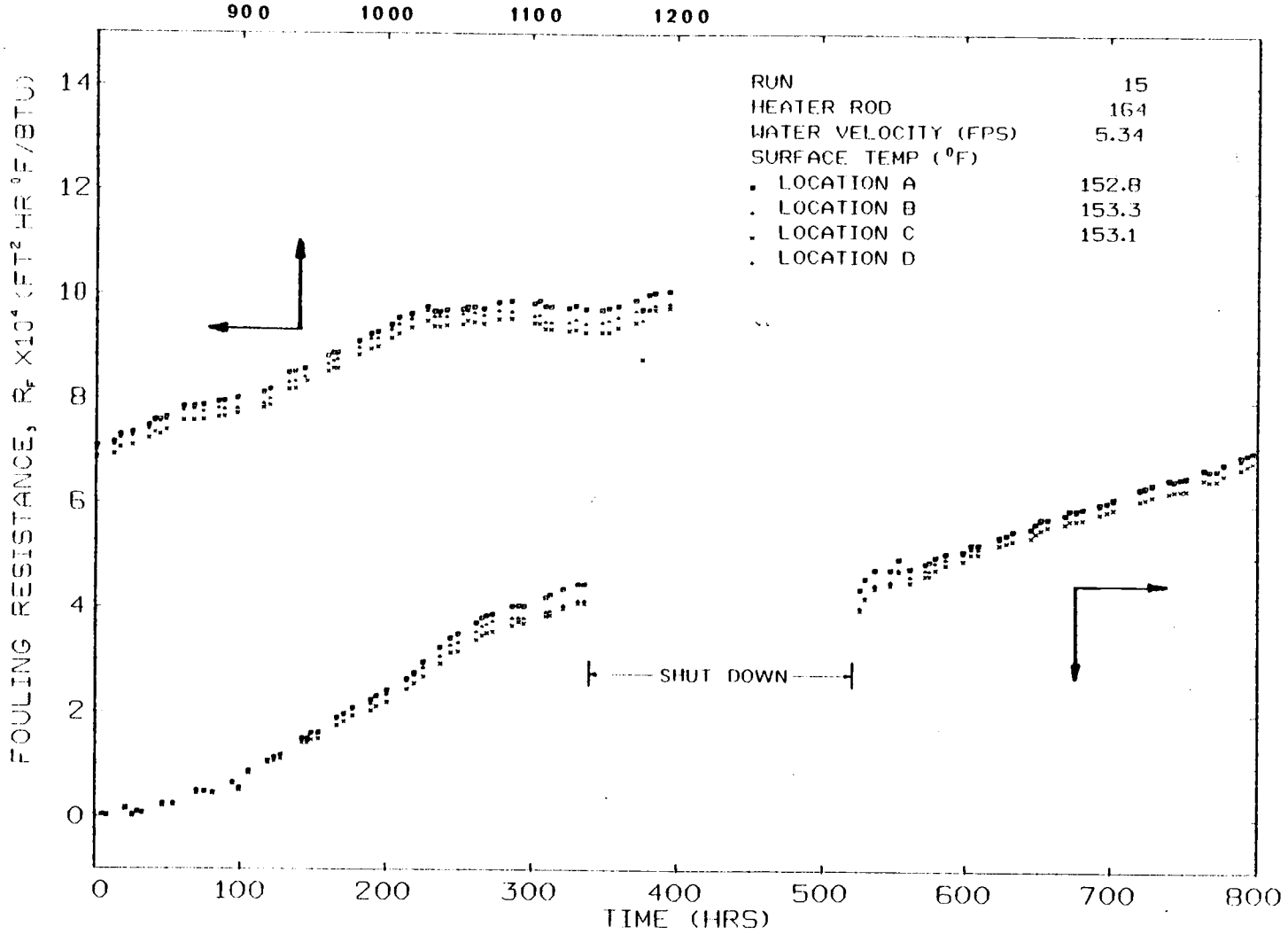

FOULING RESISTANCE, R_f X10^4 (FT^2 HR °F/BTU)
TIME (HRS)
RUN 7
HEATER ROD 111
WATER VELOCITY (FPS) 5.38
SURFACE TEMP (°F)
• LOCATION A 104.4
. LOCATION B 104.8
• LOCATION C 104.9
. LOCATION D 104.6
RUN 9
HEATER ROD 111
WATER VELOCITY (FPS) 5.38
SURFACE TEMP (°F)
• LOCATION A 115.4
. LOCATION B 116.2
• LOCATION C 116.8
. LOCATION D 116.1

