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EXPERIMENTAL DETERMINATION OF THE PERFORMANCE CHARACTERISTICS OF EIGHT COMPACT HEAT TRANSFER SURFACES

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*prepared for the U.S. ATOMIC ENERGY COMMISSION
under U.S. GOVERNMENT Contract W-7405 eng 26*

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ABSTRACT

Heat transfer and flow friction characteristics were determined experimentally for eight heat exchanger geometries. All of the exchangers were *compact* and represented a variety of gas-side surfaces: brazed aluminum plate-fin sandwiches, plate-finned tubes, plates with integral serrated fins, tubes with integral serrated fins, and tubes with integral smooth helical fins. Data were taken with heat transfer from air to water. General methods are presented for reducing the data to a dimensionless form and for comparing the performances of different surfaces.

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NOMENCLATURE

Basic Symbols

- a = constant in equation C-1, dimensionless.
 A = area, sq ft.
 b = constant in equation C-2, dimensionless.
 B = constant in equation 17, dimensionless.
 c = specific heat at constant pressure, Btu/lb-°F.
 C = capacity rate, wc, Btu/hr-°F.
 D = hydraulic diameter, ft.
 E = heat exchanger effectiveness, dimensionless.
 E'' = pumping power per unit surface area, fhp/sq ft.
 E''' = pumping power per unit volume, fhp/cu ft.
 f = Fanning friction factor, dimensionless.
 F = LMTD correction factor, dimensionless.
 g_c = gravitational constant, 32.174, lb-ft/lbf-sec².
 G = mass velocity, lb/hr-sq ft.
 h = convection heat transfer coefficient, Btu/hr-sq ft-°F.
 h'' = standard area heat transfer coefficient, Btu/hr-sq ft-°F.
 h''' = standard volumetric heat transfer coefficient, Btu/hr-cu ft-°F.
 I_0 = zero-order modified Bessel function of first kind.
 I_1 = first-order modified Bessel function of first kind.
 j = Colburn j-factor, $St Pr^{2/3}$, dimensionless.
 k = thermal conductivity, Btu/hr-ft-°F.
 K_c = contraction coefficient, dimensionless.
 K_e = expansion coefficient, dimensionless.
 K_o = zero-order modified Bessel function of second kind.

K_1 = first-order modified Bessel function of second kind.
 ℓ = fin segment length, ft.
 L = heat exchanger length, ft.
LMTD = logarithmic mean temperature difference, °F.
 m = constant in equation C-1, dimensionless.
 n = constant in equation C-2, dimensionless.
Nu = Nusselt number, hD/k , dimensionless.
 p = constant in equation C-3, dimensionless.
 P = static pressure, psia.
Pr = Prandtl number, c_p/k , dimensionless.
 q = heat transfer rate, Btu/hr.
 q'' = heat transfer rate per unit surface area, Btu/hr-sq ft.
 q''' = heat transfer rate per unit volume, Btu/hr-cu ft.
 r = tube radius, ft.
 R = heat transfer resistance, hr-sq ft-°F/Btu.
Re = Reynolds number, GD/μ , dimensionless.
St = Stanton number, $Nu/RePr$, dimensionless.
 t = wall thickness, ft.
 T = temperature, °F or °R.
 U = overall heat transfer coefficient, Btu/hr-sq ft-°F.
 v = specific volume, cu ft/lb.
 V = velocity, ft/sec.
 w = mass flow rate, lb/hr.
 W = pumping power, ft-lbf/sec.
 α = heat transfer area per unit total volume, sq ft/cu ft.
 β = heat transfer area per unit air volume, sq ft/cu ft.

δ = fin segment thickness, ft.
 ΔP = pressure difference, psia.
 ΔT = temperature difference, $^{\circ}F$ or $^{\circ}R$.
 ϵ = weighted fin efficiency, dimensionless.
 η = fin efficiency, dimensionless.
 η'' = surface area heat transfer efficiency, dimensionless.
 η''' = volumetric heat transfer efficiency, dimensionless.
 μ = viscosity, lb/ft-hr.
 ρ = density, lb/cu ft.
 σ = ratio of free-to-frontal area, dimensionless.
 ψ = function or operator.
 ψ' = function or operator.

Subscripts

base = fin segment base.
 bulk = bulk fluid.
 c = coolant or water side.
 f = fin.
 film = refers to film between wall and bulk fluid.
 front = refers to core front.
 h = hot or gas side.
 i = tube inside.
 in = core inlet.
 max = maximum.
 mean = mean value.
 min = minimum.
 o = standard value, or tube outside.

out = core outlet.

r = reference value.

rat = ratio of minimum to maximum.

s = scale or fouling condition.

t = total.

u = unfinned.

w = wall.

1 = upstream of core.

2 = downstream of core.

EXPERIMENTAL DETERMINATION OF THE
PERFORMANCE CHARACTERISTICS OF
EIGHT COMPACT HEAT TRANSFER SURFACES

INTRODUCTION AND SUMMARY

The increasing need for compact heat exchangers has resulted in greater efforts by industry to manufacture and evaluate new types of heat transfer surfaces. For example, a significant part of the expansion program for the nation's gaseous diffusion plants involves the design of new and more efficient heat exchangers. Because of their high surface area densities and subsequent low volume requirements, compact plate and fin surfaces appeared attractive for these designs. A program was therefore initiated at the Oak Ridge Gaseous Diffusion Plant (ORGDP) to test and evaluate several of these surfaces.

As a first step in the evaluation program, an experimental facility was built to obtain data from heat exchanger core samples. Experiments were conducted with surfaces representing most types which are commercially available, plus several developed at ORGDP. Accurate design data were previously unavailable for most of these surfaces.

As the designs for new gaseous diffusion plants proceed, the traditional heat removal system is undergoing critical reviews. New ideas for heat rejection and recovery are generating increased needs for reliable, general design data on compact heat exchanger surfaces. In the past, much of the existing experimental data have been presented in an awkward or inconsistent form that does not lend itself to general design usage. For instance, overall heat transfer coefficients and pressure drops in existing diffusion plant gas coolers are of little help in designing air-cooled condensers with the same surface. A major objective of this report is to present the data results in a form that is applicable to design problems in general.

There usually exists appreciable lag time between the taking of experimental data and the actual use of that data in plant designs. Simplified methods were therefore developed which indicate whether a surface is high or low performance. This facilitates the development of better heat exchanger surfaces.

The size and cost of heat exchangers can often be greatly reduced if the exchangers are constructed with a high heat transfer area per unit of volume. Such exchangers are usually termed *compact*. The surfaces used in compact heat exchangers are then termed compact surfaces. However, since no rigid definition of compact surfaces exists, confusion often results as to whether some surfaces are truly compact. For example, finned tubes might have a high surface area density when they are in a close-packed arrangement and a low surface area density when they are in a widely spaced arrangement. To eliminate this confusion, a *compact surface* is herein defined as one that "has the potential for placing approximately one hundred square feet of heat transfer area in one cubic foot of volume."

APPARATUS AND PROCEDURE

The Heat Exchange Apparatus Test (HEAT) Facility used for studying the performance of heat exchanger core samples is shown schematically in figure 1. Major parts of this facility included the air loop, the water loop, the heat exchanger itself, and the data acquisition system.

Flow was induced through the air loop by a 3,550-rpm Allis-Chalmers radial compressor. Components of the air loop were connected by 8- and 10-in. Schedule 40 steel pipe. Air flow to the core sample was controlled with butterfly valves located in the main pipe line and in the bypass line. Air temperatures could be maintained at any desired level from 120 to 300°F. Temperature levels were raised by adding heat with three independently controlled 25-kw Chromalox finned air heaters located upstream of the core sample. Temperature levels were lowered either by reducing the power supplied to the heaters or by opening valves to admit cooler ambient air.

The water loop portion of the HEAT Facility was operated in a manner similar to the air loop. Water flow to the core sample was induced by a 1,000-gpm Allis-Chalmers centrifugal pump. Water temperature levels were controlled by simultaneously regulating the water flows to the supply tank, the water-to-water heat exchanger, and the core sample.

The heat exchanger section of the system consisted of a core sample, together with parts connecting it to the air and water loops. The core samples were square faced and were of two nominal sizes: 18 in. by 18 in. and 12 in. by 13 in. Figure 2 shows a typical example. Upstream of the core, air flowed through a transition duct piece and then a straight duct where a 20-mesh screen was installed to smooth out velocity and temperature variations in the air stream. Downstream of the core, another straight duct and transition piece were installed. Headers were bolted to the top and bottom of the core sample connecting it to the water loop.

Before data were recorded for any run, steady-state temperatures and flows were attained in both the air and the water loops. Temperatures in the system were determined with calibrated 30-gauge Chromel-Alumel sheathed thermocouples. A Kaye electronic ice point reference junction, accurate to $\pm 0.05^\circ\text{C}$, and a Vidar 521 integrating digital voltmeter with paper tape printout were used in conjunction with the thermocouples. Grids of thermocouples were placed in the air loop upstream and downstream of the core sample. Velocity and temperature measurements at these positions were found to be sufficiently uniform, however, to permit inlet and outlet temperatures to be evaluated by averaging just four thermocouple readings upstream and four downstream. Three thermocouples at the water inlet header and three thermocouples at the outlet header were used to determine water temperatures.

Air flow rates were measured with a calibrated Hammel-Dahl flow tube. The accuracy of the flow tube is claimed to be $\pm 1\%$. Its pressure tap

Figure 1

SCHEMATIC DIAGRAM OF THE HEAT FACILITY FOR DETERMINING
PERFORMANCE CHARACTERISTICS OF COMPACT HEAT EXCHANGERS

Figure 2
BRAZED ALUMINUM HEAT EXCHANGER CORE SAMPLE

readings were displayed on U-tube manometers. As a check, flow rates were simultaneously determined by a pitot tube inserted in the air loop. Values for the two flow rates were within 3% of one another. Water flow rates were determined from the pressure taps of a standard orifice plate.¹ The orifice plate pressure taps were connected to a Foxboro 13A d/p cell transmitter whose output was displayed on a calibrated Robertshaw receiver gauge. Calibrated Cox turbine flow meters were used to measure water flows outside the range of the orifice plate. The signals from the turbine meters were read from a Cox A3A digital indicator.

Core sample pressure drops were displayed on a Meriam micromanometer to an accuracy of several thousandths of an inch of water. Four upstream static pressure taps, one on each side of the duct, and four downstream taps were connected to the high- and low-pressure sides of the micromanometer. Four different sets of taps, at increasing distances downstream from the core, were available for the low-pressure input. Since the static pressures at the different sets were equal to one another, fully recovered pressures were believed to be present. The downstream taps closest to the core were arbitrarily chosen to measure core pressure drops. The upstream static taps were also used, together with barometric pressure, to determine the static air pressures at the core inlet.

Data acquisition for an experimental run required approximately 5 minutes after the system achieved equilibrium. The recorded data were punched on computer cards and reduced to final form by an IBM 360 digital computer.

Air heat losses in the heat exchanger core samples, other than through the coolant channel walls, were minimized. The exterior of the core sample, the headers, and the fittings were wrapped in blanket insulation. For the fin-tube core samples, both the tube to tube-sheet bond and the insulation of the tube-sheet were effected with a Silastic rubber sealant. During single-row heat transfer experiments, tubes in other rows were capped on both ends with rubber stoppers. This served to prevent those rows from affecting the heat transfer results. Longitudinal heat conduction in the coolant channel walls was estimated and found to be negligible. Heat losses during the experiments, when all the rows were in use, were estimated to be less than 1% of the heat transferred. Corresponding losses for single-row tests were estimated to be less than 3%. Values for the balances between air heat loss and water heat gain were normally within 10%.

Possible errors in the assumed thermophysical properties of air due to the presence of water vapor were investigated. For typical runs, the partial pressure of water vapor was calculated.² The effect of the subsequent humidity ratio³ on air properties⁴ was small and within the accuracy of the equations used for those air properties.

Most of the core samples were constructed entirely from aluminum. These cores were cleaned in a sulfuric acid solution⁵ before gaskets or other rubber sealants were attached to them. The water used in the experiments was distilled and had a corrosion inhibitor added to it. Periodically, the system was flushed and fresh water added.

Uniform air flow was maintained near the walls of the fin-tube core samples.⁶ Clearances equal to one-half a transverse tube spacing were left between the wall and end row for in-line tube arrangements. Half tubes were placed at the walls in alternate rows of staggered tube arrangements. The half tubes contributed to the core pressure drop but not to the core heat transfer.

DATA REDUCTION

METHOD OF PRESENTATION

A major objective of this report is to present basic design data for a variety of compact heat exchanger surfaces. A clear and consistent method of presentation has been outlined by Kays and London.⁷ Their method will be followed here. The heat transfer and flow friction characteristics of a surface are represented by Colburn j -factors and Fanning friction factors, respectively. These dimensionless terms are functions of the mass velocity, represented by the Reynolds number. The procedure for computing these parameters is presented in the following paragraphs. Sample calculations are given in appendix A.

DETERMINATION OF j

Heat transfer by combined conduction and convection is usually described^{8,9} by analogy with the flow of electricity through a series of resistances. Just as electrical current flows due to a voltage difference, so does heat flow due to a temperature difference. In a heat exchanger, the temperature difference is between a hot fluid and a cold fluid. An overall coefficient of heat transfer is commonly used to account for the series of thermal resistances in a heat exchanger. A heat transfer rate equation can be written as follows*:

$$q = UA_r(T_h - T_c) \quad (1)$$

where

$$\frac{1}{U} = R_h + R_{s_h} + R_w + R_c + R_{s_c} \quad (2)$$

$$R_h = \frac{1}{h_h} \frac{A_r}{A_h} \quad (3)$$

$$R_{s_h} = \frac{1}{h_{s_h}} \frac{A_r}{A_h} \quad (4)$$

*See Nomenclature in the front of the report.

$$R_w = \frac{t}{k_w} \frac{A_r}{A_w} \quad (5a)$$

for flat plates, or

$$R_w = \frac{r_o \ln(r_o/r_i)}{k_w} \frac{A_r}{A_o} \quad (5b)$$

for round tubes

$$R_c = \frac{1}{h_c} \frac{A_r}{A_c} \quad (6)$$

and

$$R_{s_c} = \frac{1}{h_{s_c}} \frac{A_r}{A_c} \quad (7)$$

Equation (1) is valid at only one particular point since one or both fluid temperatures are changing throughout the heat exchanger. Figure 3 shows the resulting axial temperature difference for a single-pass counterflow heat exchanger. (Most texts^{8,9} on heat transfer describe common types of heat exchangers and their associated fluid flow patterns.) The rate of heat flow varies throughout the exchanger because the temperature difference between the fluids changes.

Usually, fluid temperatures can be determined at only the inlet and outlet of the heat exchanger. It is therefore convenient to base the average effective temperature difference between the hot and cold fluids on these temperatures. For a true counterflow heat exchanger, that difference would be defined as the logarithmic mean temperature difference:

$$LMTD = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln\left(\frac{T_{h,in} - T_{c,out}}{T_{h,out} - T_{c,in}}\right)} \quad (8)$$

Most heat exchangers are more complicated than the simple counterflow model. Cross-flow exchangers having several tube or shell passes and a combination of mixed or unmixed flows are common. It is then necessary to modify the LMTD of equation (8) by a correction factor¹⁰ to obtain the true mean temperature difference:

$$\Delta T_{mean} = LMTD \times F \quad (9)$$

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Figure 3
TEMPERATURE VARIATION IN A SINGLE-PASS
COUNTERFLOW HEAT EXCHANGER

Equations (3) through (7) suggest that area ratios effect the individual heat transfer resistances. Extended surfaces in the form of fins are commonly used to artificially decrease the thermal resistance at one or both fluid surfaces. Using the definition of fin efficiency from appendix B and assuming a constant film coefficient, the heat transfer rate from a finned surface is as follows:

$$\begin{aligned}
 q &= \eta A_f h \Delta T_{\text{film}} + A_u h \Delta T_{\text{film}} \\
 &= \frac{\eta A_f + A_u}{A_t} A_t h \Delta T_{\text{film}} \\
 &= \epsilon A_t h \Delta T_{\text{film}}
 \end{aligned} \tag{10}$$

where $A_t = A_f + A_u$ and ϵ is called the weighted fin efficiency:

$$\epsilon = \frac{\eta A_f + A_u}{A_t} = \frac{\eta A_f + (A_t - A_f)}{A_t} = 1 - (1 - \eta) \frac{A_f}{A_t} \tag{11}$$

Equations (1) and (2) can be rewritten for a conventional heat exchanger as:

$$q = U A_r \text{LMTD } F \tag{12}$$

$$\frac{1}{U} = \frac{1}{\epsilon_h h_h} \frac{A_r}{A_h} + \frac{1}{\epsilon_h h_{s_h}} \frac{A_r}{A_h} + \frac{t}{k_w} \frac{A_r}{A_w} + \frac{1}{\epsilon_c h_{s_c}} \frac{A_r}{A_c} + \frac{1}{\epsilon_c h_c} \frac{A_r}{A_c} \tag{13}$$

Equations (12) and (13) were combined and simplified for the heat exchangers in this study. Since most of the core sample surfaces were new and clean, the scale resistance terms in equation (13) were assumed to be negligible. The overall coefficient U was always based upon the total hot side area: $A_r = A_h$. The equation for heat flow in the experimental heat exchangers reduced to:

$$\frac{A_h \text{LMTD } F}{q} = \frac{1}{\epsilon_h h_h} + \frac{t}{k_w} \frac{A_h}{A_w} + \frac{1}{\epsilon_c h_c} \frac{A_h}{A_c} \tag{14}$$

The heat transferred by the air while traversing the heat exchanger was computed using the equation

$$q = w c (T_{h, 1} - T_{h, 2}) \tag{15}$$

The form of the correlation used to calculate coolant film coefficients was given by McAdams:¹¹

$$Nu_c = B Re_c^{0.8} Pr_c^{0.4} \quad (16)$$

or

$$h_c = B \frac{k_c}{D_c} Re_c^{0.8} Pr_c^{0.4} \quad (17)$$

The constant B was determined for each core sample by a modified Wilson plot. This technique is discussed in appendix D.

