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K-1847

PERFORMANCE OF
COMPACT HEAT TRANSFER SURFACES -
FINNED AND BARE TUBE BANKS

B. Cox

OAK RIDGE GASEOUS DIFFUSION PLANT
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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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Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22151
Price: Printed Copy \$5.45; Microfiche \$1.45

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Date of Issue: November 9, 1973

Report Number: K-1847

Subject Category: UC-38, Engineering
and Equipment

PERFORMANCE OF COMPACT HEAT TRANSFER SURFACES-
FINNED AND BARE TUBE BANKS

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ABSTRACT

Heat transfer and flow friction characteristics were determined experimentally for seven high-finned tube banks. A variety of fin types were represented: plate fins, integral smooth helical fins, integral serrated fins, and helical serrated fins. The experimental data results plus data from the open literature are used to determine the effects that tube pitch has on tube bank performance.

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NOMENCLATURE

Basic Symbols

- a = constant in equation 5, dimensionless.
 A = area, sq ft.
 b = constant in equation 2, dimensionless.
 c = specific heat at constant pressure, Btu/lb-°F.
 D = hydraulic diameter, ft.
 E = pumping power, fhp.
 E'' = pumping power per unit surface area, fhp/sq ft.
 E''' = pumping power per unit volume, fhp/cu ft.
 f = Fanning friction 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.
 j = Colburn j-factor, $St Pr^{2/3}$, dimensionless.
 k = thermal conductivity, Btu/hr-ft-°F.
 L = heat exchanger length, ft.
 m = constant in equation 5, dimensionless.
 n = constant in equation 2, dimensionless.
 p = constant in equation 3, dimensionless.
 Pr = Prandtl number, $c\mu/k$, dimensionless.
 Q'' = heat transfer rate per unit temperature difference per unit surface area, Btu/hr-sq ft-°F.
 Q''' = heat transfer rate per unit temperature difference per unit volume, Btu/hr-cu ft-°F.
 Re = Reynolds number, GD/μ , dimensionless.
 S_1 = lateral tube spacing, in.

St = Stanton number, h/cG , dimensionless.

S_t = transverse tube spacing, in.

t = effective wall thickness, ft.

V = velocity, ft/sec.

α = heat transfer area per unit total volume, sq ft/cu ft.

δ = fin segment thickness, in.

ΔP = static pressure drop, psi.

ϵ = weighted fin efficiency, dimensionless.

Θ = ratio of pumping power to heat transfer, fhp-hr- $^{\circ}F/Btu$.

μ = viscosity, lb/ft-hr.

ρ = density, lb/cu ft.

σ = ratio of free-to-frontal area, dimensionless.

Subscripts

c = coolant or water side.

f = fin.

$fric$ = flow friction.

$front$ = refers to core front.

h = hot or gas side.

min = minimum free flow.

t = total.

w = wall.

PERFORMANCE OF COMPACT HEAT TRANSFER SURFACES- FINNED AND BARE TUBE BANKS

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, high-finned tube surfaces appeared attractive for these designs. High-finned tubes also find applications in economizers, air-conditioners, gas-cooled nuclear reactors, air-cooled condensers, plus others discussed in reference 1.

This study documents the latest results from the Oak Ridge Gaseous Diffusion Plant (ORGDP) program to evaluate compact heat transfer surfaces. Previous reports^{2,3} described the experimental apparatus and the data reduction procedure. Those studies emphasized performance comparisons of different types of compact surfaces, including finned tubes. The present work emphasizes performance comparisons of different arrangements of finned tubes.

BASIC DESIGN DATA

Experimental heat transfer and pressure drop data were taken with air flowing across seven different banks of finned tubes. The data were reduced to the dimensionless form of Colburn j -factors and Fanning friction factors. The basic design data are shown graphically in figures 1-7. Descriptions of the geometries accompany the graphs. The experimental data and results are tabulated in Appendix A.

Table 1 describes the 13 surfaces tested during the present program. It should be noted that several of the surfaces were retested but retained their original designation number. Thus far, the compact surfaces tested have been numbered consecutively. (If many more are tested this practice could become cumbersome and a labeling system similar to that of reference 4 might be preferable.)

Several other sets of finned tube data were taken from the open literature and transformed to f and j versus Reynolds number curves. One set was from the work of Ackerman and Brunsvold,⁵ who reported results with studded tubes. Another set was from the work of Jameson,⁶ who reported results with helically finned tubes. For bare tube comparisons, the f and j curves of Kays and London⁴ were used. Appendix B discusses the derivations of these f and j curves.

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 1
SURFACE 6, INTEGRAL TUBE-HELICAL FIN

TUBE O.D. = 0.939 IN.
 FIN PITCH = 12 PER IN.
 δ = 0.016 IN.
 A_f/A_t = 0.978
 D = 0.00778 FT
 σ = 0.4851
 α = 249.4 FT²/FT³

Figure 2
SURFACE 8, EXPANDED TUBE - CONTINUOUS FIN

Figure 3
 SURFACE 9, EXPANDED TUBE - LOUVERED FIN

FIN PITCH	= 8.0 per in.
FIN WIDTH	= 0.266 in.
δ	= 0.017 in.
A_f/A_t	= 0.891
D	= 0.02686 ft
σ	= 0.74
α	= 110.2 ft ² /ft ³

NOTE: FIN EDGES NOT INCLUDED IN HEAT TRANSFER AREA.