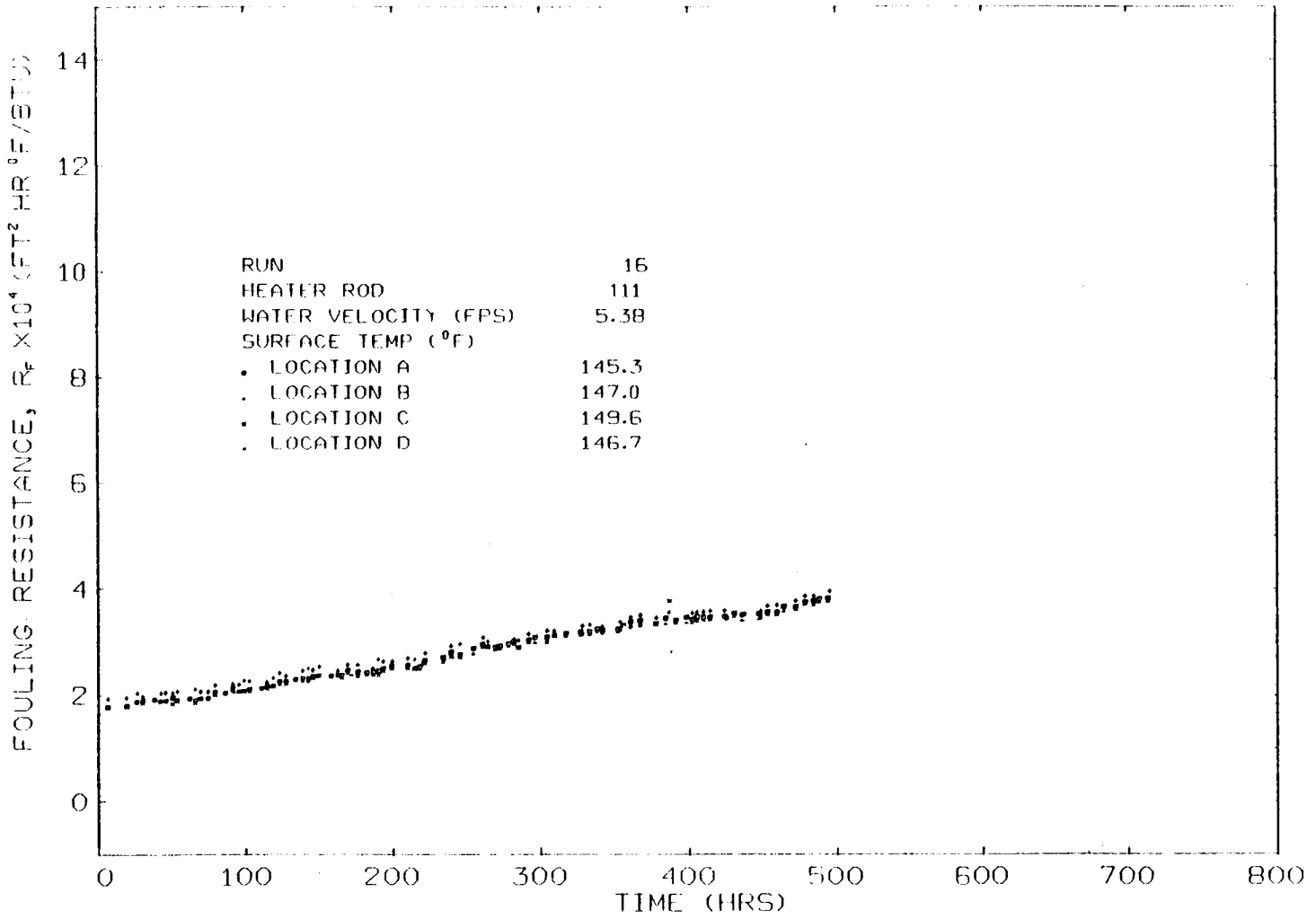

FOULING RESISTANCE, R_f X10^4 (FT^2 HR °F/BTU)
14
12
10
8
6
4
2
0
0
100
200
300
400
TIME (HRS)
RUN 10
HEATER ROD 167
WATER VELOCITY (FPS) 5.33
SURFACE TEMP (°F)
▫ LOCATION A 124.9
. LOCATION B 119.6
× LOCATION C 118.0
+ LOCATION D 123.4
RUN 12
HEATER ROD 167
WATER VELOCITY (FPS) 5.33
SURFACE TEMP (°F)
. LOCATION A 132.7
. LOCATION B 126.6
. LOCATION C 124.4
. LOCATION D 131.3