For each experimental data run, the above relations were used to obtain a value for $\epsilon_h h_h$ from equation (14). Because ϵ_h is a function of h_h , an iterative procedure was necessary to determine the one value of h_h which, when combined with ϵ_h , gave the correct product $\epsilon_h h_h$.

The value for h_h was combined with several other parameters to form a dimensionless group that expressed the heat transfer characteristic of each surface. This combination of parameters is termed the Colburn j-factor:

$$j = \frac{h_h}{cG} Pr^{2/3} \quad (18)$$

where

$$G = w_h / A_{\min}$$

MEAN PROPERTIES

Unless specified otherwise, the air and water properties were evaluated at the mean temperatures of the fluids. This mean temperature was defined at the point in a counterflow heat exchanger which divided the exchanger into two sections, each having the same effectiveness, E' . The situation was then analogous to a two-pass exchanger.¹² The mean water temperature was computed using the relation

$$T_{c,mean} = \frac{\frac{C_c}{C_{\min}} T_{c,out} - E' T_{h,in}}{\frac{C_c}{C_{\min}} - E'} \quad (19)$$

where

$$E' = \frac{1 - \Gamma}{C_{\text{rat}} - \Gamma}$$

$$\Gamma = \left(\frac{1 - E C_{\text{rat}}}{1 - E} \right)^{1/2}$$

$$C_{\text{rat}} = C_{\text{min}}/C_{\text{max}}$$

$$E = \frac{T_{h,\text{in}} - T_{h,\text{out}}}{T_{h,\text{in}} - T_{c,\text{in}}}$$

The mean air temperature was found by interchanging the c and h subscripts in equation (19).

The mean specific volume of the air was calculated using the average core pressure. This pressure was the average between the core inlet and the core outlet static pressures.

REYNOLDS NUMBER CALCULATION

Reynolds numbers were calculated using the hydraulic diameter, defined as:

$$D = 4 \frac{A_{\text{min}}}{A_h} L \quad (20)$$

giving

$$\text{Re} = \frac{G D}{\mu} \quad (21)$$

DETERMINATION OF f

The dimensionless quantity which expresses the flow friction pressure drop for a surface is the Fanning friction factor:

$$f = \frac{\Delta P_{\text{friction}}}{\frac{4 L}{D} \frac{G^2 v_{\text{mean}}}{2 g_c}} \quad (22)$$

It was not possible to directly measure the flow friction pressure drop. Instead, the difference between upstream and downstream static pressures

was measured. This pressure difference included effects due to the core entrance, the core exit, and gas acceleration, as well as flow friction. Figure 4 shows the static pressure variation through the experimental system. Hence, the determination of $\Delta P_{\text{friction}}$ for use in equation (22) required that the other pressure drops be subtracted from ΔP_{total} .

$$\Delta P_{\text{total}} = P_1 - P_2 \quad (23)$$

$$= \Delta P_{\text{entrance}} + \Delta P_{\text{friction}} + \Delta P_{\text{acceleration}} + \Delta P_{\text{exit}}$$

where

$$\Delta P_{\text{entrance}} = \frac{G^2 v_1}{2g_c} (K_c + 1 - \sigma^2)$$

$$\Delta P_{\text{friction}} = 4 f \frac{L}{D} \frac{G^2 v_{\text{mean}}}{2g_c}$$

$$\Delta P_{\text{acceleration}} = \frac{G^2 v_1}{g_c} \left(\frac{v_2}{v_1} - 1 \right)$$

$$\Delta P_{\text{exit}} = \frac{-G^2 v_2}{2g_c} (1 - \sigma^2 - K_e)$$

Equation (23) can be rewritten in the form

$$\Delta P_{\text{total}} = \frac{G^2 v_1}{2g_c} \left[(K_c + 1 - \sigma^2) + 2 \left(\frac{v_2}{v_1} - 1 \right) + 4f \frac{L}{D} \frac{v_{\text{mean}}}{v_1} - (1 - \sigma^2 - K_e) \frac{v_2}{v_1} \right] \quad (24)$$

Solving equation (24) for f gives:

$$f = \frac{D}{4L} \frac{v_1}{v_{\text{mean}}} \left[\frac{2g_c \Delta P_{\text{total}}}{G^2 v_1} - (K_c + 1 - \sigma^2) - 2 \left(\frac{v_2}{v_1} - 1 \right) + (1 - \sigma^2 - K_e) \frac{v_2}{v_1} \right] \quad (25)$$

which is the relation used to compute the friction factors given in this report. The coefficients K_c and K_e , given in reference 13, corrected the pressure drops at the core entrance and exit for irreversible effects. For tube banks, these coefficients were set equal to zero as recommended in reference 7.

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Figure 4
AIR STATIC PRESSURE VARIATION
THROUGH EXPERIMENTAL SYSTEM

DATA RESULTS

Basic heat transfer and flow friction design data for eight compact surfaces are shown graphically in figures 5-12. Descriptions of the geometries accompany the graphs. The experimental data and results are tabulated in appendix E. Table 1 summarizes the types of heat transfer surfaces studied in this report.

Air friction factors that were determined from data runs with no water flow are shown on the graphs as *adiabatic data*. Actually, a small amount of heat transfer occurred during *adiabatic* runs, although much less than occurred during *heat transfer* runs. Most adiabatic friction factors agree well with the diabatic friction factors. This indicates that no appreciable temperature-dependent fluid property effects are present over the temperature range tested.

Unless otherwise indicated, the basic design data in figures 5-12 are for the entire core sample. The design data were computed neglecting effects due to entrance regions, fin-tube contact resistance, and scale resistance.

Table 1

SUMMARY OF HEAT TRANSFER SURFACES

Surface No.	Surface Description	Figure No.
1	Brazed aluminum, three-layer plate fin, offset fins	5
2	Brazed aluminum, two-layer plate fin, continuous fins	6
3	Aluminum plate, integral serrated fins	7
4	In-line aluminum tubes, integral serrated fins	8
5	Staggered aluminum tubes, integral serrated fins	9
6	Staggered aluminum tubes, integral helical fins	10
7	Staggered copper tubes, mechanically bonded aluminum plate fins	11
8	In-line copper tubes, mechanically bonded aluminum plate fins	12

FIN PITCH = 10.0 PER IN.
 PLATE SPACING = 1.204 IN..
 FIN LENGTH FLCW DIRECTION = 0.875"
 $\delta = 0.012$ IN.
 $A_f/A_t = 0.937$
 $D = 0.01184$ FT
 $\beta = 272.7$ FT²/FT³

NOTE: SFLITTER PLATES SYMMETRICALLY LOCATED.

Figure 5
SURFACE 1, BRAZED ALUMINUM PLATE-FIN

FIN PITCH = 9.0 PER IN.
 PLATE SPACING = 0.782 IN.
 FIN LENGTH FLOW DIRECTION = 8.75 IN.
 δ = 0.008 IN.
 A_f/A_t = 0.890
 D = 0.01342 FT
 β = 259.7 FT²/FT³

NOTE: SPLITTER PLATE AT SYMMETRIC LOCATION.

Figure 6

SURFACE 2, BRAZED ALUMINUM PLATE-FIN

FIN PITCH = 8.0 PER IN.
 PLATE SPACING = 1.115 IN.
 FIN LENGTH FLOW DIRECTION = 0.266 IN.
 $\delta = 0.017$ IN.
 $A_f/A_t = 0.891$
 $D = 0.02026$ FT
 $\beta = 170.4$ FT²/FT³

NOTE: FIN EDGES NOT INCLUDED IN HEAT TRANSFER AREA.

Figure 7
SURFACE 3, INTEGRAL PLATE-SERRATED FIN

TUBE O.D. = 0.505 IN.
 FIN PITCH = 10.0 PER IN.
 FIN WIDTH = 0.115 IN.
 δ = 0.02 IN.
 A_f/A_t = 0.834
 D = 0.07341 FT
 σ = 0.6749
 α = 36.77 FT²/FT³

NOTE: FIN EDGES NOT INCLUDED IN HEAT TRANSFER AREA.

Figure 8

SURFACE 4, INTEGRAL TUBE - SERRATED FIN

TUBE O.D. = 0.505 IN.
 FIN PITCH = 10.0 PER IN.
 FIN WIDTH = 0.115 IN.
 δ = 0.02 IN.
 A_f/A_t = 0.834
 D = 0.01899 FT
 σ = 0.4414
 α = 92.97 FT²/FT³

NOTE: FIN EDGES NOT INCLUDED IN HEAT TRANSFER AREA.

Figure 9

SURFACE 5, INTEGRAL TUBE - SERRATED FIN

TUBE O.D. = 0.63 IN.
 FIN PITCH = 9.0 PER IN.
 δ = 0.019 IN.
 A_f/A_t = 0.937
 D = 0.01780 FT
 σ = 0.5086
 α = 114.3 FT²/FT³

Figure 10
 SURFACE 6, INTEGRAL TUBE - HELICAL FIN

TUBE O.D. = 0.768 IN.
FIN PITCH = 9.43 PER IN.
 δ = 0.011 IN.
 A_f/A_t = 0.963
 D = 0.01084 FT
 σ = 0.5521
 α = 203.6 FT²/FT³

Figure 11
SURFACE 7, EXPANDED TUBE - CONTINUOUS FIN

Figure 12
SURFACE 8, EXPANDED TUBE - CONTINUOUS FIN

DISCUSSION

ANALYSIS OF RESULTS

It is generally recognized that heat transfer and momentum transfer are similar processes. Equations expressing that similarity have been derived. One widely used analogy between heat and momentum transfer is the formulation by Allan Colburn:¹⁴

$$j = \frac{f}{2} \quad (26)$$

Equation (26) is applicable to the limited number of situations where the following conditions are met: fully developed turbulent flow, viscous drag, and moderate fluid Prandtl number.

Except for the surface 2 core sample, all of the heat exchangers had interrupted gas-side surfaces. Thus, friction factors for the majority of geometries included shear force effects from form drag in addition to viscous drag. The anticipated result would be an increase in the friction factor relative to the j -factor so that $j < f/2$. This was the observed result. At the higher Reynolds numbers, figure 6 indicates that the j -factors for surface 2 approximate the limiting value of $f/2$. (Based on data results from similar geometries,⁷ the slope of a j -curve through the figure 6 data would probably become more negative if the Reynolds number were increased above the values shown.)

Physically, the ratio j/f is related to the frontal area of a heat exchanger design. Since core velocity varies as the square root of this ratio,⁷ a large j/f would permit a smaller free flow area, hence, a smaller frontal area. For instance, use of surface 2 would probably result in a smaller heat exchanger frontal area than would the use of, say, surface 3.

Comparative performances of compact surfaces are often illustrated^{7,22} by plotting their standardized heat transfer coefficients versus standardized power expenditures. The higher curves on this type plot are usually indicative of high-performance surfaces. Comparisons of the geometries listed in table 1 are shown in figures 13 and 14. Figure 13 is based on a square foot of surface heat transfer area. Figure 14 is based on a cubic foot of heat exchanger volume. Several comments should be made about these curves. First, the equations used are from appendix C with thermophysical properties evaluated for dry air at 500°F and 1 atm. Second, performance curves for the plate-fin geometries, surfaces 1, 2, and 3, shown in figure 14, do not include the water-side volume; the tubed surfaces do. This is because the two fluid sides are independent of each other for plate-fin geometries. This is not true for the tube geometries. Thus, the plate-fin surfaces appear higher, by approximately 15%, than they really should for the volumetric comparison. Third, the performance lines of surface 8 are based on Paducah Gaseous Diffusion Plant j -factors. Reasons for this are discussed below.

Figure 13 indicates that higher heat transfer coefficients are obtainable with the interrupted surfaces. Heat transfer rates are often decreased by the formation of thick boundary layers on a surface. Surface interruptions can minimize boundary layer growth and improve the rate of

Figure 13

SURFACE COMPARISONS BASED ON
A UNIT OF SURFACE AREA

Figure 14

SURFACE COMPARISONS BASED ON
A UNIT OF HEAT EXCHANGER VOLUME

heat transfer. Figure 14 indicates that higher volumetric heat transfer coefficients are obtainable with high surface area densities. Also shown in figure 14, interrupted surface 3 is superior to smooth surface 2 over a limited range of pumping powers despite the latter's larger surface area density. The attractiveness of surface 3 is greatest at the lower values of pumping power expenditure. This corresponds to lower core velocities. To maintain a specified mass throughput, a lower velocity must be accompanied by a higher free flow area. Hence, a larger heat exchanger frontal area would probably be used with surface 3. This was anticipated from the above discussion on j/f ratios.

One shortcoming of plots such as figures 13 and 14 is that, while they indicate heat transfer coefficients, they do not directly indicate heat transfer rates. The rate of heat transfer is determined from equation (10) which includes the important fin efficiency term. Low fin efficiencies can destroy any advantage that a high heat transfer coefficient might have given a surface. A high fin density is often desirable, but the larger the fin the lower the fin efficiency.

Perhaps a more vivid comparison of finned tube performance is possible by examining their *efficiencies*. Designating surface 8 the reference standard, figures 15 and 16 depict the surface and volumetric efficiencies of surfaces 4 to 8. By definition, the *surface area efficiency* of a tube bank was the ratio of its heat transfer rate to the surface 8 heat transfer rate at equal pumping powers and equal gas-side surface areas. By definition, the *volumetric efficiency* of a tube bank was the ratio of its heat transfer rate to the surface 8 heat transfer rate at equal pumping powers and equal total exchanger volumes. Details are given in appendix C.

Because of their low fin efficiencies, the apparent volumetric attractiveness of fin-tube surfaces 7 and 8 disappears when the curves of figure 14 are transformed to those of figure 16. It should be emphasized that comparisons such as figure 16 are dependent upon both the fluid and the fin material. For example, the plate-finned tubes would probably appear more attractive when used in conjunction with poorer heat transfer gases than air. This is because the lower heat transfer coefficient results in an increased fin efficiency.

In addition to having relatively high heat transfer coefficients, surface geometries 4 and 5 have small fins that are very efficient. As a result, these tubes are attractive, especially when placed in a close-packed arrangement. This is evident in figure 15 where, for equal amounts of surface area and equal pumping powers, surface 5 might transfer three to four times as much heat as surface 8. Alternately, for a given heat load, much less of surface 5 would be required. Figure 16 indicates that a smaller volume would be required if surface 5 were used instead of surface 8. These efficiency curves are oversimplified in that they are based upon equations that neglect heat exchanger dimensions. Restrictions on the

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Figure 15
SURFACE EFFICIENCIES OF TUBE AND FIN SURFACES

Figure 16
VOLUMETRIC EFFICIENCIES OF TUBE AND FIN SURFACES

frontal area and/or depth of the exchanger could change the results somewhat.

Figures 13 through 16 show the improvement in performance possible by changing the tube pitch of surface 4 to that of surface 5. More information is needed to determine the effects of other pitches on finned tube performance in general.

Heat transfer coefficients increase with distance through a tube bank when the tubes are in a staggered arrangement.¹⁵ This variation must be accounted for when designing a heat exchanger with a finite number of tube rows. All results in figures 5, 6, 7, 8, 9, 11, and 12 are average values for the entire core samples. Mean j -factor values for the first few rows of surface 6 are shown in figure 10. Heat transfer was fully developed at the fourth row of the eight-row core sample. The influence of row-to-row heat transfer is compared with the bare-tube results of reference 15 in figure 17. The row-to-row variations appear to be less pronounced for finned tubes than for bare tubes. However, the difference indicated in figure 17 is within the accuracy claimed for results in this report.

COMMENTS

The uncertainties in the data results were determined as follows. Input parameters to the data reduction code were either measured or calculated. Thus, each value for a dimension, manometer reading, etc., had an associated uncertainty or *error band*. Such a band was assigned to all input parameters, the independent variables. The standard deviations of the dependent variables f and j were then determined by Monte Carlo techniques: random values within each independent variable's error band were used to calculate f and j thousands of times. Standard deviations varied with Reynolds number and from one core sample to another. However, the maximum standard deviations were 6% for j and 4% for f .

As mentioned previously, scale resistance was neglected for data reduction purposes. Also, no fouling effects were assumed when determining standard deviations for j . Most core samples were new and clean prior to the experiments. It was felt that if fouling were to become significant, the effects would show up as shifts in j -curves when data points were repeated. This apparently occurred to a measurable extent in figure 5. However, uncertainties due to fouling were greatest when the ratio of air to water surface areas was large. This was expressed in equation (13). Surface 8 had a large area ratio plus badly fouled tube insides. Fortunately, when this core sample was new, extensive heat transfer data had been taken with it at the Paducah Gaseous Diffusion Plant. Paducah's data were used in determining the j -factors shown in figure 12. The uncertainties in j for surfaces 1 and 8 are considerably higher than the 6% standard deviation mentioned above. More tests are planned with these surfaces after the heat exchangers are cleaned.

Figure 17
INFLUENCE OF ROW-TO-ROW VARIATIONS
ON TUBE BANK HEAT TRANSFER

Two heat exchanger core samples with the air-side surface depicted in figure 6 were tested. Experimental j -factors for the two cores were essentially the same, but the friction factors differed. This difference could have been the result of brazing roughness and/or instrument error. Also, because a low pressure drop was characteristic of this geometry, the expansion and contraction coefficients used in equation (25) were quite significant in determining f . The core sample whose f and j data are plotted in figure 6 suddenly developed stopped-up water passages after several data runs.

Over the midrange of experimental Reynolds numbers, surface 5 emitted a high-frequency whistling noise. Visual observations of the core during the whistling indicated no excessive tube vibrations or other irregularities. No irregularities were noted in the experimental data either. Earlier tests with a different fin-tube surface had resulted in a similar high-frequency noise accompanied by core sample vibrations. Experimental data for those tests exhibited much scatter. It was felt that the peculiar behavior was probably due to natural frequency of vibration effects. Excessive vibrations could result in severe structural problems with full-sized heat exchangers.