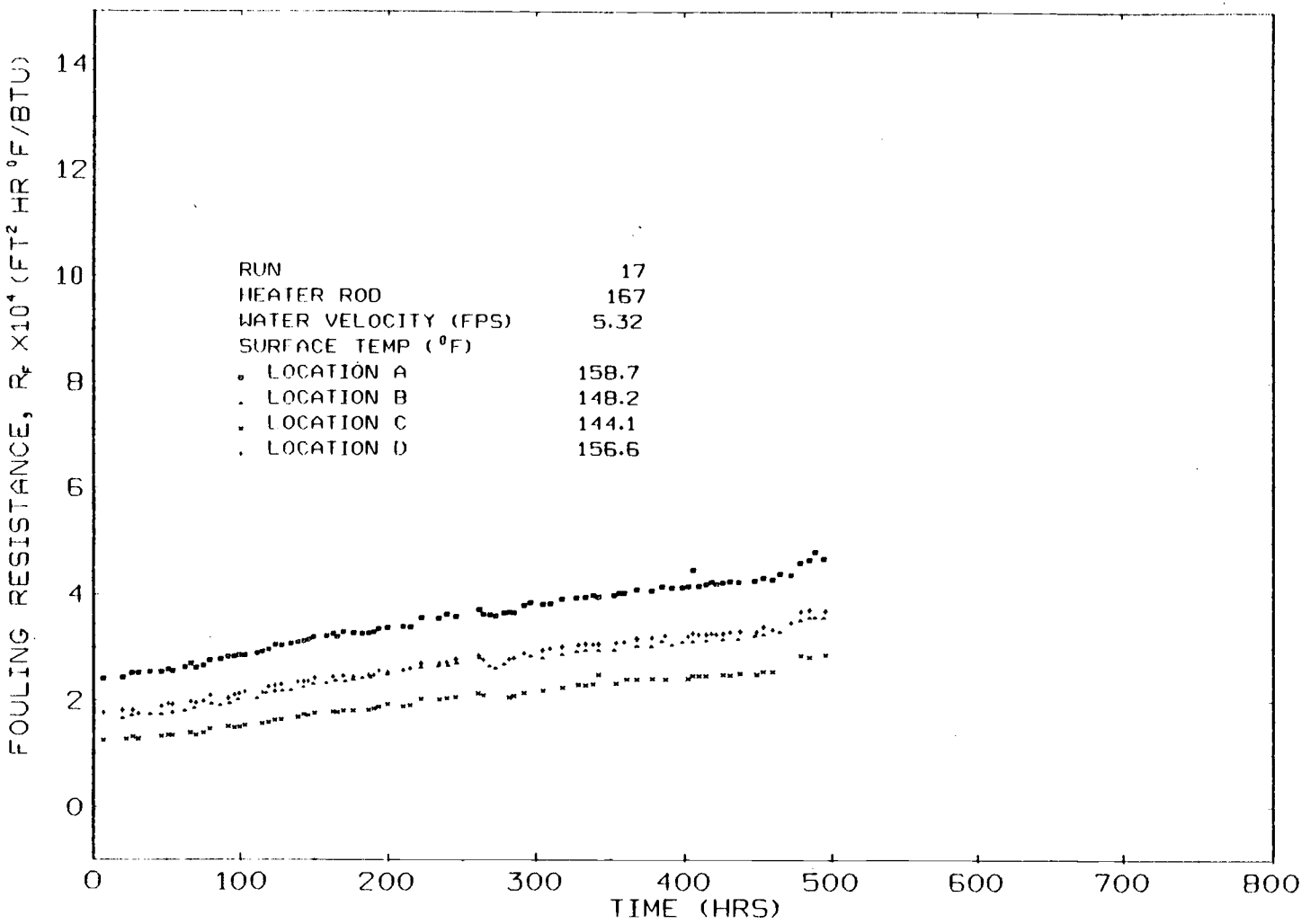

FOULING RESISTANCE, R_f X10^4 (FT^2 HR ^{0}F/BTU)
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
TIME (HRS)
RUN 11
HEATER ROD 111
WATER VELOCITY (FPS) 5.38
SURFACE TEMP (^{0}F)
• LOCATION A 123.7
. LOCATION B 124.9
. LOCATION C 125.9
. LOCATION D 124.4

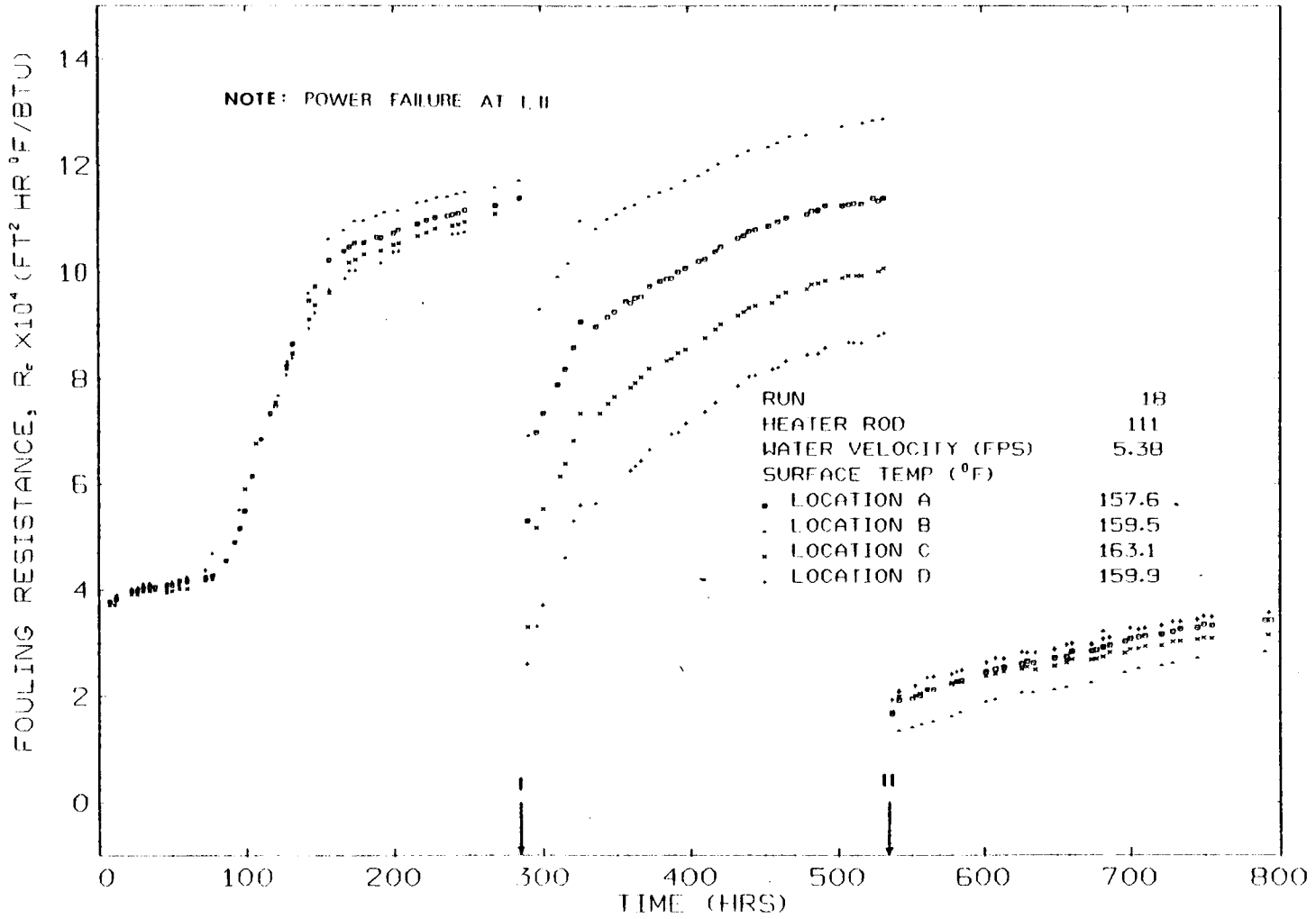

FOULING RESISTANCE, R_f X10^4 (FT^2 HR ^{0}F/BTU)
14
12
10
8
6
4
2
0
RUN 13
HEATER ROD 111
WATER VELOCITY (FPS) 5.38
SURFACE TEMP (^{0}F)
LOCATION A 136.1
LOCATION B 137.6
LOCATION C 139.4
LOCATION D 136.9
SHUT DOWN
0
100
200
300
400
500
600
700
800
TIME (HRS)