CONCLUSIONS

1. A comprehensive method for obtaining and reducing experimental data is described. The method is valid for a variety of compact heat exchanger geometries.
2. Basic heat transfer and flow friction design data are presented for eight compact surfaces in figures 5 through 12 and appendix E. Most of these surfaces are commercially available.
3. Methods for comparing the simultaneous heat transfer and pumping power performances of compact surfaces are described. Figures 13 through 16 illustrate the methods using the equations derived in appendix C. The attractiveness of a surface depends upon the particular application.
4. Integral fin-and-tube geometries are attractive for applications where surface area and pumping power are to be minimized. These geometries are especially attractive when the fins are serrated.
5. Designers should be continually aware of possible vibrational effects on compact heat exchangers. Excessive vibrations could result in severe structural problems.
6. The effects that tube pitch has on fin-tube performance have not been adequately determined. Experiments with additional fin-tube pitches should therefore be conducted.
7. The heat removal systems for gaseous diffusion plants must be designed from the surface performance data that are available at design time. Since new surfaces and new arrangements of previously tested surfaces

are continually being developed, it is important that an up-to-date library of design data be maintained. The aim of the continuing program described in this report is to generate such a library.

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APPENDIX A

Sample Calculations

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APPENDIX A

SAMPLE CALCULATIONS

As an example of the data reduction method, a calculation for surface 3, run 6, is presented in the following paragraphs. Data are available from figure 7 and appendix E.

Using a *petal* area of 0.2345 sq in., the geometric quantities can be determined:

$$D = \frac{4 (0.125 \times 1.115/2 - 0.017 \times 0.563) \frac{0.266}{12}}{0.2345 + (0.125 - 0.017) \frac{0.266}{12}} = 0.02026 \text{ ft}$$

$$\beta = \frac{0.2345 + (0.125 - 0.017) \frac{0.266}{12}}{0.125 \times 0.266 \times 1.115/2} \times \frac{1728}{144} = 170.4 \text{ sq ft/cu ft}$$

$$\frac{A_f}{A_t} = \frac{0.2345}{0.2345 + (0.125 - 0.017) \frac{0.266}{12}} = 0.891$$

Using equations (15) and (21),

$$q = 229 \times 0.241 (644.6 - 592.2) = 2900 \text{ Btu/min}$$

and

$$Re = \frac{229 \times 60 \frac{0.02026}{0.8017}}{0.04915} = 7060$$

From appendix D, $B = 0.0211$. Equation (17) gives

$$h_c = 0.0211 \times \frac{0.370}{0.01274} \times (12,015)^{0.8} (3.983)^{0.4} = 1955 \text{ Btu/hr-sq ft-}^\circ\text{F}$$

The LMTD is calculated from equation (8) as

$$LMTD = \frac{(644.6 - 572.0) - (592.2 - 570.4)}{\ln \left(\frac{644.6 - 572.0}{592.2 - 570.4} \right)} = 42.23^\circ\text{F}$$

The water-side surface efficiency is determined from equations (11) and (B-4) with $A_f/A_t = 0.335$,

$$\epsilon_c = 1 - (1 - 0.9054) 0.335 = 0.968$$

Equation (14) can now be solved for $\epsilon_h h_h$:

$$\frac{1}{\epsilon_h h_h} = \frac{174.1 \times 42.23 \times 0.962}{2900 \times 60} - \frac{0.00292}{96} \frac{174.1}{24.05} - \frac{1}{0.968 \times 1955} \frac{174.1}{28.0}$$

giving

$$\epsilon_h h_h = 26.92 \text{ Btu/hr-sq ft-}^\circ\text{F}$$

One must *guess* $\epsilon_h = 0.772$, calculate h_h , and then check to see if the initial guess was a good one.

$$h_h = \frac{26.92}{0.772} = 34.9 \text{ Btu/hr-sq ft-}^\circ\text{F}$$

$$\eta_h = \frac{\tanh(1.062)}{1.062} = 0.741$$

$$\epsilon_h = 1 - (1 - 0.741) 0.891 = 0.77$$

This value of ϵ_h is close to the original guess, so h_h is known. From equation (18),

$$j = \frac{34.9}{0.241 \times 17,000} (0.70)^{2/3} = 0.0067$$

Friction factors are computed directly from equation (25). Assuming ideal gas behavior,

$$f \approx \frac{0.02026}{4 \times 1.094} \frac{16.44}{15.57} \left[\frac{2 \times 32.2 \times 4.202 \times 0.03613 \times 144}{(4.75)^2 \times 16.44} \right. \\ \left. - (0.18 + 1 - 0.548) \right. \\ \left. - 2 \left(\frac{15.10}{16.44} - 1 \right) \right. \\ \left. + (1 - 0.548 - 0.07) \frac{15.10}{16.44} \right]$$

$$f \approx 0.0180.$$

APPENDIX B

Fin Efficiency

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APPENDIX B

FIN EFFICIENCY

Expressions for fin efficiencies used in equation (11) are given in this appendix. For simple geometries such as straight rectangular fins, circular rectangular fins, etc., fin efficiency equations are available.¹⁶ The general one-dimensional heat conduction equation is discussed by Schneider.¹⁷ Using his presentation as a starting point, an equation is derived for the efficiency of a four-layer sandwich matrix.

Figure B-1(a) shows the model considered: a compact surface with four sandwich layers between the coolant channels and straight rectangular fins. Because of symmetry about the middle splitter plate and the repetitive fin geometry, the problem reduces to finding the efficiency of one fin composed of six segments. This is shown in figure B-1(b). The following assumptions are made in the analysis.

1. Steady-state heat flow is established throughout the fin.
2. The fluid temperature is everywhere uniform.
3. The thickness of each fin segment is constant, although not necessarily equal to the thickness of any other segment.
4. The heat transfer coefficient is uniform over the entire fin surface.
5. Each segment of the fin has a thickness that is small compared to its length.
6. The thermal conductivity of all segments is constant and equal.
7. Contact resistance between fin segments is negligible.
8. The temperature at the fin base is uniform.

Using these assumptions, the equation for one-dimensional heat conduction in each fin segment is as follows:

$$\frac{d^2\theta}{dx^2} - m^2\theta = 0 \quad (B-1)$$

where

$$\theta = \frac{T - T_{\text{base}}}{T_w - T_{\text{base}}}$$

$$m = \sqrt{\frac{2h}{k\delta}}$$

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(a) Four Sandwich Compact Surface

(b) Six Segment Fin

Figure B-1
FIN EFFICIENCY MODELS

Equation B-1 has solutions of the form

$$\theta = C_1 e^{mx} + C_2 e^{-mx} \quad (\text{B-2})$$

where C_1 and C_2 are constants to be determined by the boundary conditions of each segment, and x is the longitudinal distance from the base of the segment. The boundary conditions are:

$$\text{Segment 1: } \theta = 1 \text{ at } x = 0$$

$$-k\delta_1 \frac{dT}{dx} = q_1 \text{ at } x = \ell_1$$

where

$$q_1 = q_2 + q_3 + q_4$$

$$= \sum_{2,3,4} -k\delta_1 \left. \frac{dT}{dx_i} \right|_{x_i} = 0$$

$$\text{Segments 2, 4, 5, 6: } \theta = 1 \text{ at } x_i = 0$$

$$\left. \frac{d\theta_i}{dx_i} \right|_{x_i} = 0 \text{ at } x_i = \ell_i$$

$$\text{Segment 3: } \theta_3 = 1 \text{ at } x = 0$$

$$-k\delta_3 \frac{dT}{dx} = q_3 \text{ at } x = \ell_3$$

where

$$q_3 = q_5 + q_6$$

$$= \sum_{5,6} -k\delta_1 \left. \frac{dT}{dx_i} \right|_{x_i} = 0$$

The fin efficiency, η , is defined as the ratio of the heat removed from the fin to the heat removed from an isothermal fin at the base temperature. The final form of η for the four-layer sandwich matrix is as follows:

$$\eta = \frac{1}{m_1 (\ell_1 + \ell_2 + \ell_3 + \ell_4 + \frac{\ell_5}{2} + \frac{\ell_6}{2})} \left[\tanh(m_1 \ell_1) + \frac{1}{[\cosh(m_1 \ell_1)]^2} \right. \\ \frac{[B_2 + B_3 + B_4] [\cosh(m_3 \ell_3)]^2 [\delta_3 m_3 + \frac{(B_5 + B_6)}{2} \tanh(m_3 \ell_3)]}{\delta_1 m_1 [\cosh(m_3 \ell_3)]^2 [\delta_3 m_3 + \frac{B_5 + B_6}{2} \tanh(m_3 \ell_3)] + \{[B_2 + B_3 + B_4] \\ + \delta_3 m_3 \frac{(B_5 + B_6)}{2}\}} \\ \left. \frac{[\cosh(m_3 \ell_3)]^2 [\delta_3 m_3 + \frac{B_5 + B_6}{2} \tanh(m_3 \ell_3)] + \delta_3 m_3 \frac{(B_5 + B_6)}{2}}{[\cosh(m_3 \ell_3)]^2 [\delta_3 m_3 + \frac{B_5 + B_6}{2} \tanh(m_3 \ell_3)] + \delta_3 m_3 \frac{(B_5 + B_6)}{2}} \tanh(m_1 \ell_1) \right] \quad (B-3)$$

where

ℓ_i = length of segment i

$B_i = \delta_i m_i \tanh(m_i \ell_i)$

$m_i = \sqrt{\frac{2h}{k\delta_i}}$

Equation B-3 is applicable to rectangular or triangular matrices of one, two, three, or four layers. For example, by setting $\ell_4 = \ell_5 = \ell_6 = 0$, equation B-3 can be used to determine the efficiency of a triangular three-layer sandwich matrix with symmetry about the middle sandwich. If $\ell_2 = \ell_3 = \ell_4 = \ell_5 = \ell_6 = 0$, then it reduces to the well-known relation for a straight rectangular fin:

$$\eta = \frac{\tanh(m_1 \ell_1)}{m_1 \ell_1} \quad (B-4)$$

Gardner's fin efficiency equation¹⁶ was used for annular fins:

$$\eta = \frac{2}{U_b [1 - (\frac{U_e}{U_b})^2]} \left[\frac{I_1(U_b) - \beta K_1(U_b)}{I_0(U_b) + \beta K_0(U_b)} \right] \quad (B-5)$$

where

$$\beta = \frac{I_1(U_e)}{K_1(U_e)}$$

$$U_b = \frac{m(r_f - r_o)}{\frac{r_f}{r_o} - 1}$$

$$U_e = U_b \frac{r_f}{r_o}$$

Analytical and numerical solutions for the fin efficiencies of square and rectangular fins on round tubes have been reported.¹⁸⁻²⁰ Also, the errors resulting from assuming one-dimensional radial heat flow when computing annular fin efficiencies were studied.²¹ Using the results of these studies, it was deemed permissible to assume that the fins of surfaces 7 and 8 were annular.

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APPENDIX C

Performance Equations

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APPENDIX C

PERFORMANCE EQUATIONS

The overall performance of a compact surface depends upon its heat transfer rate relative to the mechanical power required to overcome fluid flow friction. Methods for comparing the performance of various surfaces have been presented in the literature.^{7,22,23} The following is similar to the development of Mitskevich.²⁴

Over some arbitrarily small Reynolds number range, graphs of f and j versus Re are straight lines for logarithmic coordinates. Thus,

$$f = a Re^m \quad (C-1)$$

$$j = b Re^n \quad (C-2)$$

$$St = j Pr^{-2/3} = b Re^n Pr^p \quad (C-3)$$

where $p = -2/3$ in this study, and a, b, m, n are constants.

$$St = \frac{h}{cG} = \frac{q}{\epsilon A_h \Delta T_{film}} \frac{A_{min} \Delta T_{bulk}}{q} = \frac{A_{min} \Delta T_{bulk}}{\epsilon A_h \Delta T_{film}}$$

The heat transfer rate per unit volume is

$$\begin{aligned} q''' &= \frac{wc \Delta T_{bulk}}{A_{front} L} = \frac{G A_{min} c \epsilon St A_h \Delta T_{film}}{A_{front} L A_{min}} \\ &= \frac{\epsilon^4 \sigma b k}{D^2} Re^{n+1} Pr^{p+1} \Delta T_{film} \end{aligned}$$

or, in terms of a standard volumetric heat transfer coefficient,

$$h''' = \frac{q'''}{\epsilon \Delta T_{film}} = \frac{4 \sigma b k}{D^2} Re^{n+1} Pr^{p+1} \quad (C-4)$$

Similarly, for a unit of surface area:

$$q'' = \frac{\epsilon b k}{D} Re^{n+1} Pr^{p+1} \Delta T_{film}$$

and

$$h'' = \frac{q''}{\epsilon \Delta T_{film}} = \frac{b k}{D} Re^{n+1} Pr^{p+1} \quad (C-5)$$

Ignoring compressibility, the pumping power required to overcome fluid friction can be written as

$$\begin{aligned} W &= \Delta P A_{\min} V \\ &= 4f \frac{L}{D} \frac{\rho V^2}{2} A_{\min} V \\ &= \frac{2L A_{\min} \mu^3 a \text{Re}^{m+3}}{D^4 \rho^2} \end{aligned}$$

The pumping power per unit volume is

$$E''' = \frac{W}{A_{\text{front}} L} = \frac{2\sigma \mu^3 a \text{Re}^{m+3}}{D^4 \rho^2} \quad (\text{C-6})$$

and the pumping power per unit of surface area is

$$E'' = \frac{W}{A_h} = \frac{\mu^3 a}{2D^3 \rho^2} \text{Re}^{m+3} \quad (\text{C-7})$$

For two different systems, the ratio of heat transfer rates can now be calculated at equal pumping powers per unit volume. Denoting one system as the standard, subscripted "0", this ratio represents a volumetric efficiency. Setting $E''' = E_0'''$,

$$\frac{2\sigma \mu^3 a \text{Re}^{m+3}}{D^4 \rho^2} = \frac{2\sigma_0 \mu_0^3 a_0 \text{Re}_0^{m_0+3}}{D_0^4 \rho_0^2}$$

Thus, at equal pumping powers, the Reynolds number of two systems are related by the expression

$$\text{Re} = \left[\left(\frac{\sigma}{\sigma_0} \right) \left(\frac{D}{D_0} \right)^4 \left(\frac{\mu_0}{\mu} \right)^3 \left(\frac{\rho}{\rho_0} \right)^2 \left(\frac{a_0}{a} \right) \right]^{1/(m+3)} \text{Re}_0^{(m_0+3)/(m+3)}$$

The volumetric efficiency is

$$\eta''' = \frac{q'''}{q_0'''} = \eta_1 \eta_2 \eta_3 \frac{\Delta T_{\text{film}}}{\Delta T_{\text{film},0}} \frac{\epsilon}{\epsilon_0} \quad (\text{C-8})$$

where

$$\eta_1 = \left(\frac{\sigma_o}{\sigma}\right)^{(n+1)/(m+3)-1} \left(\frac{D}{D_o}\right)^{4(n+1)/(m+3)-2} \quad (C-8a)$$

$$\eta_2 = \left(\frac{b}{b_o}\right) \left(\frac{a_o}{a}\right)^{(n+1)/(m+3)} Re_o^{(m_o+3)(n+1)/(m+3) - (n_o+1)} \quad (C-8b)$$

$$\eta_3 = \frac{k}{k_o} \left[\left(\frac{\mu_o}{\mu}\right)^3 \left(\frac{\rho}{\rho_o}\right)^2 \right]^{(n+1)/(m+3)} \frac{Pr_o^{p+1}}{Pr_o^p + 1} \quad (C-8c)$$

In a like manner, the ratio of heat transfer rates for two systems can be calculated at equal pumping powers per unit surface area. This ratio defines a surface area efficiency. The two Reynolds numbers are related by

$$Re = \left[\left(\frac{D}{D_o}\right)^3 \left(\frac{\mu_o}{\mu}\right)^3 \left(\frac{\rho}{\rho_o}\right)^2 \left(\frac{a_o}{a}\right) \right]^{1/(m+3)} Re_o^{(m_o+3)/(m+3)}$$

The surface area efficiency is

$$\eta'' = \frac{q'''}{q_o'''} = \eta_4 \eta_5 \eta_6 \frac{\Delta T_{film}}{\Delta T_{film,o}} \frac{\epsilon}{\epsilon_o} \quad (C-9)$$

where

$$\eta_4 = \left(\frac{D}{D_o}\right)^3 (n+1)/(m+3)^{-1} \quad (C-9a)$$

$$\eta_5 = \left(\frac{b}{b_o}\right) \left(\frac{a_o}{a}\right)^{(n+1)/(m+3)} Re_o^{(m_o+3)(n+1)/(m+3) - (n_o+1)} \quad (C-9b)$$

$$\eta_6 = \frac{k}{k_o} \left[\left(\frac{\mu_o}{\mu}\right)^3 \left(\frac{\rho}{\rho_o}\right)^2 \right]^{(n+1)/(m+3)} \frac{Pr_o^{p+1}}{Pr_o^p + 1} \quad (C-9c)$$

Surface comparisons with equations C-8 and C-9 permit evaluation of the separate effects that contribute to the total amount of heat transferred. Terms η_1 and η_4 represent the effect of geometry; η_2 and η_5 represent the effect of flow turbulence; η_3 and η_6 show thermal property influence on system performance. As demonstrated by Mitskevich, these latter terms can be used to compare system performance for identical surfaces but different working fluids.

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APPENDIX D

Modified Wilson Plot

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APPENDIX D

MODIFIED WILSON PLOT

In developing heat transfer correlations for the surfaces studied, it was necessary to first separate the water-side and wall components from the overall thermal resistance. The wall resistance was essentially constant and could be determined from equation (5). During turbulent flow, the water resistance varied with h_c as indicated by equations (6) and (17). A technique, known as a Wilson plot²⁵ or a modified Wilson plot²⁶, was used to determine the constant B in equation (17).