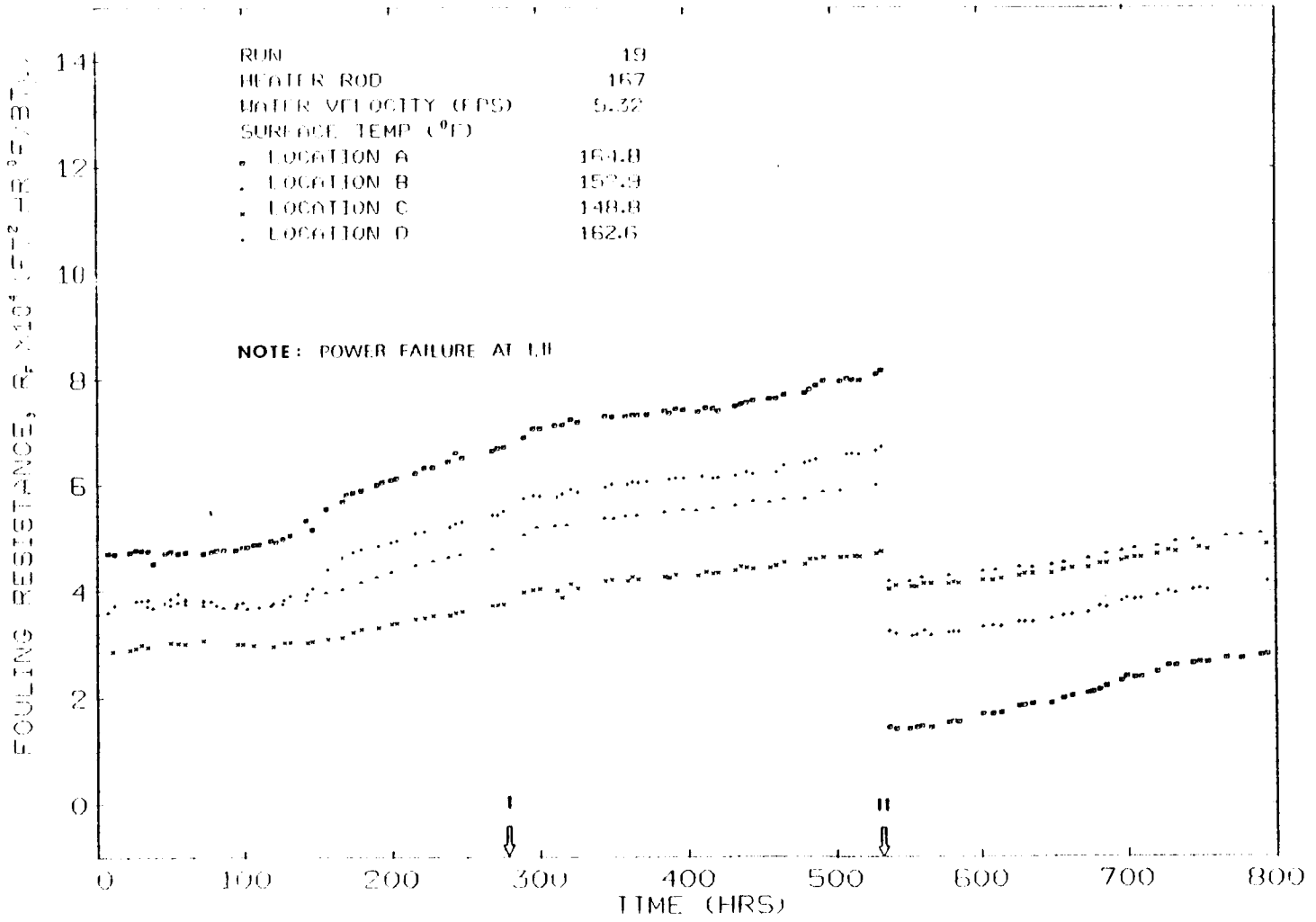

FOULING RESISTANCE, R_f X10^4 (FT^2 HR ^{0}F/BTU)
14
12
10
8
6
4
2
0
RUN 14
HEATER ROD 167
WATER VELOCITY (FPS) 5.33
SURFACE TEMP (^{0}F)
• LOCATION A 146.2
. LOCATION B 137.7
. LOCATION C 134.4
. LOCATION D 144.2
SHUT DOWN
0
100
200
300
400
500
600
700
800
TIME (HRS)

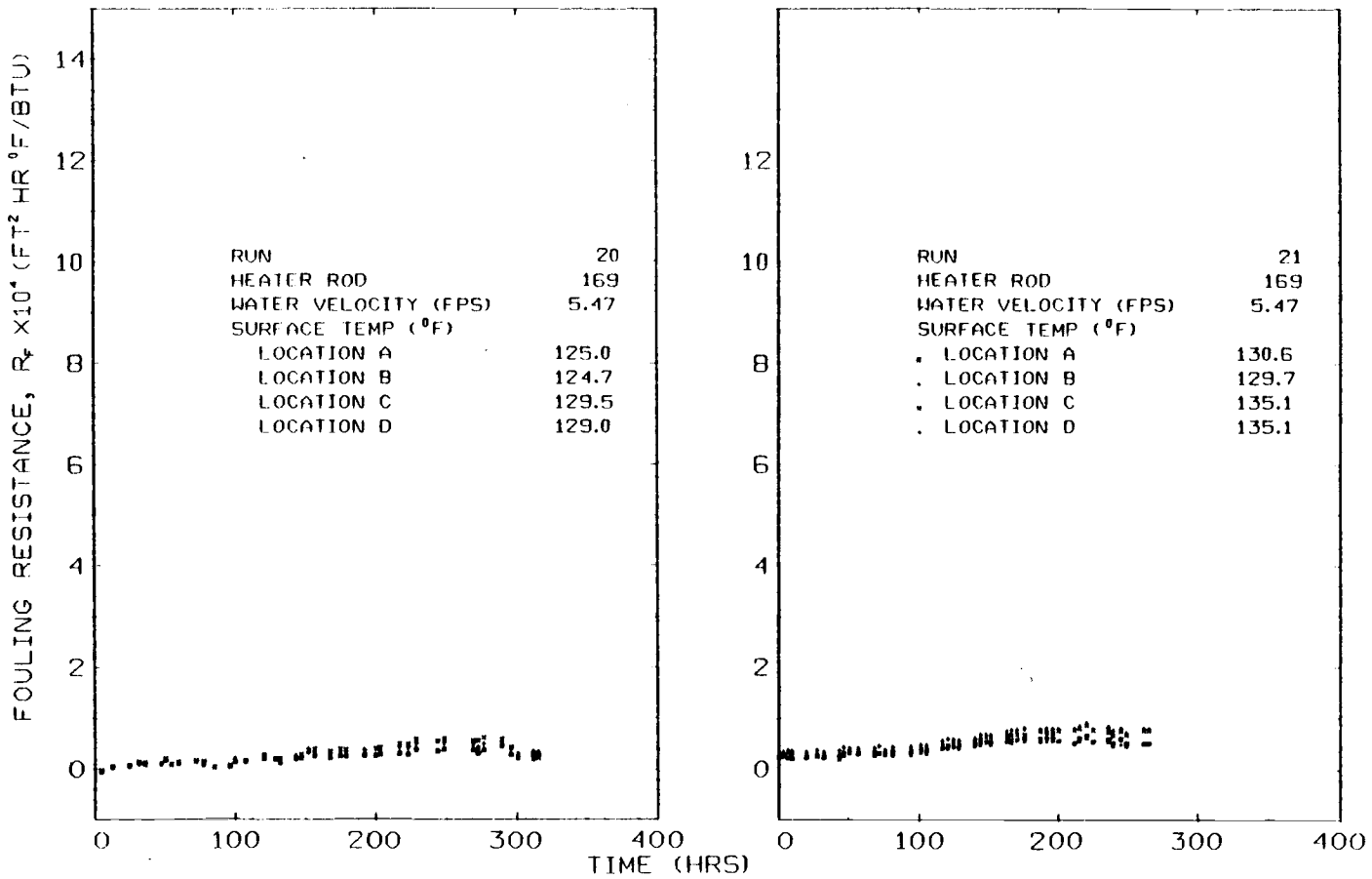

900
1000
1100
1200
RUN 15
HEATER ROD 164
WATER VELOCITY (FPS) 5.34
SURFACE TEMP (°F)
. LOCATION A 152.8
. LOCATION B 153.3
. LOCATION C 153.1
. LOCATION D
SHUT DOWN
FOULING RESISTANCE, R_f X10⁴ (FT² HR °F/BTU)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
TIME (HRS)

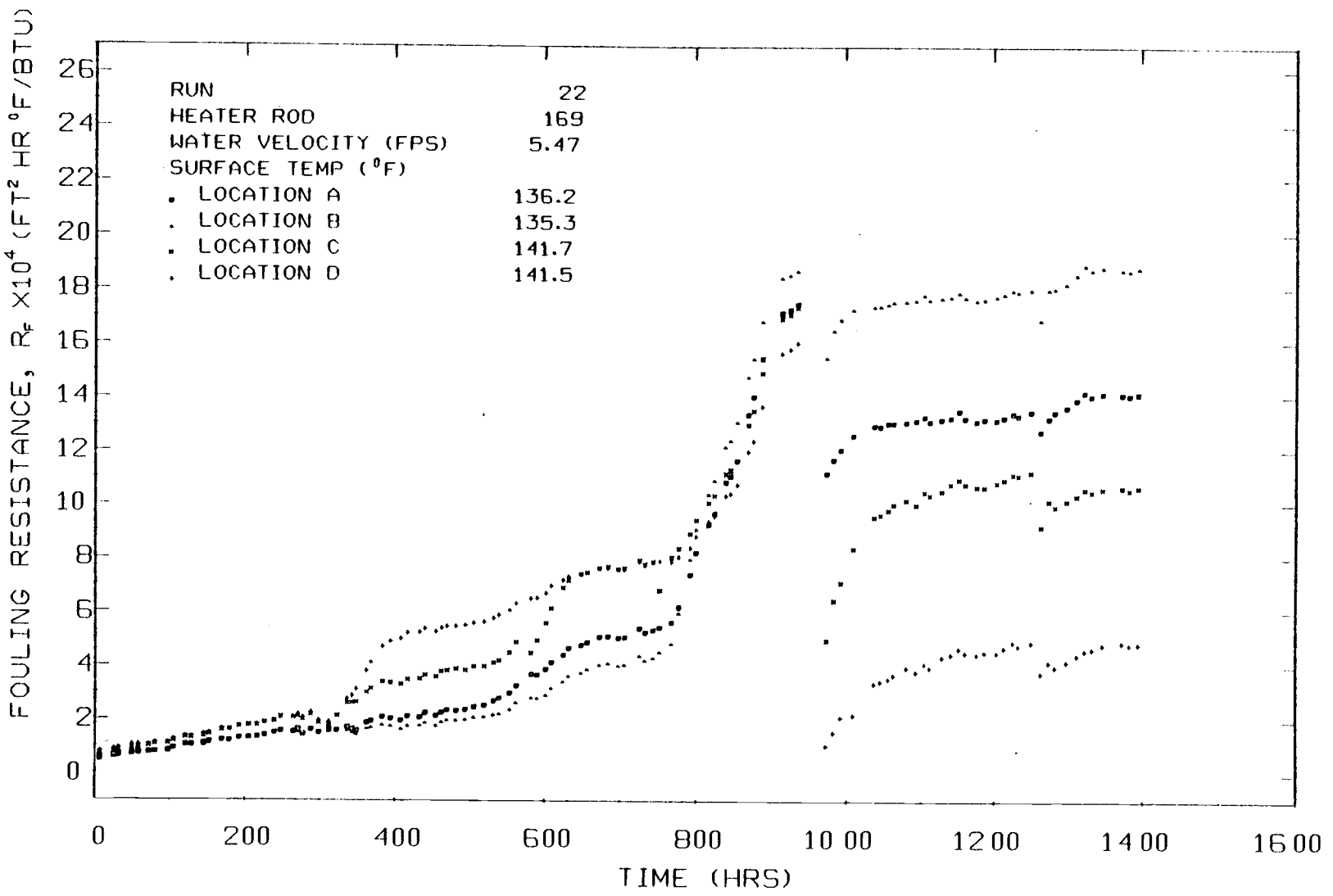

FOULING RESISTANCE, R_f X10^4 (FT^2 HR ^{0}F/BTU)
14
12
10
8
6
4
2
0
RUN 16
HEATER ROD 111
WATER VELOCITY (FPS) 5.38
SURFACE TEMP (^{0}F)
. LOCATION A 145.3
. LOCATION B 147.0
. LOCATION C 149.6
. LOCATION D 146.7
0
100
200
300
400
500
600
700
800
TIME (HRS)