Noting that

$$\epsilon_h h_h = \frac{\epsilon_h j_c G}{Pr^{2/3}} = \psi (Re_h, T_h)$$

$$\frac{1}{\epsilon_c h_c} \frac{A_h}{A_c} = \left(\frac{1}{h_c} + R_f \right) \frac{A_h}{A_c} = \psi' (Re_c, T_c)$$

$$R_f = \frac{1/\epsilon_c - 1}{h_c}$$

the following heat transfer rate equation can be written:

$$\frac{1}{U} = \frac{1}{\psi} + R_w + R_f \frac{A_h}{A_c} + \frac{1}{B \frac{k_c}{D_c} Re_c^{0.8} Pr_c^{0.4}} \frac{A_h}{A_c} \quad (D-1)$$

Equation D-1 can be rewritten as:

$$\left(\frac{1}{U} - R_f \frac{A_h}{A_c} \right) = \left(\frac{1}{\psi} + R_w \right) + \frac{1}{B} \left(\frac{A_h/A_c}{\frac{k_c}{D_c} Re_c^{0.8} Pr_c^{0.4}} \right) \quad (D-2)$$

If Re_h and T_h are held constant while Re_c is varied, equation (D-2) plots as a straight line with slope $1/B$. An example using surface 3, appendix E, data is shown in figure D-1. For unfinned coolant passages, $R_f = 0$. For finned coolant passages, R_f is a function of h_c , hence of B. For the latter case, an iterative procedure must be employed to determine B.

DWG. NO. G-72-355

$T_h(^{\circ}R)$	Re_h	Re_c	$T_c(^{\circ}R)$	X-AXIS	Y-AXIS
609.4	5766	10685	571.2	0.0000738	0.045781
609.0	5769	11551	571.2	0.0000694	0.045584
609.1	5776	13154	571.7	0.0000626	0.045276
608.9	5775	14989	571.7	0.0000564	0.044979
608.6	5798	18172	571.6	0.0000483	0.044510
608.7	5785	21694	571.9	0.0000420	0.044286
608.8	5786	26718	572.2	0.0000356	0.044002

Figure D-1
MODIFIED WILSON PLOT FOR
THE COOLANT SIDE OF SURFACE 3

APPENDIX E

Geometric and Experimental Data

This Appendix consists of tables E-1 and E-2 and computer printout data for Surfaces 1 through 8.

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Table E-1
CORE SAMPLE GEOMETRIC DATA

	Surface Number							
	1	2	3	4	5	6	7	8
k_f , Btu/hr-ft-°F	119	119	96	96	96	91.7	119	119
k_w , Btu/hr-ft-°F	119	119	96	96	96	91.7	223	218
L_h , ft	0.667	0.896	1.094	2.415	1.094	1.167	1.0833	1.310
L_c , ft	1.45	0.896	1.0	1.5	1.0	0.99	3.0	1.0
$A_{min, h}$, sq ft	1.353	0.661	0.802	1.413	0.480	0.531	1.242	0.473
$A_{min, c}$, sq ft	0.0815	0.0754	0.0892	0.169	0.144	0.0975	0.094	0.1194
A_h , sq ft	268	143	174	186	104	129	495	315
A_c , sq ft	69.4	53.0	28.0	30.1	17.1	8.49	19.0	7.25
A_w , sq ft	14.0	17.0	24.05	37.5	21.3	9.79	20.5	8.60
A_{front} , sq ft	2.081	0.952	1.083	2.094	1.083	1.042	2.25	0.969
t , ft	0.0027	0.00367	0.00292	0.00464	0.00464	0.00376	0.00242	0.0067
No. Rows Wide	-	-	-	9	12	8	9	5
No. Rows Deep	-	-	-	21	14	8	8	7
No. Coolant Passes	1	1	1	1	1	1	2	1
Coolant Fins/in.	15	18	3.8	-	-	-	-	-
Coolant Fin Length, ft	0.0167	0.0125	0.00958	-	-	-	-	-
Coolant Fin Thickness, ft	0.00133	0.00133	0.00292	-	-	-	-	-

GEOMETRIC AND EXPERIMENTAL DATA

APPENDIX E

Table E-2

SURFACE NO. 8 j-VALUES FROM
PADUCAH GASEOUS DIFFUSION PLANT DATA

<u>Re</u>	<u>j</u>	<u>Re</u>	<u>j</u>
3617	0.00332	3663	0.00317
3032	0.00319	4201	0.00324
4080	0.00308	5442	0.00280
5857	0.00280	5967	0.00276
5056	0.00292	4205	0.00315
4440	0.00305	5392	0.00289
3051	0.00317	1887	0.00348
3733	0.00323	5953	0.00269
3356	0.00328	4842	0.00288
2902	0.00331	4814	0.00276
2558	0.00328	4765	0.00329
2264	0.00327	4837	0.00280
2506	0.00331	4865	0.00288
1820	0.00326	4943	0.00289
2382	0.00326	4647	0.00304
3070	0.00327	4631	0.00308
3585	0.00323	4605	0.00309

SURFACE ONE

RUN	AIR IN DEG R	AIR OUT DEG R	H2O IN DEG R	H2O OUT DEG R	AIR MEAN PRESSURE PSFA	CORE DP IN. H2O	AIR FLOW SCFM	WATER FLOW GPM	HEAT TRANSFER BTU/MIN	AIR HEAT TRANSFER COEFF. BTU/HR FT F	AIR REYNOLDS NUMBER	F	J
1.	674.0	606.8	565.7	572.4	2184.	2.064	3704.	80.3	4588.0	24.66	2944.	0.01531	0.00642
2.	673.8	609.1	565.5	572.5	2192.	2.380	4034.	80.3	4812.0	25.56	3200.	0.01484	0.00611
3.	640.6	595.2	569.9	572.3	2174.	1.871	3557.	159.7	2975.0	22.79	2899.	0.01532	0.00619
4.	642.3	594.8	570.1	572.3	2129.	1.786	3413.	176.4	2989.0	22.64	2782.	0.01558	0.00641
5.	641.3	594.8	569.8	572.2	2129.	1.785	3409.	148.4	2922.0	22.34	2779.	0.01562	0.00633
6.	641.2	595.1	569.9	572.6	2129.	1.785	3415.	129.6	2902.0	22.35	2783.	0.01554	0.00632
7.	641.0	595.1	568.9	572.3	2129.	1.785	3412.	98.9	2885.0	22.29	2780.	0.01556	0.00631
8.	640.4	595.4	567.3	572.5	2130.	1.785	3413.	61.8	2831.0	22.38	2779.	0.01555	0.00633
9.	639.4	595.8	562.7	572.4	2130.	1.782	3404.	30.7	2732.0	22.46	2769.	0.01557	0.00637
10.	639.2	599.4	567.1	572.2	2246.	3.843	5431.	91.8	3985.0	32.90	4409.	0.01368	0.00585
11.	639.7	597.6	567.7	572.3	2197.	3.000	4671.	91.8	3623.0	29.74	3797.	0.01423	0.00615
12.	641.1	595.5	568.1	572.2	2157.	2.202	3892.	91.8	3272.0	26.33	3168.	0.01489	0.00654
13.	642.9	594.6	568.6	572.4	2139.	1.802	3455.	91.8	3074.0	24.33	2814.	0.01541	0.00680
14.	644.0	593.2	568.5	572.2	2127.	1.494	3082.	91.8	2884.0	22.55	2513.	0.01605	0.00707
15.	645.2	591.7	568.9	572.3	2115.	1.198	2694.	91.8	2654.0	20.70	2199.	0.01666	0.00743
16.	648.8	589.8	569.4	572.3	2104.	0.901	2240.	91.8	2435.0	18.76	1831.	0.01842	0.00809
17.	641.5	596.8	567.8	572.2	2274.	2.457	4263.	92.2	3513.0	28.16	3466.	0.01453	0.00638
18.	642.1	595.8	568.2	572.3	2229.	2.090	3823.	92.2	3263.0	25.83	3111.	0.01515	0.00653
19.	642.5	594.5	568.1	572.1	2200.	1.802	3497.	92.2	3121.0	24.53	2848.	0.01547	0.00678
20.	643.6	592.9	568.6	572.1	2171.	1.495	3108.	92.2	2901.0	22.98	2535.	0.01614	0.00714
21.	644.5	591.8	568.5	572.0	2151.	1.252	2784.	92.2	2724.0	21.20	2272.	0.01677	0.00736
22.	645.9	589.9	569.2	572.2	2131.	0.970	2364.	92.2	2436.0	19.17	1934.	0.01799	0.00784
23.	649.4	585.7	570.0	572.4	2105.	0.590	2054.	92.2	2413.0	21.27	1689.	0.01427	0.01001
24.	651.6	581.8	570.4	572.4	2094.	0.400	1252.	92.2	1611.0	14.07	1035.	0.02700	0.01088
25.	641.3	596.7	567.9	572.0	2282.	2.473	4274.	93.4	3514.0	28.26	3475.	0.01461	0.00639

26.	642.0	595.6	568.3	572.4	2236.	2.104	3853.	93.4	3296.0	26.42	3136.	0.01506	0.00662
27.	643.6	594.7	568.5	572.2	2205.	1.803	3501.	93.4	3153.0	24.84	2850.	0.01548	0.00686
28.	644.0	593.1	568.6	572.1	2175.	1.491	3102.	93.4	2910.0	22.86	2530.	0.01618	0.00712
29.	644.7	591.9	568.9	572.2	2155.	1.240	2761.	93.4	2689.0	21.02	2254.	0.01693	0.00736
30.	644.2	590.0	569.5	572.0	2146.	1.002	2414.	93.4	2413.0	19.34	1976.	0.01794	0.00774
31.	645.5	585.2	569.9	572.0	2119.	0.611	1722.	93.4	1925.0	16.26	1418.	0.02166	0.00913
32.	649.4	582.0	570.6	572.4	2107.	0.417	1302.	93.4	1617.0	14.41	1077.	0.02612	0.01070
33.	638.7	599.0	567.4	572.2	2260.	3.890	5474.	93.4	4005.0	33.71	4445.	0.01373	0.00595
34.	640.9	595.1	568.3	572.2	2167.	2.158	3842.	93.4	3246.0	26.42	3130.	0.01507	0.00664
35.	641.2	598.0	563.9	569.3	2237.	3.858	5425.	93.4	4319.0	33.79	4403.	0.01374	0.00601
36.	641.4	597.0	563.8	568.8	2216.	3.492	5101.	93.4	4171.0	32.32	4144.	0.01399	0.00612
37.	641.2	596.1	564.9	569.5	2187.	3.002	4652.	93.4	3869.0	30.22	3783.	0.01433	0.00627
38.	642.4	594.5	564.5	568.8	2162.	2.506	4177.	93.4	3687.0	28.20	3401.	0.01475	0.00652
39.	644.7	593.2	565.0	568.9	2137.	1.983	3645.	94.1	3459.0	25.94	2969.	0.01524	0.00688
40.	643.0	590.7	565.6	569.1	2119.	1.572	3168.	94.1	3054.0	23.64	2590.	0.01599	0.00721
41.	644.8	588.0	566.4	569.3	2101.	1.070	2497.	94.1	2615.0	20.24	2047.	0.01757	0.00784
42.	623.4	590.4	563.4	567.6	2239.	3.878	5481.	94.1	3336.0	33.07	4514.	0.01373	0.00584
43.	623.1	589.5	563.7	567.5	2215.	3.482	5129.	94.1	3173.0	31.57	4229.	0.01357	0.00595
44.	624.0	588.9	564.1	567.7	2185.	2.981	4661.	94.1	3014.0	29.63	3844.	0.01435	0.00615
45.	624.3	587.6	564.1	567.5	2160.	2.494	4190.	94.1	2831.0	27.63	3460.	0.01475	0.00638
46.	625.5	586.8	564.4	567.6	2137.	1.981	3662.	94.1	2644.0	25.22	3025.	0.01525	0.00666
47.	627.0	585.3	564.6	567.5	2120.	1.561	3171.	94.1	2435.0	22.95	2622.	0.01601	0.00700
48.	628.6	582.8	564.7	567.3	2109.	1.060	2508.	94.1	2116.0	19.88	2079.	0.01741	0.00767
49.	586.6	570.8	560.5	561.7	2181.	2.908	3813.	93.2	1109.0	23.42	3252.	0.01496	0.00596
50.	587.4	570.2	560.4	561.6	2180.	1.573	3310.	93.2	1050.0	21.59	2824.	0.01563	0.00633
51.	588.5	569.5	560.6	561.6	2255.	1.042	2669.	93.2	933.0	18.72	2278.	0.01658	0.00681
52.	586.1	571.3	560.5	561.9	2181.	2.450	4275.	93.2	1171.0	25.23	3646.	0.01446	0.00573
53.	666.9	608.1	565.7	572.3	2098.	3.702	5045.	93.2	5462.0	32.96	4016.	0.01408	0.00630
54.	667.8	606.5	565.9	572.2	2102.	3.106	4578.	93.2	5171.0	30.81	3648.	0.01445	0.00649
55.	670.5	605.4	566.4	572.3	2106.	2.511	4068.	93.2	4880.0	28.27	3243.	0.01489	0.00670

56.	674.0	604.1	566.7	572.1	2108.	1.996	3523.	93.2	4538.0	25.16	2808.	0.01592	0.00689
57.	676.3	602.0	567.0	572.2	2111.	1.580	3122.	93.2	4272.0	23.55	2492.	0.01615	0.00727
58.	680.9	598.1	567.8	572.1	2113.	1.041	2418.	93.2	3691.0	19.99	1936.	0.01800	0.00798
59.	683.2	608.0	565.9	572.3	2110.	2.352	3901.	94.1	5402.0	28.22	3087.	0.01516	0.00697
60.	686.6	607.6	566.1	572.1	2113.	1.987	3527.	94.1	5136.0	25.63	2788.	0.01573	0.00700
61.	689.3	605.4	566.5	572.1	2115.	1.582	3093.	94.1	4777.0	23.48	2449.	0.01642	0.00732
62.	690.0	601.8	567.3	572.2	2116.	1.186	2506.	94.1	4235.0	21.08	2072.	0.01753	0.00779
63.	695.7	597.4	568.3	572.6	2116.	0.806	2027.	94.1	3673.0	18.34	1618.	0.01999	0.00872
64.	700.5	586.1	569.2	572.1	2111.	0.400	1230.	94.1	2592.0	14.46	997.	0.02787	0.01136
65.	641.7	596.2	570.2	572.4	2272.	2.450	4260.	206.2	3573.0	28.18	3467.	0.01453	0.00639
66.	657.9	581.3	569.6	572.0	2109.	0.380	1222.	79.9	1726.0	14.34	1099.	0.02711	0.01135
67.	654.8	584.2	569.7	572.3	2111.	0.501	1489.	79.9	1935.0	15.60	1224.	0.02384	0.01014
68.	653.0	586.0	569.3	572.2	2113.	0.601	1710.	79.9	2112.0	16.66	1403.	0.02151	0.00942
69.	651.1	587.3	569.3	572.3	2114.	0.707	1895.	79.9	2229.0	17.58	1553.	0.02050	0.00897
70.	650.0	588.4	568.8	572.1	2117.	0.803	2076.	79.9	2357.0	18.38	1699.	0.01933	0.00856
71.	648.3	589.2	569.0	572.1	2124.	0.891	2229.	80.6	2426.0	19.12	1824.	0.01359	0.00829
72.	647.5	589.8	568.5	571.9	2125.	0.984	2391.	80.6	2545.0	19.99	1955.	0.01778	0.00808
73.	647.1	590.4	568.3	571.9	2126.	1.068	2521.	80.6	2637.0	20.69	2060.	0.01732	0.00793
74.	646.3	590.9	568.5	572.3	2127.	1.143	2633.	80.6	2685.0	21.33	2151.	0.01596	0.00783
75.	645.7	591.5	568.4	572.3	2128.	1.255	2782.	80.6	2779.0	22.22	2271.	0.01665	0.00772
76.	645.2	591.9	568.2	572.2	2128.	1.352	2911.	80.6	2858.0	22.93	2376.	0.01635	0.00761
77.	644.5	592.2	568.2	572.2	2128.	1.446	3017.	80.6	2906.0	23.46	2462.	0.01627	0.00751
78.	644.2	592.8	567.8	572.1	2128.	1.582	3184.	80.6	3018.0	24.28	2597.	0.01593	0.00737
79.	643.6	593.2	567.8	572.2	2129.	1.690	3308.	80.6	3074.0	24.91	2697.	0.01574	0.00728
80.	643.6	593.9	567.9	572.4	2128.	1.811	3457.	80.6	3171.0	25.82	2816.	0.01541	0.00722
81.	643.3	594.1	567.6	572.2	2130.	1.930	3563.	80.3	3230.0	26.29	2902.	0.01546	0.00713
82.	642.9	594.5	567.4	572.1	2130.	2.056	3702.	80.3	3305.0	26.90	3015.	0.01523	0.00702
83.	642.7	594.8	567.3	572.2	2130.	2.152	3831.	80.3	3382.0	27.68	3119.	0.01484	0.00696
84.	642.0	595.1	567.2	572.2	2130.	2.288	3967.	80.3	3430.0	28.34	3229.	0.01470	0.00690
85.	642.9	595.5	567.2	572.3	2130.	2.340	4011.	80.3	3500.0	28.67	3262.	0.01469	0.00690