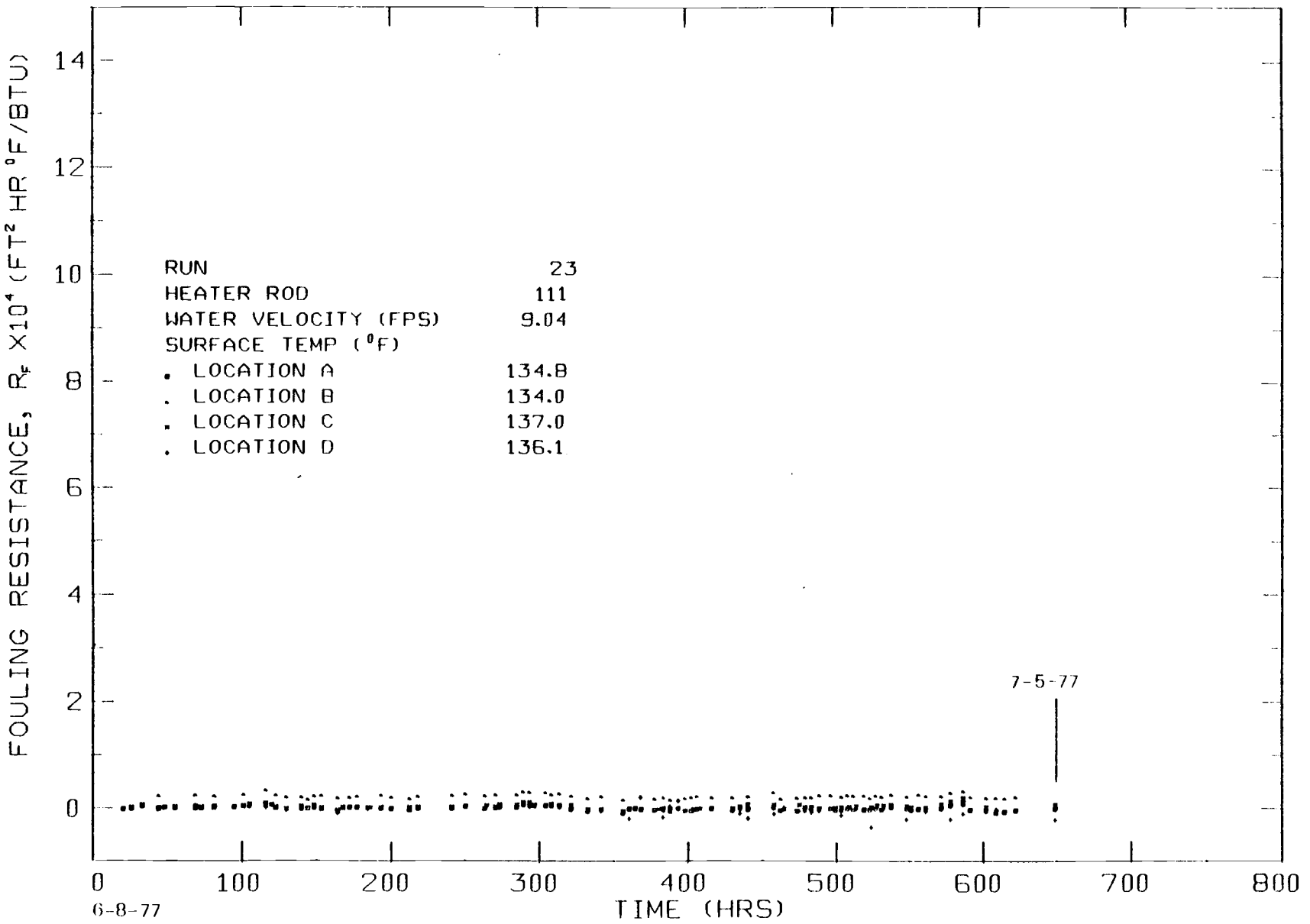

FOULING RESISTANCE, R_f X10^4 (FT^2 HR ^{0}F/BTU)
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
700
800
TIME (HRS)
RUN 17
HEATER ROD 167
WATER VELOCITY (FPS) 5.32
SURFACE TEMP (^{0}F)
LOCATION A 158.7
LOCATION B 148.2
LOCATION C 144.1
LOCATION D 156.6