86.	637.4	595.4	568.0	572.3	2172.	2.197	3901.	80.3	3016.0	24.92	3181.	0.01489	0.00617
87.	638.1	597.8	567.1	572.0	2201.	2.928	4629.	80.3	3438.0	27.86	3764.	0.01415	0.00581
88.	637.5	598.6	567.4	572.4	2212.	3.252	4922.	80.3	3527.0	29.09	4009.	0.01393	0.00571
89.	637.7	599.3	566.6	571.9	2231.	3.570	5204.	80.3	3691.0	29.93	4227.	0.01376	0.00555
90.	637.2	599.8	566.9	572.4	2246.	3.823	5434.	80.3	3739.0	30.86	4412.	0.01358	0.00546
91.	650.3	587.5	569.3	572.1	2122.	0.706	1898.	80.7	2197.0	17.25	1555.	0.02048	0.00878
92.	644.6	596.1	567.2	571.9	2195.	2.151	3869.	80.7	3456.0	26.91	3143.	0.01496	0.00672
93.	601.1	574.3	568.0	569.1	2101.	0.483	1486.	79.9	734.0	14.44	1258.	0.02348	0.00942
94.	598.7	575.6	568.1	569.3	2115.	0.695	1920.	79.9	818.0	16.29	1624.	0.02012	0.00823
95.	596.7	577.3	567.5	569.0	2163.	1.341	2979.	79.9	1067.0	21.27	2516.	0.01616	0.00692
96.	594.8	577.6	567.6	569.0	2121.	1.448	3095.	79.9	980.0	19.60	2615.	0.01583	0.00614
97.	651.7	585.9	565.7	569.2	2125.	0.790	2051.	79.4	2485.0	18.49	1681.	0.01965	0.00872
98.	652.7	585.3	566.0	569.4	2120.	0.714	1916.	79.4	2380.0	17.83	1572.	0.02037	0.00900
99.	654.7	583.6	565.9	569.1	2115.	0.612	1722.	79.4	2258.0	16.91	1415.	0.02171	0.00949
100.	655.9	581.9	566.6	569.5	2110.	0.509	1509.	79.4	2059.0	15.90	1243.	0.02362	0.01019
101.	660.7	578.9	566.4	569.2	2105.	0.385	1236.	79.4	1861.0	14.63	1022.	0.02689	0.01145
102.	646.0	590.6	565.3	569.0	2134.	1.143	2620.	80.3	2673.0	19.10	2139.	0.01720	0.00705
103.	654.4	599.4	563.8	569.3	2133.	2.147	3752.	80.3	3805.0	23.80	3025.	0.01536	0.00612
104.	615.0	590.9	580.9	581.9	2146.	1.070	2528.	78.9	1126.0	19.30	2094.	0.01746	0.00738
105.	613.9	595.9	579.8	582.4	2239.	3.833	5443.	78.9	1807.0	30.09	4486.	0.01364	0.00535
106.	589.4	568.3	560.6	562.0	2123.	0.783	2112.	79.9	822.0	17.18	1805.	0.01897	0.00789
107.	589.5	569.3	560.6	562.0	2139.	0.993	2479.	79.9	923.0	18.76	2115.	0.01745	0.00734
108.	590.8	570.4	560.6	561.9	2148.	0.992	2455.	80.3	925.0	16.81	2092.	0.01764	0.00664
109.	589.6	572.0	560.1	561.7	2210.	1.742	3538.	80.3	1145.0	20.85	3010.	0.01528	0.00572
110.	636.1	577.5	565.1	567.4	2108.	0.498	1495.	79.9	1615.0	15.45	1245.	0.02375	0.01001
111.	631.1	582.7	564.4	567.5	2137.	0.967	2389.	79.9	2131.0	19.75	1979.	0.01782	0.00799
112.	628.6	585.2	564.1	567.7	2165.	1.476	3105.	79.9	2485.0	23.48	2566.	0.01613	0.00732
113.	627.3	586.3	563.5	567.5	2182.	1.887	3624.	79.9	2733.0	26.21	2993.	0.01514	0.00699
114.	626.6	587.7	563.1	567.5	2197.	2.387	4167.	79.9	2991.0	29.10	3436.	0.01451	0.00675
115.	623.4	587.9	564.0	567.7	2156.	2.220	3945.	79.9	2580.0	24.72	3257.	0.01479	0.00606

116.	541.7	594.8	570.1	572.3	2163.	1.869	3545.	169.5	3063.0	23.68	2890.	0.01534	0.00645
117.	541.1	594.9	570.1	572.5	2163.	1.869	3540.	149.4	3009.0	23.47	2886.	0.01538	0.00640
118.	640.8	595.0	569.5	572.4	2163.	1.869	3537.	120.9	2981.0	23.31	2882.	0.01541	0.00637
119.	640.7	595.2	568.5	572.3	2163.	1.869	3540.	92.2	2968.0	23.26	2884.	0.01537	0.00635
120.	640.3	595.5	567.8	572.4	2163.	1.868	3531.	72.8	2918.0	23.05	2876.	0.01543	0.00631
121.	640.2	595.9	566.5	572.7	2162.	1.868	3534.	51.2	2887.0	23.37	2876.	0.01537	0.00639
122.	638.8	595.7	562.5	572.3	2161.	1.863	3533.	30.3	2805.0	23.66	2875.	0.01532	0.00647
123.	672.5	611.0	564.9	573.0	2157.	3.731	5151.	81.1	5839.0	33.97	4079.	0.01392	0.00635
124.	699.0	583.5	569.7	572.7	2089.	0.320	1088.	81.1	2316.0	14.02	887.	0.02840	0.01245
125.	672.2	600.3	567.5	572.4	2152.	1.191	2661.	80.3	3525.0	19.56	2132.	0.01721	0.00709
126.	594.6	594.6	*****		2101.	0.343	1115.	0.0	0.0	*****	930.	0.02905	*****
127.	594.2	594.2	*****		2121.	0.648	1795.	0.0	0.0	*****	1497.	0.02058	*****
128.	595.6	595.6	*****		2154.	1.109	2587.	0.0	0.0	*****	2154.	0.01724	*****
129.	660.7	660.7	*****		2273.	2.390	3919.	0.0	0.0	*****	3017.	0.01522	*****
130.	658.4	658.4	*****		2208.	1.800	3271.	0.0	0.0	*****	2524.	0.01613	*****
131.	658.1	658.1	*****		2149.	1.103	2382.	0.0	0.0	*****	1839.	0.01836	*****
132.	652.9	652.9	*****		2119.	0.643	1627.	0.0	0.0	*****	1263.	0.02319	*****
133.	656.0	656.0	*****		2101.	0.355	968.	0.0	0.0	*****	749.	0.03654	*****
134.	656.4	656.4	*****		2150.	1.965	3406.	0.0	0.0	*****	2634.	0.01583	*****
135.	658.5	658.5	*****		2178.	2.560	3989.	0.0	0.0	*****	3078.	0.01511	*****
136.	659.6	659.6	*****		2212.	3.202	4565.	0.0	0.0	*****	3518.	0.01457	*****
137.	660.6	660.8	*****		2237.	3.657	4936.	0.0	0.0	*****	3798.	0.01434	*****
138.	593.7	593.7	*****		2155.	2.035	3730.	0.0	0.0	*****	3112.	0.01508	*****
139.	595.7	595.7	*****		2204.	3.040	4709.	0.0	0.0	*****	3920.	0.01432	*****
140.	597.1	597.1	*****		2254.	3.910	5495.	0.0	0.0	*****	4565.	0.01373	*****

SURFACE TWO

RUN	AIR IN DEG R	AIR OUT DEG R	H2O IN DEG R	H2O OUT DEG R	AIR MEAN PRESSURE PSFA	CORE DP IN. H2O	AIR FLOW SCFM	WATER FLOW GPM	HEAT TRANSFER BTU/MIN	AIR HEAT TRANSFER COEFF. BTU/HR FT F	AIR REYNOLDS NUMBER	F	J
1.	642.0	606.6	577.1	578.4	2251.	6.180	3974.	290.8	2612.8	33.13	7438.	0.00785	0.00392
2.	638.0	610.0	588.3	589.3	2171.	3.600	2879.	285.1	1497.6	23.76	5386.	0.00846	0.00388
3.	642.0	603.1	570.9	572.3	2186.	4.530	3314.	230.1	2396.2	26.76	6219.	0.00814	0.00380
4.	642.4	602.5	571.2	572.5	2162.	3.630	2915.	231.0	2159.4	23.87	5472.	0.00839	0.00385
5.	642.8	601.8	571.3	572.5	2154.	2.730	2497.	229.5	1902.8	20.77	4691.	0.00861	0.00391
6.	644.1	600.6	571.3	572.4	2140.	1.860	1993.	229.5	1608.8	17.10	3745.	0.00926	0.00404
7.	642.9	598.7	571.6	572.4	2128.	0.960	1346.	230.9	1104.9	11.70	2535.	0.01060	0.00409
8.	636.4	636.3	*****	*****	2090.	0.940	1214.	0.0	0.0	*****	2231.	0.01191	*****
9.	640.7	640.3	*****	*****	2110.	1.865	1885.	0.0	0.0	*****	3446.	0.00960	*****
10.	652.4	650.8	*****	*****	2084.	0.629	926.	0.0	0.0	*****	1671.	0.01266	*****
11.	649.8	648.4	*****	*****	2101.	0.781	1076.	0.0	0.0	*****	1948.	0.01162	*****
12.	650.3	648.7	*****	*****	2110.	1.185	1424.	0.0	0.0	*****	2577.	0.01068	*****
13.	655.1	654.4	*****	*****	2240.	6.030	3729.	0.0	0.0	*****	6706.	0.00800	*****
14.	647.6	646.9	*****	*****	2187.	4.515	3171.	0.0	0.0	*****	5752.	0.00823	*****
15.	644.6	644.3	*****	*****	2159.	3.630	2799.	0.0	0.0	*****	5094.	0.00846	*****
16.	646.6	646.4	*****	*****	2133.	2.736	2365.	0.0	0.0	*****	4293.	0.00886	*****
17.	645.1	645.4	*****	*****	2106.	1.564	1717.	0.0	0.0	*****	3121.	0.00961	*****
18.	631.4	631.1	*****	*****	2176.	4.196	3062.	0.0	0.0	*****	5660.	0.00839	*****
19.	631.2	630.8	*****	*****	2151.	3.387	2701.	0.0	0.0	*****	4994.	0.00865	*****
20.	631.4	630.7	*****	*****	2125.	2.421	2201.	0.0	0.0	*****	4069.	0.00931	*****
21.	631.0	630.3	*****	*****	2112.	1.900	1925.	0.0	0.0	*****	3561.	0.00952	*****
22.	630.8	630.1	*****	*****	2102.	1.484	1677.	0.0	0.0	*****	3103.	0.00979	*****
23.	631.3	630.5	*****	*****	2095.	1.134	1428.	0.0	0.0	*****	2641.	0.01035	*****
24.	630.6	629.7	*****	*****	2086.	0.769	1098.	0.0	0.0	*****	2033.	0.01202	*****
25.	605.9	605.5	*****	*****	2121.	2.290	2224.	0.0	0.0	*****	4242.	0.00891	*****

26.	605.6	605.1*****	2110.	1.836	1940.	0.0	0.0*****	3703.	0.00941*****
27.	605.9	605.4*****	2100.	1.360	1651.	0.0	0.0*****	3148.	0.00961*****
28.	605.6	605.0*****	2092.	1.023	1397.	0.0	0.0*****	2666.	0.01013*****
29.	606.4	605.6*****	2086.	0.764	1155.	0.0	0.0*****	2203.	0.01113*****

SURFACE THREE

RUN	AIR IN DEG R	AIR OUT DEG R	H2O IN DEG R	H2O OUT DEG R	AIR MEAN PRESSURE PSFA	CORE DP IN. H2O	AIR FLOW SCFM	WATER FLOW GPM	HEAT TRANSFER BTU/MIN	AIR HEAT TRANSFER COEFF. BTU/HR FT F	AIR REYNOLDS NUMBER	F	J
1.	641.9	594.5	570.9	572.6	2083.	6.269	3705.	250.0	3264.5	40.53	8726.	0.01706	0.00624
2.	643.0	594.3	570.4	572.2	2084.	6.001	3639.	250.0	3289.5	40.02	8567.	0.01695	0.00628
3.	643.2	593.5	570.3	571.9	2086.	5.489	3455.	250.0	3187.6	38.73	8141.	0.01726	0.00640
4.	643.0	593.9	571.4	573.0	2089.	5.052	3291.	250.0	3004.8	36.91	7754.	0.01755	0.00640
5.	643.8	592.7	570.8	572.3	2092.	4.503	3116.	250.0	2958.1	36.02	7347.	0.01753	0.00660
6.	644.6	592.2	570.4	572.0	2093.	4.202	2989.	250.0	2915.3	35.08	7051.	0.01781	0.00670
7.	645.4	591.9	570.3	571.8	2095.	3.924	2868.	250.0	2850.7	33.85	6765.	0.01811	0.00674
8.	644.4	590.9	570.6	572.0	2109.	3.442	2658.	249.0	2642.3	31.98	6278.	0.01870	0.00687
9.	645.5	590.9	570.9	572.3	2110.	3.212	2555.	249.0	2592.7	31.18	6035.	0.01890	0.00697
10.	645.2	590.3	570.7	572.0	2110.	2.993	2475.	249.0	2526.3	30.44	5850.	0.01880	0.00703
11.	645.5	590.5	571.1	572.4	2111.	2.766	2391.	249.0	2440.6	29.26	5650.	0.01861	0.00699
12.	645.6	590.4	570.7	572.0	2111.	2.623	2358.	249.0	2419.3	28.62	5573.	0.01814	0.00693
13.	645.9	590.3	570.7	572.0	2112.	2.402	2255.	249.0	2328.6	27.13	5328.	0.01819	0.00687
14.	646.0	590.2	571.2	572.5	2113.	2.226	2165.	249.0	2241.6	26.33	5117.	0.01830	0.00695
15.	645.7	589.9	571.2	572.4	2087.	2.042	2057.	250.0	2134.3	25.04	4865.	0.01838	0.00695
16.	646.5	589.0	570.8	572.0	2087.	1.787	1915.	250.0	2046.4	23.79	4531.	0.01862	0.00710
17.	647.1	588.7	571.3	572.4	2088.	1.602	1797.	250.0	1946.9	22.73	4255.	0.01898	0.00722
18.	647.5	588.0	571.2	572.3	2088.	1.418	1679.	250.0	1854.9	21.66	3977.	0.01931	0.00737
19.	648.5	586.9	570.9	571.9	2089.	1.202	1516.	250.0	1733.7	20.08	3595.	0.02016	0.00757
20.	649.8	586.1	570.9	571.9	2088.	1.004	1377.	250.0	1627.9	18.72	3268.	0.02046	0.00777
21.	665.5	605.2	575.2	577.3	2083.	6.216	3671.	249.0	4143.4	40.26	8482.	0.01693	0.00625
22.	667.0	603.9	575.5	577.6	2089.	4.982	3263.	249.0	3825.0	36.91	7546.	0.01731	0.00645
23.	670.0	600.8	575.2	577.0	2097.	3.541	2675.	249.0	3443.2	32.85	6203.	0.01857	0.00700
24.	669.4	600.0	576.0	577.6	2102.	2.524	2272.	249.0	2932.0	27.80	5276.	0.01843	0.00697
25.	672.2	597.1	575.7	577.1	2105.	1.536	1745.	249.0	2435.1	22.62	4062.	0.01922	0.00739

26.	645.6	590.5	570.6	572.1	2099.	2.946	2441.	222.0	2497.9	29.87	5766.	0.01891	0.00699
27.	645.2	590.3	570.6	572.0	2099.	2.931	2441.	240.0	2487.1	29.85	5769.	0.01882	0.00698
28.	645.2	590.6	571.2	572.4	2098.	2.946	2444.	272.0	2479.8	29.84	5776.	0.01886	0.00697
29.	645.0	590.3	571.2	572.3	2097.	2.948	2443.	310.0	2482.7	29.84	5775.	0.01890	0.00698
30.	645.0	590.1	571.2	572.2	2097.	2.949	2452.	376.0	2501.0	29.92	5798.	0.01877	0.00697
31.	645.3	590.1	571.4	572.3	2097.	2.950	2446.	448.0	2507.4	29.85	5785.	0.01886	0.00697
32.	645.6	590.3	571.7	572.6	2097.	2.949	2447.	550.0	2513.8	29.84	5786.	0.01884	0.00696
33.	623.2	588.7	570.9	572.3	2063.	6.228	3714.	251.0	2381.2	39.61	8862.	0.01667	0.00610
34.	624.0	587.9	571.0	572.3	2070.	5.004	3290.	251.0	2210.6	36.37	7855.	0.01741	0.00632
35.	625.8	586.2	571.0	572.1	2077.	3.519	2694.	251.0	1978.7	32.13	6440.	0.01846	0.00682
36.	628.4	586.0	571.5	572.5	2078.	1.993	2046.	251.0	1612.6	24.55	4889.	0.01818	0.00686
37.	631.5	583.2	571.2	572.1	2084.	1.018	1390.	251.0	1247.0	18.51	3331.	0.02040	0.00762
38.	639.2	615.4	580.4	582.6	2065.	6.118	3576.	302.0	4913.8	39.41	8121.	0.01714	0.00627
39.	639.7	614.1	581.3	583.4	2071.	5.010	3220.	302.0	4526.6	36.62	7320.	0.01744	0.00647
40.	694.4	609.8	579.6	581.5	2081.	3.523	2629.	302.0	4139.6	32.42	5995.	0.01869	0.00702
41.	697.3	606.2	577.9	579.5	2086.	2.019	2009.	302.0	3403.6	25.17	4593.	0.01857	0.00713
42.	699.6	600.9	578.7	580.0	2089.	1.015	1361.	302.0	2498.5	18.92	3134.	0.02065	0.00791

SURFACE FOUR

RUN	AIR IN DEG R	AIR OUT DEG R	H2O IN DEG R	H2O OUT DEG R	AIR MEAN PRESSURE PSFA	CORE DP IN. H2O	AIR FLOW SCFM	WATER FLOW GPM	HEAT TRANSFER BTU/MIN	AIR HEAT TRANSFER COEFF. BTU/HR FT F	AIR REYNOLDS NUMBER	F	J
1.	656.9	656.3	*****	*****	2181.	1.800	2847.	0.0	0.0	*****	13073.	0.04321	*****
2.	652.1	651.4	*****	*****	2134.	0.802	1722.	0.0	0.0	*****	7952.	0.05189	*****
3.	595.0	593.9	*****	*****	2115.	1.113	2353.	0.0	0.0	*****	11650.	0.04191	*****
4.	594.2	593.9	*****	*****	2157.	2.540	3658.	0.0	0.0	*****	18118.	0.04034	*****
5.	604.9	605.0	*****	*****	2194.	3.731	4420.	0.0	0.0	*****	21593.	0.04049	*****
6.	620.3	620.2	*****	*****	2209.	4.160	4634.	0.0	0.0	*****	22214.	0.04034	*****
7.	658.5	657.8	*****	*****	2170.	3.010	3783.	0.0	0.0	*****	17341.	0.04058	*****
8.	659.6	659.8	*****	*****	2198.	3.782	4271.	0.0	0.0	*****	19545.	0.04038	*****
9.	679.4	679.5	*****	*****	2236.	4.878	4798.	0.0	0.0	*****	21481.	0.04074	*****
10.	642.2	597.3	568.6	572.4	2115.	2.894	3976.	98.9	3317.2	39.36	19186.	0.03763	0.00996
11.	643.4	596.9	568.5	572.3	2115.	2.625	3772.	98.9	3260.4	37.95	18202.	0.03755	0.01012
12.	643.8	596.4	568.5	572.2	2116.	2.406	3595.	98.9	3171.2	36.55	17353.	0.03836	0.01023
13.	643.9	595.8	569.0	572.4	2118.	2.182	3425.	98.9	3058.6	35.48	16540.	0.03841	0.01042
14.	645.2	595.3	568.9	572.3	2119.	1.983	3260.	98.9	3020.7	34.51	15746.	0.03857	0.01065
15.	643.0	594.1	569.4	572.6	2116.	1.791	3064.	98.6	2779.5	32.73	14829.	0.03948	0.01075
16.	644.2	593.6	569.3	572.4	2116.	1.600	2887.	98.6	2714.4	31.37	13974.	0.03978	0.01094
17.	645.8	592.9	569.1	572.1	2117.	1.389	2681.	98.6	2636.7	29.74	12983.	0.04008	0.01116
18.	645.9	591.8	569.4	572.3	2116.	1.184	2453.	98.6	2465.8	27.97	11892.	0.04089	0.01147
19.	647.5	590.8	569.7	572.3	2117.	0.981	2199.	98.6	2315.3	26.01	10668.	0.04223	0.01190
20.	647.1	589.7	570.2	572.5	2116.	0.802	1950.	98.6	2078.8	23.53	9476.	0.04396	0.01215
21.	648.2	588.0	570.3	572.4	2114.	0.604	1649.	98.6	1844.1	20.80	8030.	0.04636	0.01269
22.	650.2	584.9	570.6	572.2	2113.	0.388	1207.	98.6	1463.6	16.69	5901.	0.05571	0.01392
23.	639.4	599.7	567.9	572.4	2093.	4.716	5081.	98.3	3751.4	46.84	24485.	0.03698	0.00927
24.	639.8	599.6	568.1	572.4	2094.	4.493	4955.	98.3	3704.3	45.90	23877.	0.03707	0.00932
25.	640.1	599.4	568.1	572.4	2095.	4.285	4838.	98.3	3663.4	44.97	23315.	0.03710	0.00935

26.	640.2	599.1	568.0	572.4	2096.	4.109	4738.	98.3	3617.3	44.21	22838.	0.03714	0.00938
27.	640.0	598.5	567.9	572.1	2096.	3.900	4610.	98.3	3557.6	43.44	22234.	0.03729	0.00948
28.	640.8	598.6	568.2	572.5	2098.	3.689	4488.	98.3	3520.8	42.63	21639.	0.03724	0.00955
29.	641.1	598.3	568.0	572.1	2098.	3.491	4362.	98.3	3467.9	41.43	21037.	0.03734	0.00955
30.	641.7	598.3	568.5	572.5	2099.	3.300	4231.	98.3	3413.9	40.56	20397.	0.03754	0.00964
31.	641.7	597.7	568.4	572.5	2099.	3.094	4098.	98.3	3348.8	39.82	19770.	0.03756	0.00977
32.	642.4	597.4	568.3	572.3	2100.	2.901	3958.	98.3	3311.9	38.81	19094.	0.03778	0.00986
33.	642.5	596.8	568.4	572.2	2102.	2.706	3813.	98.3	3234.6	37.90	18405.	0.03805	0.01000
34.	643.3	596.7	569.0	572.6	2100.	2.482	3640.	98.3	3153.3	36.86	17571.	0.03828	0.01018
35.	643.8	595.9	568.8	572.4	2100.	2.293	3498.	98.3	3116.1	36.39	16895.	0.03835	0.01046
36.	643.3	595.1	568.7	572.1	2102.	2.102	3349.	98.3	3003.0	35.13	16188.	0.03846	0.01055
37.	644.3	594.7	569.1	572.5	2102.	1.891	3159.	98.3	2915.4	33.84	15273.	0.03891	0.01078
38.	644.9	594.2	569.0	572.2	2103.	1.692	2966.	98.3	2794.3	31.71	14346.	0.03954	0.01076
39.	645.7	593.8	569.1	572.4	2104.	1.481	2783.	98.3	2682.9	30.00	13460.	0.03937	0.01085
40.	646.9	593.0	569.4	572.3	2104.	1.301	2572.	98.3	2576.0	28.68	12449.	0.04054	0.01122
41.	639.8	599.7	567.7	572.1	2089.	4.689	5074.	99.7	3780.0	46.39	24448.	0.03678	0.00919
42.	640.3	598.7	568.1	572.4	2092.	3.882	4611.	99.7	3505.8	43.29	22236.	0.03701	0.00944
43.	645.2	593.6	571.1	572.5	2096.	2.742	3869.	350.0	3707.8	36.49	18736.	0.03762	0.00949
44.	644.9	593.7	570.9	572.6	2096.	2.743	3860.	299.8	3672.2	36.81	18689.	0.03780	0.00959
45.	644.8	594.1	570.5	572.3	2096.	2.748	3868.	249.6	3646.4	37.05	18719.	0.03768	0.00964
46.	644.2	594.7	570.4	572.6	2096.	2.743	3858.	200.0	3546.5	37.20	18658.	0.03776	0.00970
47.	643.9	595.3	569.4	572.2	2096.	2.743	3847.	149.6	3473.4	37.75	18592.	0.03792	0.00987
48.	642.9	596.2	569.0	572.4	2096.	2.740	3836.	119.3	3328.5	37.59	18525.	0.03802	0.00986
49.	642.3	597.5	568.4	572.3	2096.	2.749	3840.	92.1	3199.2	37.88	18523.	0.03756	0.00992
50.	640.6	599.6	566.7	572.1	2096.	2.761	3825.	63.0	2915.4	36.79	18419.	0.03828	0.00967
51.	637.2	606.0	563.9	572.4	2096.	2.761	3788.	32.4	2192.5	108.77	18165.	0.03861	0.02886
52.	633.4	596.2	568.6	572.4	2088.	4.709	5100.	99.7	3246.1	46.19	24754.	0.03680	0.00911
53.	631.4	595.9	568.4	572.2	2090.	4.287	4853.	99.7	3199.1	44.40	23553.	0.03705	0.00921
54.	630.9	595.3	568.7	572.4	2092.	3.902	4638.	99.7	3069.2	42.86	22525.	0.03701	0.00930
55.	632.4	595.1	568.9	572.3	2093.	3.400	4311.	99.7	2987.9	40.44	20928.	0.03738	0.00944

56.	632.7	594.2	569.1	572.5	2096.	2.901	3965.	99.7	2836.6	38.30	19264.	0.03783	0.00972
57.	634.2	593.5	569.0	572.2	2098.	2.501	3665.	99.7	2767.0	36.43	17806.	0.03825	0.01000
58.	633.2	594.2	569.0	572.4	2104.	2.894	3981.	99.6	2885.0	38.90	19337.	0.03758	0.00983
59.	635.1	593.2	569.3	572.3	2107.	2.202	3434.	99.6	2672.2	34.62	16684.	0.03856	0.01015
60.	633.8	591.5	569.7	572.4	2109.	1.804	3093.	99.6	2432.6	32.53	15067.	0.03910	0.01059
61.	635.5	590.3	569.8	572.4	2111.	1.400	2693.	99.6	2259.8	29.51	13128.	0.04013	0.01103
62.	639.8	588.6	570.0	572.3	2111.	1.002	2232.	99.6	2122.7	26.98	10884.	0.04156	0.01217
63.	639.0	586.2	570.5	572.3	2109.	0.602	1659.	99.6	1626.9	20.71	8121.	0.04574	0.01257
64.	638.2	583.3	570.9	572.3	2108.	0.389	1220.	99.6	1244.7	16.61	6000.	0.05479	0.01371
65.	657.9	602.6	567.7	572.4	2104.	2.854	3936.	99.6	4047.7	39.29	18777.	0.03730	0.01003
66.	660.2	601.0	568.1	572.5	2108.	2.191	3409.	99.6	3753.9	35.43	16275.	0.03835	0.01044
67.	661.4	599.2	568.3	572.2	2090.	1.800	3051.	98.9	3525.4	33.08	14588.	0.03913	0.01090
68.	662.1	597.6	568.7	572.3	2091.	1.397	2689.	98.9	3224.7	30.01	12880.	0.03924	0.01121
69.	663.3	595.3	569.2	572.4	2092.	1.006	2239.	98.9	2831.7	26.16	10747.	0.04056	0.01175
70.	666.9	591.8	569.7	572.4	2092.	0.607	1661.	98.9	2317.6	21.00	7999.	0.04510	0.01272
71.	670.7	585.3	570.5	572.3	2089.	0.299	1002.	98.9	1591.9	15.21	4871.	0.06137	0.01528
72.	654.7	605.5	566.7	572.2	2092.	4.670	5050.	99.5	4617.1	46.95	24053.	0.03663	0.00934
73.	655.1	605.1	566.9	572.4	2094.	4.285	4835.	99.5	4495.7	45.26	23036.	0.03673	0.00940
74.	655.4	604.3	567.2	572.4	2095.	3.898	4600.	99.5	4369.0	43.84	21928.	0.03700	0.00957
75.	656.2	604.0	567.4	572.6	2097.	3.396	4291.	99.5	4164.6	40.66	20458.	0.03710	0.00952
76.	658.2	602.8	567.5	572.3	2099.	2.911	3955.	99.5	4079.7	39.30	18864.	0.03756	0.00998
77.	659.5	601.9	567.8	572.3	2100.	2.500	3642.	99.5	3905.1	37.01	17377.	0.03813	0.01021
78.	672.5	612.3	565.8	572.2	2087.	4.615	4980.	100.0	5576.4	46.87	23405.	0.03666	0.00944
79.	672.6	611.9	566.2	572.7	2088.	4.310	4820.	100.0	5443.5	45.63	22661.	0.03661	0.00949
80.	675.6	610.6	566.4	572.5	2092.	3.406	4270.	100.0	5158.1	41.51	20075.	0.03703	0.00975
81.	676.3	608.9	566.2	572.1	2094.	2.901	3932.	100.0	4929.9	39.14	18510.	0.03735	0.00999
82.	677.9	607.9	566.9	572.4	2095.	2.480	3611.	100.0	4697.3	36.83	17008.	0.03794	0.01023
83.	676.6	608.7	566.6	572.4	2095.	2.815	3879.	99.5	4893.3	39.10	18264.	0.03727	0.01011
84.	679.2	606.8	566.8	572.2	2096.	2.200	3394.	99.5	4566.1	35.43	15994.	0.03820	0.01047
85.	681.4	605.6	567.3	572.2	2099.	1.820	3070.	99.5	4327.1	32.92	14474.	0.03876	0.01076

86.	681.4	602.8	567.9	572.3	2100.	1.400	2669.	99.5	3900.3	29.89	12626.	0.03965	0.01124
87.	685.5	600.3	568.5	572.4	2100.	0.982	2199.	99.5	3483.6	25.98	10417.	0.04117	0.01186
88.	639.0	595.9	569.1	572.2	2099.	0.607	1653.	99.5	2860.4	21.18	7869.	0.04526	0.01286
89.	690.5	590.3	570.0	572.2	2097.	0.361	1135.	99.5	2115.4	16.22	5445.	0.05736	0.01436
90.	648.8	590.9	569.9	572.4	2105.	0.900	2087.	99.5	2246.9	24.65	10119.	0.04277	0.01189
91.	650.1	589.1	569.8	572.1	2103.	0.700	1799.	99.5	2037.8	22.20	8738.	0.04466	0.01243
92.	648.6	586.9	570.3	572.1	2102.	0.517	1492.	99.5	1712.3	19.31	7276.	0.04628	0.01303
93.	649.7	585.8	570.5	572.2	2102.	0.441	1330.	99.5	1579.0	17.87	6495.	0.05185	0.01353
94.	652.3	583.7	570.6	572.2	2101.	0.351	1105.	99.5	1408.1	16.24	5406.	0.05955	0.01481
95.	652.2	582.7	571.0	572.2	2100.	0.261	882.	99.5	1138.8	13.10	4324.	0.06954	0.01497
96.	645.7	592.6	571.2	572.4	2104.	2.322	3546.	347.5	3497.6	34.58	17185.	0.03817	0.00982
97.	645.3	592.6	571.0	572.4	2105.	2.310	3542.	300.8	3471.0	35.03	17167.	0.03806	0.00995
98.	645.6	593.5	571.0	572.7	2105.	2.320	3540.	250.5	3428.5	34.92	17140.	0.03819	0.00992
99.	644.8	593.7	570.5	572.6	2104.	2.314	3541.	200.4	3360.8	35.34	17144.	0.03803	0.01004
100.	645.0	594.5	569.7	572.4	2104.	2.309	3537.	148.8	3313.7	35.85	17102.	0.03797	0.01020
101.	643.7	596.0	568.6	572.4	2104.	2.310	3530.	100.0	3126.5	36.16	17047.	0.03800	0.01030
102.	642.6	597.5	567.4	572.2	2104.	2.313	3530.	72.8	2960.2	36.42	17022.	0.03795	0.01038
103.	639.1	602.0	565.7	572.4	2104.	2.312	3489.	42.8	2401.6	31.25	16775.	0.03851	0.00900
104.	621.5	584.5	570.7	572.2	2104.	0.898	2071.	99.7	1423.6	23.80	10215.	0.04391	0.01155
105.	635.8	588.1	570.2	572.3	2104.	0.952	2194.	99.7	1943.8	25.71	10722.	0.04119	0.01180
106.	559.8	594.1	569.1	572.1	2105.	0.997	2231.	99.7	2725.2	26.06	10736.	0.04120	0.01175
107.	569.6	597.0	568.8	572.1	2104.	1.053	2307.	99.7	3111.8	26.83	11028.	0.04045	0.01169
108.	685.0	601.3	568.2	572.4	2104.	1.105	2366.	99.7	3682.7	27.56	11200.	0.04001	0.01169
109.	696.8	602.3	568.1	572.3	2104.	0.922	2126.	99.7	3736.2	25.36	10012.	0.04126	0.01197
110.	617.7	588.4	569.7	572.1	2101.	2.741	3858.	100.1	2100.6	37.20	18968.	0.03829	0.00972
111.	628.8	592.4	569.3	572.4	2101.	2.789	3878.	100.1	2623.6	37.92	18908.	0.03823	0.00985
112.	638.9	595.8	568.6	572.2	2101.	2.812	3893.	100.1	3119.3	38.43	18837.	0.03800	0.00993
113.	663.5	604.5	567.5	572.6	2101.	2.829	3912.	100.1	4290.9	39.10	18590.	0.03723	0.01004
114.	674.3	607.6	566.6	572.2	2100.	2.741	3847.	100.1	4773.2	38.85	18147.	0.03707	0.01013
115.	690.5	612.9	565.9	572.3	2101.	2.677	3782.	100.1	5456.9	38.40	17645.	0.03710	0.01018

SURFACE FIVE

RUN	AIR IN DEG R	AIR OUT DEG R	H2O IN DEG R	H2O OUT DEG R	AIR MEAN PRESSURE PSFA	CORE OP IN. H2O	AIR FLOW SCFM	WATER FLOW GPM	HEAT TRANSFER BTU/MIN	AIR HEAT TRANSFER COEFF. BTU/HR FT F	AIR REYNOLDS NUMBER	F	J
1.	678.5	676.7	*****		2189.	22.550	2652.	0.0	0.0	*****	9050.	0.03970	*****
2.	678.6	677.0	*****		2168.	19.786	2469.	0.0	0.0	*****	8426.	0.03979	*****
3.	677.8	676.2	*****		2153.	17.041	2276.	0.0	0.0	*****	7772.	0.04015	*****
4.	677.9	676.3	*****		2133.	14.055	2045.	0.0	0.0	*****	6983.	0.04065	*****
5.	678.4	676.6	*****		2115.	11.011	1786.	0.0	0.0	*****	6097.	0.04143	*****
6.	678.0	676.2	*****		2103.	7.949	1499.	0.0	0.0	*****	5118.	0.04230	*****
7.	678.2	676.0	*****		2084.	5.819	1275.	0.0	0.0	*****	4353.	0.04245	*****
8.	678.8	676.1	*****		2127.	5.095	1189.	0.0	0.0	*****	4058.	0.04362	*****
9.	678.3	675.8	*****		2121.	4.060	1048.	0.0	0.0	*****	3578.	0.04464	*****
10.	678.3	675.9	*****		2118.	3.512	984.	0.0	0.0	*****	3360.	0.04373	*****
11.	678.4	676.1	*****		2115.	3.022	886.	0.0	0.0	*****	3026.	0.04633	*****
12.	678.0	675.7	*****		2113.	2.553	810.	0.0	0.0	*****	2766.	0.04685	*****
13.	646.8	579.0	570.8	572.3	2099.	4.524	1205.	130.0	1517.7	42.50	4533.	0.04283	0.01209
14.	647.5	578.4	570.8	572.1	2097.	4.406	1180.	160.0	1514.9	41.28	4444.	0.04352	0.01199
15.	647.8	578.0	570.7	572.0	2097.	4.531	1193.	180.0	1546.6	41.91	4493.	0.04387	0.01205
16.	647.7	578.1	571.3	572.4	2097.	4.566	1205.	223.0	1557.4	42.25	4541.	0.04334	0.01202
17.	647.3	577.8	571.6	572.5	2098.	4.357	1169.	272.0	1509.4	41.24	4409.	0.04405	0.01210
18.	647.7	577.5	571.6	572.4	2097.	4.543	1206.	332.0	1569.6	42.56	4551.	0.04318	0.01211
19.	647.6	577.3	571.6	572.3	2097.	4.472	1194.	415.0	1559.7	42.05	4510.	0.04340	0.01208
20.	641.5	586.8	564.9	572.2	2049.	24.050	2807.	150.0	2849.9	74.41	10432.	0.04004	0.00908
21.	642.4	585.9	570.3	572.4	2060.	19.811	2552.	150.0	2675.6	69.99	9497.	0.04021	0.00939
22.	642.4	584.3	570.5	572.5	2073.	14.956	2221.	150.0	2394.5	63.57	8284.	0.04055	0.00980
23.	647.5	578.8	570.7	572.0	2098.	5.124	1286.	150.0	1639.7	45.01	4834.	0.04263	0.01200
24.	648.5	578.0	571.4	572.6	2101.	3.508	1036.	150.0	1358.4	38.28	3907.	0.04512	0.01266
25.	642.2	585.2	570.1	572.2	2088.	18.159	2457.	154.0	2601.6	67.62	9153.	0.04040	0.00943