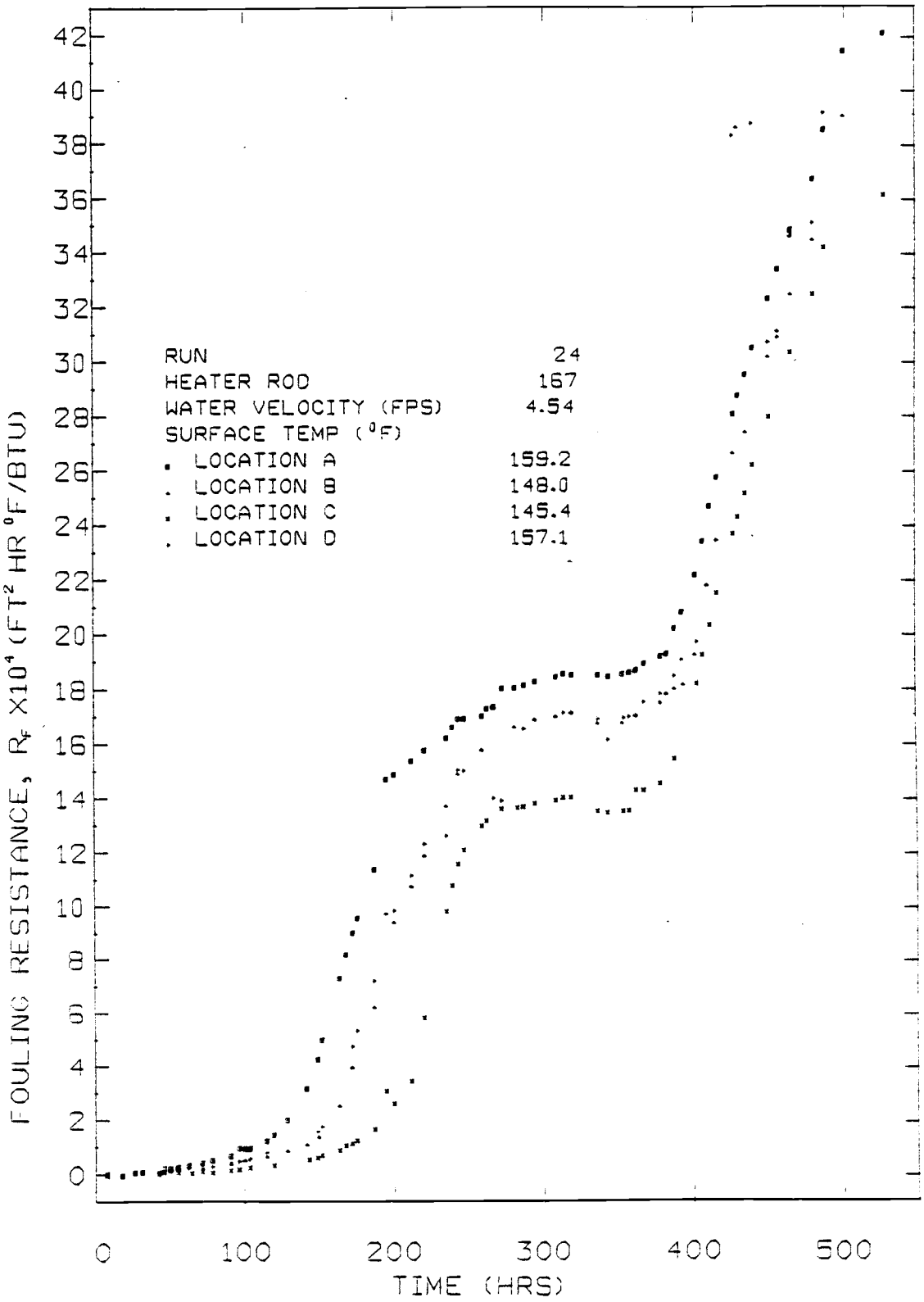

NOTE: POWER FAILURE AT I, II
RUN 18
HEATER ROD 111
WATER VELOCITY (FPS) 5.38
SURFACE TEMP (°F)
LOCATION A 157.6
LOCATION B 159.5
LOCATION C 163.1
LOCATION D 159.9
FOULING RESISTANCE, R_f X10^4 (FT^2 HR °F/BTU)
TIME (HRS)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
I
II


RUN 19
HEATER ROD 167
WATER VELOCITY (FPS) 5.32
SURFACE TEMP (°F)
. LOCATION A 164.8
. LOCATION B 159.9
. LOCATION C 148.8
. LOCATION D 162.6
NOTE: POWER FAILURE AT I, II
FOULING RESISTANCE, Rf x10³ (ft²-hr-°F/BTU)
0
2
4
6
8
10
12
14
I
II
0
100
200
300
400
500
600
700
800
TIME (HRS)


FOULING RESISTANCE, R_f X10⁴ (FT² HR °F/BTU)
14
12
10
8
6
4
2
0
0
100
200
300
400
TIME (HRS)
RUN 20
HEATER ROD 169
WATER VELOCITY (FPS) 5.47
SURFACE TEMP (°F)
LOCATION A 125.0
LOCATION B 124.7
LOCATION C 129.5
LOCATION D 129.0
RUN 21
HEATER ROD 169
WATER VELOCITY (FPS) 5.47
SURFACE TEMP (°F)
LOCATION A 130.6
LOCATION B 129.7
LOCATION C 135.1
LOCATION D 135.1


RUN 22
HEATER ROD 169
WATER VELOCITY (FPS) 5.47
SURFACE TEMP (°F)
. LOCATION A 136.2
. LOCATION B 135.3
. LOCATION C 141.7
. LOCATION D 141.5
FOULING RESISTANCE, R_F X10^4 (FT^2 HR °F/BTU)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
200
400
600
800
10 00
12 00
14 00
16 00
TIME (HRS)


FOULING RESISTANCE, R_f X10^4 (FT^2 HR ^{0}F/BTU)
14
12
10
8
6
4
2
0
RUN 23
HEATER ROD 111
WATER VELOCITY (FPS) 9.04
SURFACE TEMP (^{0}F)
• LOCATION A 134.8
. LOCATION B 134.0
▪ LOCATION C 137.0
. LOCATION D 136.1
7-5-77
0
100
200
300
400
500
600
700
800
6-8-77
TIME (HRS)


RUN 24
HEATER ROD 167
WATER VELOCITY (FPS) 4.54
SURFACE TEMP (°F)
LOCATION A 159.2
LOCATION B 148.0
LOCATION C 145.4
LOCATION D 157.1
FOULING RESISTANCE, R_f X10^4 (FT^2 HR °F/BTU)
TIME (HRS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
0
100
200
300
400
500