26.	644.3	582.2	570.6	572.4	2109.	10.161	1827.	154.0	2106.2	55.93	6833.	0.04168	0.01049
27.	645.2	580.8	570.3	572.1	2116.	7.957	1622.	154.0	1941.1	51.81	6081.	0.04168	0.01094
28.	646.1	579.6	570.6	572.1	2120.	6.016	1401.	154.0	1730.8	46.94	5263.	0.04247	0.01148
29.	647.5	578.0	570.8	572.0	2123.	4.071	1138.	154.0	1469.1	40.76	4288.	0.04384	0.01228
30.	647.6	578.6	570.9	572.3	2123.	4.529	1212.	154.0	1552.4	42.81	4563.	0.04292	0.01210
31.	658.7	577.5	571.0	572.3	2111.	2.879	919.	154.0	1385.9	35.02	3458.	0.04735	0.01307
32.	659.8	576.1	571.0	572.3	2115.	2.036	779.	154.0	1210.5	32.03	2944.	0.04666	0.01409
33.	641.7	585.6	570.1	572.3	2065.	18.998	2511.	150.0	2615.9	68.29	9350.	0.03999	0.00931
34.	643.5	583.3	570.1	572.2	2082.	13.157	2072.	150.0	2314.2	61.19	7736.	0.04126	0.01012
35.	644.5	581.7	570.8	572.6	2093.	8.817	1696.	150.0	1977.8	52.99	6349.	0.04170	0.01070
36.	645.2	580.8	570.9	572.5	2097.	7.116	1517.	150.0	1815.2	48.95	5688.	0.04227	0.01106
37.	648.0	578.2	571.0	572.4	2103.	3.975	1106.	150.0	1431.6	39.56	4164.	0.04490	0.01227
38.	648.8	577.7	571.1	572.3	2105.	3.352	1023.	150.0	1352.1	37.80	3858.	0.04433	0.01267
39.	625.2	580.0	571.3	572.4	2053.	14.753	2206.	250.0	1849.3	62.95	8326.	0.04066	0.00978
40.	626.2	579.1	571.1	572.1	2059.	12.055	1985.	250.0	1735.7	59.54	7502.	0.04127	0.01029
41.	633.3	576.9	571.1	572.0	2070.	5.065	1268.	250.0	1329.3	43.33	4803.	0.04306	0.01172
42.	634.0	576.5	571.6	572.4	2074.	3.937	1115.	250.0	1189.0	39.86	4228.	0.04347	0.01227

SURFACE SIX

RUN	AIR IN DEG R	AIR OUT DEG R	H2O IN DEG R	H2O OUT DEG R	AIR MEAN PRESSURE PSFA	CORE DP IN. H2O	AIR FLOW SCFM	WATER FLOW GPM	HEAT TRANSFER BTU/MIN	AIR HEAT TRANSFER COEFF. BTU/HR FT F	AIR REYNOLDS NUMBER	F	J
1.	644.7	602.6	572.3	574.7	2047.	13.908	3262.	130.3	2550.2	52.07	10104.	0.01804	0.00603
2.	644.6	601.1	572.7	575.0	2054.	12.001	3001.	130.3	2427.9	50.27	9311.	0.01852	0.00633
3.	647.3	598.9	572.2	574.3	2063.	9.023	2548.	130.3	2288.6	44.81	7913.	0.01950	0.00664
4.	649.8	596.7	573.4	575.3	2072.	5.995	2013.	130.3	1984.7	37.85	6262.	0.02095	0.00710
5.	653.3	592.1	573.9	575.5	2081.	3.018	1356.	130.3	1541.7	28.35	4240.	0.02353	0.00790
6.	645.2	601.4	572.4	574.7	2055.	12.609	3096.	135.4	2518.2	51.49	9599.	0.01827	0.00628
7.	645.7	600.2	573.6	575.7	2063.	10.032	2710.	135.4	2293.4	46.22	8413.	0.01912	0.00644
8.	648.8	597.5	572.8	574.7	2073.	6.987	2215.	135.4	2115.1	40.12	6888.	0.02014	0.00684
9.	650.3	595.2	573.6	575.4	2079.	4.958	1817.	135.4	1858.8	35.09	5663.	0.02139	0.00730
10.	651.8	593.3	573.3	574.9	2083.	3.971	1608.	135.4	1748.2	32.61	5019.	0.02201	0.00767
11.	656.1	589.3	573.9	575.3	2087.	2.084	1106.	135.4	1372.2	25.12	3468.	0.02464	0.00859
12.	669.7	601.9	573.0	575.5	2078.	5.919	1986.	124.9	2505.6	38.85	6103.	0.02106	0.00738
13.	671.6	600.4	573.0	575.4	2081.	4.976	1796.	124.9	2376.5	36.08	5523.	0.02174	0.00758
14.	672.4	598.5	573.1	575.3	2082.	4.064	1610.	124.9	2210.3	33.30	4961.	0.02219	0.00781
15.	674.5	596.0	573.2	575.2	2085.	3.045	1363.	124.9	1987.8	29.50	4211.	0.02334	0.00817
16.	676.7	592.6	573.8	575.6	2087.	1.989	1078.	124.9	1685.8	25.25	3344.	0.02456	0.00885
17.	683.1	586.8	573.2	574.6	2087.	0.994	729.	124.9	1303.4	19.24	2277.	0.02717	0.00998
18.	649.9	596.6	572.4	574.0	2088.	4.731	1775.	83.4	1760.5	35.05	5523.	0.02142	0.00746
19.	649.4	595.6	572.9	575.0	2088.	4.739	1767.	97.9	1768.3	35.33	5506.	0.02168	0.00755
20.	650.1	594.5	573.5	575.4	2087.	4.761	1610.	120.8	1651.1	30.19	5018.	0.02621	0.00709
21.	651.0	594.1	573.8	575.4	2088.	4.676	1769.	151.6	1872.3	35.46	5520.	0.02143	0.00757
22.	651.3	593.2	573.9	575.1	2087.	4.648	1757.	192.8	1897.7	34.77	5487.	0.02163	0.00748
23.	652.1	592.3	574.1	575.1	2088.	4.703	1771.	278.9	1966.0	34.90	5538.	0.02158	0.00745
24.	652.4	591.0	573.7	574.5	2088.	4.740	1782.	422.8	2030.5	34.97	5578.	0.02155	0.00742
25.	653.3	590.6	575.4	576.0	2088.	4.627	1744.	780.3	2032.4	35.51	5466.	0.02199	0.00770

26.	647.0	600.0	573.2	575.2	2067.	9.877	2689.	141.3	2348.5	46.03	8346.	0.01915	0.00646
27.	648.0	598.3	573.0	575.0	2073.	7.896	2357.	141.3	2176.4	41.46	7327.	0.02005	0.00664
28.	649.5	595.8	572.8	574.5	2077.	6.061	2035.	141.3	2028.6	38.27	6337.	0.02080	0.00710
29.	652.1	592.5	573.7	575.1	2083.	3.990	1607.	141.3	1780.5	34.43	5023.	0.02216	0.00809
30.	656.1	588.0	573.7	574.9	2086.	1.992	1081.	141.3	1368.0	25.63	3395.	0.02471	0.00896
31.	631.9	622.6	561.6	562.2	2205.	12.013	3081.	133.7	533.8	40.69	9454.	0.01835	0.00498
32.	629.0	619.7	561.0	561.6	2178.	9.958	2726.	133.7	468.9	35.87	8396.	0.01930	0.00497
33.	630.4	620.5	560.5	561.1	2153.	8.011	2376.	133.7	437.2	31.65	7308.	0.02020	0.00503
34.	630.6	619.2	559.2	559.8	2111.	3.931	1530.	133.7	322.0	21.19	4710.	0.02352	0.00522
35.	630.4	619.3	557.8	558.3	2129.	6.078	2020.	133.9	416.4	28.58	6216.	0.02103	0.00534
36.	631.6	618.0	558.5	559.0	2099.	2.988	1296.	133.9	327.7	21.45	3991.	0.02481	0.00624
37.	631.5	618.1	559.8	560.2	2095.	2.404	1137.	133.9	282.8	18.41	3501.	0.02588	0.00611
38.	631.6	616.7	559.9	560.3	2094.	2.152	1061.	133.9	293.2	19.53	3270.	0.02663	0.00694
39.	638.1	612.7	567.9	569.1	2162.	8.073	2425.	141.2	1146.7	37.81	7471.	0.01578	0.00588
40.	639.1	612.1	569.6	570.6	2140.	6.078	2044.	141.2	1023.3	33.46	6294.	0.02080	0.00618
41.	640.5	610.2	569.5	570.5	2119.	4.017	1603.	141.2	903.6	28.56	4941.	0.02219	0.00673
42.	644.0	606.1	569.0	569.9	2102.	1.992	1030.	141.2	726.0	21.69	3182.	0.02451	0.00795
43.	637.7	612.4	562.0	563.4	2213.	11.806	3110.	132.2	1460.3	47.97	9580.	0.01799	0.00582
44.	638.5	612.1	561.3	562.7	2187.	9.887	2780.	132.2	1364.4	42.30	8561.	0.01865	0.00574
45.	644.9	606.6	560.8	561.8	2111.	3.098	1361.	132.2	969.8	26.15	4199.	0.02370	0.00725
46.	645.6	604.4	560.5	561.4	2106.	2.404	1162.	132.2	887.8	23.49	3588.	0.02526	0.00763
47.	641.8	623.7	563.4	564.3	2194.	11.900	3092.	132.2	1037.4	42.76	9431.	0.01788	0.00521
48.	642.9	623.7	563.8	564.9	2173.	10.090	2788.	131.9	999.0	40.58	8499.	0.01848	0.00549
49.	642.3	621.6	563.5	564.5	2157.	8.000	2415.	132.3	930.1	37.50	7373.	0.01947	0.00585
50.	644.2	622.2	563.7	564.6	2147.	6.195	2075.	132.1	849.5	32.47	6329.	0.02030	0.00590
51.	645.4	620.1	563.2	563.9	2136.	3.950	1606.	132.3	757.5	27.92	4901.	0.02158	0.00655
52.	646.8	619.8	563.3	564.2	2132.	3.056	1376.	132.9	690.9	24.41	4198.	0.02270	0.00669
53.	647.5	618.7	563.4	564.2	2130.	2.513	1227.	132.5	657.4	23.15	3746.	0.02347	0.00711
54.	647.9	617.4	563.5	564.2	2126.	2.038	1081.	131.9	614.1	21.59	3302.	0.02452	0.00753

SURFACE SEVEN

RUN	AIR IN DEG R	AIR OUT DEG R	H2O IN DEG R	H2O OUT DEG R	AIR MEAN PRESSURE PSFA	CORE DP IN. H2O	AIR FLOW SCFM	WATER FLOW GPM	HEAT TRANSFER BTU/MIN	AIR HEAT TRANSFER COEFF. BTU/HR FT F	AIR REYNOLDS NUMBER	F	J
1.	598.7	598.5	*****	*****	2066.	0.798	1458.	0.0	0.0	*****	1207.	0.01925	*****
2.	598.7	598.9	*****	*****	2074.	0.998	1710.	0.0	0.0	*****	1415.	0.01756	*****
3.	598.7	598.9	*****	*****	2080.	1.166	1871.	0.0	0.0	*****	1548.	0.01720	*****
4.	598.6	599.1	*****	*****	2088.	1.389	2096.	0.0	0.0	*****	1734.	0.01638	*****
5.	598.3	598.9	*****	*****	2096.	1.603	2279.	0.0	0.0	*****	1886.	0.01606	*****
6.	615.9	615.9	*****	*****	2086.	1.408	2058.	0.0	0.0	*****	1667.	0.01674	*****
7.	615.8	616.3	*****	*****	2096.	1.608	2247.	0.0	0.0	*****	1820.	0.01609	*****
8.	615.6	616.1	*****	*****	2103.	1.801	2398.	0.0	0.0	*****	1942.	0.01589	*****
9.	615.9	616.5	*****	*****	2112.	2.001	2547.	0.0	0.0	*****	2062.	0.01569	*****
10.	615.7	616.5	*****	*****	2121.	2.185	2712.	0.0	0.0	*****	2196.	0.01518	*****
11.	615.8	616.5	*****	*****	2131.	2.401	2880.	0.0	0.0	*****	2332.	0.01486	*****
12.	633.6	633.6	*****	*****	2183.	2.155	2671.	0.0	0.0	*****	2118.	0.01545	*****
13.	633.3	633.7	*****	*****	2193.	2.377	2835.	0.0	0.0	*****	2248.	0.01519	*****
14.	632.8	633.5	*****	*****	2188.	2.585	2983.	0.0	0.0	*****	2366.	0.01491	*****
15.	633.1	633.9	*****	*****	2200.	2.818	3159.	0.0	0.0	*****	2505.	0.01456	*****
16.	633.1	633.8	*****	*****	2209.	3.001	3284.	0.0	0.0	*****	2604.	0.01440	*****
17.	658.8	659.6	*****	*****	2205.	3.031	3205.	0.0	0.0	*****	2466.	0.01465	*****
18.	658.7	659.4	*****	*****	2213.	3.182	3309.	0.0	0.0	*****	2547.	0.01448	*****
19.	658.6	659.4	*****	*****	2227.	3.396	3403.	0.0	0.0	*****	2620.	0.01471	*****
20.	658.7	659.5	*****	*****	2181.	2.585	2891.	0.0	0.0	*****	2225.	0.01519	*****
21.	616.2	616.7	*****	*****	2198.	4.493	4191.	0.0	0.0	*****	3392.	0.01352	*****
22.	615.9	616.4	*****	*****	2184.	4.018	3926.	0.0	0.0	*****	3179.	0.01370	*****
23.	615.8	616.4	*****	*****	2169.	3.521	3615.	0.0	0.0	*****	2927.	0.01407	*****
24.	633.6	634.3	*****	*****	2245.	5.913	4884.	0.0	0.0	*****	3870.	0.01300	*****
25.	633.4	634.1	*****	*****	2218.	5.121	4470.	0.0	0.0	*****	3543.	0.01330	*****

26.	632.8	633.4*****	2178.	3.812	3728.	0.0	0.0*****	2957.	0.01400*****
27.	659.5	660.1*****	2243.	5.916	4745.	0.0	0.0*****	3649.	0.01323*****
28.	659.0	659.7*****	2217.	5.098	4327.	0.0	0.0*****	3329.	0.01357*****
29.	658.7	659.4*****	2187.	4.142	3806.	0.0	0.0*****	2929.	0.01408*****
30.	650.9	588.2 571.4 572.8	2095.	2.765	3135.	353.8	3656.1 19.33	2565.	0.01472 0.00546
31.	649.8	588.3 571.1 572.8	2093.	2.753	3139.	273.6	3584.9 19.46	2568.	0.01461 0.00549
32.	649.4	589.0 570.4 572.6	2093.	2.750	3135.	197.0	3515.2 19.18	2562.	0.01460 0.00541
33.	648.2	589.1 569.1 571.9	2094.	2.745	3126.	149.6	3432.0 18.97	2553.	0.01465 0.00537
34.	646.8	591.4 569.3 572.9	2094.	2.739	3130.	93.5	3219.8 19.04	2550.	0.01452 0.00538
35.	645.4	593.3 566.2 571.9	2093.	2.745	3114.	56.5	3013.3 18.24	2531.	0.01462 0.00518
36.	645.8	593.0 568.8 572.2	2093.	3.972	3805.	122.5	3738.7 21.47	3096.	0.01420 0.00499
37.	646.8	592.3 568.6 572.0	2094.	3.696	3731.	122.5	3775.0 21.85	3036.	0.01377 0.00518
38.	648.2	592.0 568.8 572.2	2095.	3.403	3614.	122.5	3780.6 21.84	2942.	0.01353 0.00534
39.	648.5	590.9 568.6 571.9	2096.	3.108	3363.	122.5	3600.5 20.30	2740.	0.01430 0.00534
40.	648.4	590.4 569.5 572.5	2097.	2.796	3168.	122.5	3410.5 19.40	2583.	0.01452 0.00542
41.	649.2	589.2 569.1 572.1	2098.	2.491	2946.	122.5	3281.4 18.30	2405.	0.01500 0.00550
42.	651.4	588.5 569.2 572.2	2099.	2.201	2753.	122.5	3217.2 17.61	2248.	0.01520 0.00566
43.	652.6	588.1 569.7 572.6	2100.	1.995	2596.	122.5	3112.4 16.96	2120.	0.01552 0.00578
44.	652.2	585.9 570.1 572.5	2101.	1.589	2255.	122.5	2775.0 15.38	1848.	0.01644 0.00603
45.	654.2	584.6 569.7 572.2	2102.	1.393	2091.	122.5	2701.2 14.75	1716.	0.01680 0.00624
46.	655.3	584.1 570.7 572.8	2101.	1.198	1899.	122.5	2511.4 13.83	1560.	0.01755 0.00645
47.	655.7	582.3 570.4 572.4	2102.	1.001	1718.	122.5	2343.8 13.07	1415.	0.01798 0.00673
48.	653.9	580.3 570.5 572.3	2102.	0.799	1479.	122.5	2019.7 11.62	1223.	0.01945 0.00696
49.	642.3	555.9 568.3 572.2	2062.	6.045	4873.	127.0	4201.6 25.76	3557.	0.01291 0.00467
50.	643.2	555.6 568.2 572.2	2064.	5.712	4713.	127.0	4172.9 25.15	3827.	0.01306 0.00472
51.	643.1	555.1 568.7 572.5	2065.	5.389	4554.	127.0	4065.1 24.75	3701.	0.01322 0.00481
52.	644.0	554.9 568.6 572.5	2066.	5.102	4424.	127.0	4038.6 24.14	3594.	0.01327 0.00483
53.	644.6	554.7 568.7 572.4	2087.	4.802	4297.	127.0	3987.9 23.44	3491.	0.01338 0.00482
54.	645.4	554.2 568.7 572.4	2087.	4.498	4160.	127.0	3955.8 23.14	3380.	0.01335 0.00492
55.	645.6	553.5 568.7 572.4	2090.	4.205	3994.	127.0	3862.1 22.52	3248.	0.01361 0.00498

56.	646.1	592.9	568.7	572.3	2090.	3.905	3812.	127.0	3767.7	21.41	3101.	0.01389	0.00497
57.	647.7	592.5	568.3	572.4	2092.	3.398	3635.	127.0	3724.5	20.81	2957.	0.01233	0.00506
58.	648.2	591.9	570.0	572.7	2091.	3.292	3457.	127.0	3612.5	20.77	2815.	0.01428	0.00531
59.	649.2	591.1	569.0	572.4	2093.	3.002	3268.	127.0	3525.9	19.31	2661.	0.01460	0.00523
60.	649.9	590.5	568.9	572.2	2094.	2.799	3144.	127.0	3466.6	18.80	2562.	0.01472	0.00529
61.	650.1	590.1	569.2	572.4	2094.	2.613	3015.	127.0	3358.6	18.17	2458.	0.01456	0.00533
62.	650.9	589.3	569.0	572.1	2096.	2.406	2879.	127.0	3297.2	17.68	2349.	0.01514	0.00543
63.	650.1	588.3	569.3	572.2	2095.	2.198	2739.	127.0	3144.6	17.22	2238.	0.01531	0.00556
64.	651.2	587.6	569.4	572.2	2096.	2.001	2586.	127.0	3053.1	16.52	2114.	0.01566	0.00565
65.	651.8	586.9	569.6	572.3	2097.	1.805	2448.	127.0	2949.9	16.04	2003.	0.01580	0.00580
66.	623.0	590.0	569.5	572.4	2105.	5.994	4964.	127.0	3050.9	25.32	4087.	0.01276	0.00452
67.	623.2	589.6	569.5	572.4	2107.	5.692	4824.	127.0	3013.7	25.07	3973.	0.01285	0.00460
68.	623.4	589.2	569.4	572.3	2108.	5.398	4671.	127.0	2966.7	24.39	3848.	0.01302	0.00462
69.	623.9	589.3	569.8	572.3	2108.	5.094	4510.	127.0	2904.1	23.35	3714.	0.01218	0.00459
70.	624.9	588.8	569.2	572.1	2111.	4.826	4405.	127.0	2959.8	23.57	3628.	0.01312	0.00474
71.	625.2	588.3	569.3	572.2	2112.	4.482	4197.	127.0	2874.6	22.69	3458.	0.01344	0.00479
72.	625.3	588.1	569.7	572.4	2112.	4.205	4043.	127.0	2790.6	21.76	3333.	0.01359	0.00477
73.	625.9	587.7	569.8	572.4	2112.	3.889	3868.	127.0	2739.6	21.20	3189.	0.01374	0.00485
74.	626.5	587.3	569.7	572.4	2114.	3.602	3690.	127.0	2688.8	20.41	3043.	0.01401	0.00490
75.	627.3	586.7	569.6	572.2	2115.	3.305	3519.	127.0	2652.7	19.96	2903.	0.01415	0.00502
76.	628.3	586.4	570.0	572.5	2116.	2.991	3308.	127.0	2573.7	19.14	2730.	0.01451	0.00512
77.	627.9	585.8	570.1	572.5	2117.	2.698	3125.	127.0	2448.2	18.23	2581.	0.01469	0.00517
78.	629.3	584.9	569.8	572.2	2118.	2.398	2906.	127.0	2399.4	17.49	2401.	0.01513	0.00533
79.	630.0	584.6	570.1	572.4	2118.	2.192	2771.	127.0	2334.6	16.92	2290.	0.01522	0.00541
80.	626.9	584.6	570.4	572.2	2109.	2.396	2909.	115.0	2287.7	18.18	2407.	0.01503	0.00554
81.	627.2	583.8	570.5	572.4	2109.	2.092	2680.	115.0	2163.4	17.07	2220.	0.01545	0.00564
82.	628.5	582.9	570.2	572.1	2109.	1.792	2457.	115.0	2078.1	15.94	2036.	0.01581	0.00575
83.	629.9	581.8	570.5	572.3	2110.	1.491	2177.	115.0	1942.0	14.92	1807.	0.01675	0.00607
84.	629.9	581.1	570.7	572.4	2110.	1.302	2028.	115.0	1837.0	14.28	1685.	0.01694	0.00624
85.	630.9	579.9	570.6	572.1	2110.	1.099	1827.	115.0	1730.1	13.47	1521.	0.01764	0.00653

86.	631.1	578.7	570.6	572.1	2110.	0.901	1606.	115.0	1560.8	12.16	1339.	0.01876	0.00671
87.	632.3	578.0	571.3	572.5	2109.	0.689	1350.	115.0	1361.9	10.76	1128.	0.02033	0.00707
88.	654.3	599.5	567.9	572.5	2095.	5.898	4805.	119.0	4887.2	26.77	3870.	0.01306	0.00492
89.	654.7	598.8	567.6	572.3	2095.	5.586	4664.	119.0	4839.9	26.32	3758.	0.01315	0.00499
90.	655.1	598.4	567.6	572.2	2096.	5.309	4535.	119.0	4780.0	25.74	3655.	0.01323	0.00501
91.	656.2	598.2	567.9	572.4	2097.	5.004	4377.	119.0	4722.1	25.04	3527.	0.01340	0.00505
92.	657.1	597.7	567.9	572.4	2097.	4.701	4222.	119.0	4664.4	24.45	3403.	0.01355	0.00512
93.	657.3	597.1	568.1	572.5	2099.	4.405	4060.	119.0	4548.9	23.72	3275.	0.01375	0.00516
94.	657.7	596.3	568.1	572.4	2100.	4.095	3899.	119.0	4446.2	23.00	3147.	0.01389	0.00521
95.	658.8	595.9	568.3	572.5	2101.	3.812	3743.	119.0	4370.7	22.29	3021.	0.01404	0.00526
96.	656.8	595.2	568.2	572.3	2102.	3.496	3568.	119.0	4084.1	20.18	2884.	0.01420	0.00500
97.	661.2	593.8	568.7	572.7	2104.	3.202	3378.	119.0	4229.4	21.61	2732.	0.01455	0.00565
98.	662.1	593.4	568.3	572.3	2105.	2.912	3204.	119.0	4088.0	19.93	2591.	0.01472	0.00550
99.	663.1	592.4	568.5	572.3	2106.	2.598	2997.	119.0	3935.9	19.01	2426.	0.01505	0.00561
100.	664.0	591.2	568.6	572.2	2107.	2.306	2794.	119.0	3777.4	18.12	2265.	0.01541	0.00573
101.	661.1	590.7	568.6	572.3	2093.	2.399	2867.	113.0	3749.9	19.16	2327.	0.01514	0.00591
102.	662.1	589.7	568.9	572.4	2093.	2.107	2652.	113.0	3565.8	18.01	2155.	0.01557	0.00601
103.	664.9	588.5	569.0	572.3	2094.	1.799	2413.	113.0	3425.9	16.86	1963.	0.01609	0.00618
104.	666.6	586.9	569.4	572.5	2095.	1.498	2161.	113.0	3200.0	15.75	1761.	0.01677	0.00645
105.	667.7	585.4	569.4	572.3	2096.	1.292	1975.	113.0	3018.5	14.82	1613.	0.01736	0.00664
106.	665.1	583.9	569.9	572.6	2095.	1.091	1783.	113.0	2689.6	13.68	1461.	0.01806	0.00679
107.	666.8	581.8	569.9	572.2	2095.	0.891	1577.	113.0	2489.6	12.84	1296.	0.01893	0.00721
108.	668.3	579.9	570.1	572.2	2095.	0.715	1366.	113.0	2241.9	11.74	1127.	0.02031	0.00761
109.	684.8	599.9	566.8	572.1	2083.	3.382	3436.	121.5	5420.2	21.19	2737.	0.01450	0.00544
110.	685.2	599.5	567.3	572.4	2083.	3.196	3321.	121.5	5290.6	20.64	2646.	0.01469	0.00549
111.	686.2	599.0	567.5	572.5	2085.	3.003	3201.	121.5	5190.2	20.06	2552.	0.01487	0.00553
112.	687.1	597.9	567.1	572.2	2086.	2.808	3089.	121.5	5123.4	19.65	2464.	0.01496	0.00561
113.	688.1	597.3	567.7	572.5	2087.	2.615	2948.	121.5	4976.1	18.98	2353.	0.01532	0.00568
114.	687.4	596.0	567.7	572.2	2087.	2.412	2831.	121.5	4813.3	18.51	2264.	0.01537	0.00577
115.	689.5	595.2	567.8	572.4	2087.	2.194	2679.	121.5	4699.1	17.82	2144.	0.01563	0.00587

116.	688.7	594.2	568.4	572.4	2088.	2.009	2556.	121.5	4491.9	17.21	2049.	0.01576	0.00595
117.	690.8	592.9	568.4	572.4	2088.	1.795	2379.	121.5	4329.5	16.37	1909.	0.01629	0.00608
118.	691.6	591.2	568.7	572.5	2089.	1.585	2217.	121.5	4137.7	15.86	1783.	0.01663	0.00632
119.	694.2	589.8	568.7	572.3	2089.	1.381	2039.	121.5	3957.5	14.91	1642.	0.01717	0.00646
120.	683.3	594.9	567.8	572.2	2095.	2.405	2841.	120.0	4669.4	18.89	2278.	0.01532	0.00587
121.	685.4	593.8	568.2	572.5	2096.	2.102	2626.	120.0	4473.0	17.84	2108.	0.01570	0.00600
122.	687.7	591.5	567.7	571.8	2097.	1.799	2396.	120.0	4285.0	16.89	1928.	0.01621	0.00623
123.	689.5	590.1	568.8	572.5	2098.	1.502	2144.	120.0	3964.4	15.63	1728.	0.01656	0.00644
124.	689.5	587.9	568.7	572.2	2097.	1.285	1956.	120.0	3692.5	14.72	1582.	0.01751	0.00665
125.	690.6	586.4	569.3	572.6	2098.	1.078	1757.	120.0	3403.3	13.60	1424.	0.01825	0.00685
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127.	694.6	581.9	569.8	572.5	2096.	0.708	1335.	120.0	2796.1	11.43	1091.	0.02065	0.00757
128.	690.4	587.5	571.3	572.7	2079.	2.696	3091.	349.7	3610.2	19.41	2531.	0.01468	0.00556
129.	690.7	588.1	571.1	572.7	2079.	2.705	3092.	275.2	3593.9	19.36	2529.	0.01469	0.00554
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132.	649.2	589.9	569.1	572.3	2079.	2.686	3052.	120.0	3360.9	18.79	2489.	0.01460	0.00545
133.	649.0	591.0	568.7	572.7	2078.	2.689	3060.	91.5	3297.9	19.26	2492.	0.01480	0.00557
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135.	646.4	592.1	566.2	572.4	2078.	2.679	3053.	46.5	3079.5	23.36	2484.	0.01477	0.00676
136.	648.7	589.4	568.7	572.4	2133.	2.432	2925.	100.4	3227.2	18.84	2388.	0.01568	0.00570
137.	690.3	589.0	570.0	572.6	2129.	2.433	2933.	149.5	3340.8	18.36	2395.	0.01501	0.00554
138.	690.6	588.1	571.1	573.0	2132.	2.426	2937.	220.3	3411.3	18.64	2402.	0.01498	0.00562
139.	649.6	586.9	571.2	572.6	2133.	2.422	2937.	306.7	3419.8	18.62	2407.	0.01500	0.00561
140.	690.0	586.8	571.6	572.8	2132.	2.421	2937.	402.3	3453.1	18.59	2408.	0.01500	0.00560
141.	690.1	586.1	571.5	572.5	2132.	2.429	2939.	501.1	3489.0	18.70	2411.	0.01505	0.00563
142.	690.7	586.1	571.8	572.6	2130.	2.429	2938.	597.8	3520.9	18.73	2411.	0.01505	0.00564

SURFACE EIGHT

RUN	AIR IN DEG R	AIR OUT DEG R	H2O IN DEG R	H2O OUT DEG R	AIR MEAN PRESSURE PSFA	CORE DP IN. H2O	AIR FLOW SCFM	WATER FLOW GPM	HEAT TRANSFER BTU/MIN	AIR HEAT TRANSFER COEFF. BTU/HR FT F	AIR REYNOLDS NUMBER	F	J
1.	662.4	601.0	567.1	569.0	2146.	5.457	1756.	138.0	2004.1	11.89	2654.	0.00793	0.00228
2.	661.7	606.2	572.6	574.5	2154.	6.412	1922.	138.0	1983.3	12.59	2894.	0.00774	0.00220
3.	663.0	611.5	577.4	579.4	2156.	7.470	2089.	138.0	2001.6	13.08	3130.	0.00758	0.00210
4.	662.1	615.5	581.6	583.6	2163.	8.906	2304.	138.0	1997.0	13.79	3441.	0.00741	0.00201
5.	661.8	619.8	585.8	587.9	2174.	10.946	2588.	136.5	2019.4	14.88	3854.	0.00720	0.00193
6.	672.6	630.2	591.8	594.1	2201.	13.925	2959.	136.5	2332.9	16.36	4350.	0.00696	0.00185
7.	646.2	597.0	570.3	571.9	2071.	5.000	1649.	117.5	1508.9	11.44	2519.	0.00803	0.00233
8.	648.1	597.2	571.3	572.9	2072.	5.010	1649.	145.5	1558.3	11.39	2517.	0.00805	0.00232
9.	648.3	598.5	573.1	574.5	2208.	5.057	1668.	172.5	1544.2	11.02	2544.	0.00843	0.00222
10.	647.9	597.8	574.2	575.3	2123.	5.003	1668.	221.5	1553.5	11.21	2547.	0.00804	0.00226
11.	647.1	597.1	574.6	575.5	2124.	5.007	1669.	285.0	1550.6	11.16	2552.	0.00805	0.00225
12.	647.1	596.0	574.4	575.3	2156.	4.995	1670.	383.0	1586.0	11.33	2557.	0.00816	0.00228
13.	651.8	595.0	573.1	573.8	2100.	5.005	1662.	566.5	1753.7	11.53	2542.	0.00805	0.00233
14.	645.5	589.4	569.3	570.2	2134.	3.515	1363.	313.5	1421.6	9.96	2101.	0.00863	0.00246
15.	646.2	592.4	571.4	572.4	2137.	4.012	1475.	313.5	1474.2	10.41	2266.	0.00837	0.00237
16.	645.6	595.1	573.3	574.3	2139.	4.702	1620.	314.0	1518.0	10.90	2481.	0.00812	0.00227
17.	648.9	609.4	576.7	577.9	2136.	16.442	3260.	322.0	2394.7	17.11	4920.	0.00679	0.00176
18.	648.4	610.1	579.8	581.0	2134.	14.986	3092.	321.0	2202.2	16.48	4666.	0.00688	0.00179
19.	642.5	609.7	584.4	585.5	2132.	13.997	2977.	322.0	1823.2	15.94	4507.	0.00694	0.00180
20.	645.9	608.0	585.3	586.3	2109.	8.905	2303.	320.5	1622.5	13.70	3488.	0.00734	0.00200
21.	651.2	607.6	585.9	586.9	2100.	6.410	1901.	321.5	1539.4	12.08	2875.	0.00773	0.00213
22.	673.1	622.3	591.4	594.2	2059.	15.723	3036.	105.0	2306.2	16.84	4454.	0.00695	0.00186
23.	678.8	632.9	600.5	602.6	2184.	8.935	2281.	144.0	1949.3	13.50	3349.	0.00745	0.00198
24.	678.6	627.1	604.0	605.7	2096.	4.012	1396.	103.0	1335.7	10.38	2056.	0.00867	0.00249
25.	641.2	604.9	582.8	584.6	2138.	5.005	1666.	85.0	1122.4	11.34	2535.	0.00804	0.00229

26.	641.5	605.4	584.2	585.7	2138.	5.000	1665.	99.0	1115.7	11.04	2532.	0.00804	0.00223
27.	642.5	606.0	586.0	587.3	2138.	5.008	1664.	120.0	1127.1	11.11	2529.	0.00805	0.00224
28.	641.7	606.6	588.6	589.8	2132.	4.997	1660.	145.0	1082.2	11.16	2523.	0.00805	0.00226
29.	638.0	606.6	590.9	591.9	2129.	5.005	1658.	174.0	969.3	10.97	2525.	0.00808	0.00222
30.	638.8	607.2	592.1	593.0	2129.	5.010	1656.	220.0	971.8	10.81	2521.	0.00810	0.00219
31.	638.8	606.9	592.7	593.5	2125.	5.000	1657.	286.0	981.0	11.03	2522.	0.00807	0.00224
32.	677.2	619.9	561.0	564.4	2119.	15.695	3096.	123.0	3298.7	16.76	4572.	0.00697	0.00181
33.	683.5	613.9	561.7	564.6	2105.	8.925	2253.	124.0	2917.8	13.80	3335.	0.00753	0.00205
34.	687.2	606.6	561.5	564.1	2097.	5.458	1702.	123.0	2551.4	11.69	2533.	0.00813	0.00231
35.	651.0	601.7	561.0	563.4	2094.	4.012	1419.	123.0	2355.0	10.61	2119.	0.00665	0.00251
36.	706.3	607.9	557.2	560.8	2092.	4.020	1404.	84.0	2571.2	10.73	2072.	0.00672	0.00256
37.	703.1	615.3	559.4	563.3	2097.	5.458	1677.	84.0	2743.3	11.61	2461.	0.00823	0.00232
38.	692.2	621.3	560.7	565.0	2103.	8.905	2223.	84.0	2931.9	13.72	3258.	0.00761	0.00207
39.	674.1	628.3	562.0	566.6	2113.	15.678	3064.	84.0	2613.0	11.78	4500.	0.00701	0.00129
40.	640.4	639.1*****			2161.	4.012	1409.	0.0	0.0*****		2091.	0.00671*****	
41.	642.1	641.1*****			2169.	5.458	1717.	0.0	0.0*****		2542.	0.00757*****	
42.	640.2	639.4*****			2165.	8.925	2292.	0.0	0.0*****		3400.	0.00731*****	
43.	670.5	669.4*****			2230.	15.620	3098.	0.0	0.0*****		4440.	0.00686*****	

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