Figure 4

SURFACE 10, INTEGRAL FLAT TUBE - SERRATED FIN

Figure 5
SURFACE 11, WELDED TUBE - SERRATED FIN

NOTE: POOR BOND BETWEEN TUBE AND FINs.

Figure 6
SURFACE 12, WELDED 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	= 0.02587 ft
σ	= 0.581
α	= 89.84 ft ² /ft ³

NOTES: FIN EDGES NOT INCLUDED IN HEAT TRANSFER AREA.
FLOW AREA IN TRANSVERSE SPACES EQUALS FLOW AREA IN
DIAGONAL SPACES.

Figure 7

SURFACE 13, INTEGRAL TUBE - SERRATED FIN

Table 1

SUMMARY OF EXPERIMENTAL HEAT TRANSFER SURFACES

Surface No.	Surface Description	Figure No. This Report	Figure No. Reference 2
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	1	10
7	Staggered copper tubes, mechanically bonded aluminum plate fins	-	11
8	In-line copper tubes, mechanically bonded aluminum plate fins	2	12
9	In-line tubes, mechanically bonded to plate fins, all aluminum	3	-
10	In-line aluminum flat tubes, integral serrated fins	4	-
11	In-line tubes, spot welded serrated helical fins, all aluminum	5	-
12	In-line tubes, spot welded serrated helical fins, all aluminum	6	-
13	Staggered aluminum tube, integral serrated fins	7	-

ANALYSIS OF RESULTS

PERFORMANCE EQUATIONS

The methods used in determining tube bank performance were those described in reference 3. Pertinent equations from that reference are as follows:

Colburn j factors were defined by

$$j = \frac{h}{cG} Pr^{2/3}. \quad (1)$$

If experimental j factors are plotted versus Reynolds number, it is found that the data can be approximated by equations of the form

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

or

$$St = b Re^n Pr^p \quad (3)$$

where b and n are constants and $p = -2/3$ for this study.

Fanning friction factors were defined by the expression

$$f = \frac{\Delta P_{fric}}{\frac{L}{D} \frac{G^2}{2 \rho g_c}} \quad (4)$$

If experimental f factors are plotted versus Reynolds number, it is found that the data can again be approximated by equations of the form

$$f = a Re^m \quad (5)$$

where a and m are constants.

Heat transfer rates per unit temperature difference were based on a unit of surface area and on a unit of volume:

$$Q'' = \frac{\epsilon k b Re^{n+1} Pr^{p+1}}{D}, \quad (6)$$

$$Q''' = \frac{4 \sigma \epsilon k b Re^{n+1} Pr^{p+1}}{D^2} \quad (7)$$

Pumping power required to overcome fluid flow friction was calculated using the following expressions:

$$E = \Delta P_{fric} A_{min} V, \quad (8)$$

$$E'' = \frac{\mu^3 a Re^{m+3}}{2 D^3 \rho^2 g_c} \quad (9)$$

$$E''' = \frac{2 \sigma \mu^3 a Re^{m+3}}{D^4 \rho^2 g_c} \quad (10)$$

Equations (8), (9), and (10) represent total pumping power, pumping power per unit of surface area, and pumping power per unit of volume, respectively.

The ratio of energy expended to energy transferred is calculated by

$$\theta = \frac{E''}{Q''} = \frac{E'''}{Q'''} = \frac{\mu^3 a \text{Re}^{m-n+2}}{2 D^2 \rho^2 g_c \epsilon k b \text{Pr}^{p+1}} \quad (11)$$

EFFECTS OF TUBE PITCH

To evaluate the effects that tube pitch had on tube bank performance, the method described in reference 3 was used: values of Q'' and Q''' were plotted versus θ , equations (6), (7), and (11). This type of graph gives a direct comparison of the heat transfer area and volume required by different tube banks at a given power expenditure. For a given mass throughput, values of face mass velocity then indicate the relative frontal areas required for the tube bank heat exchanger. Thermophysical properties were evaluated at standard conditions.*

On the above basis, Ackerman and Brunsvold's data are shown in figure 8; Jameson's in figure 9; Cox and Jallouk's in figure 10; and Kays and London's in figure 11. Tube arrangement designations are from table B-1.

With the exception of in-line AB-4, the figure 8 heat transfer rates per unit area, Q'' , are very close to one another. The differences may well be within the experimental accuracy of the data, but some trends are apparent:

1. If S_t is held constant, a decrease in S_1 (AB-1,3,5), requires either an increased power expenditure or an increased frontal area at a given Q'' .
2. If S_1 is held constant, a decrease in S_t (AB-1,6; AB-2,5) increases Q'' but also increases the pumping power for a given frontal area.
3. The staggered and in-line arrangements, which have equal S_t , S_1 , and α (AB-3,4), show the staggered arrangement to have both a higher Q'' and higher pumping power requirement at the same G_{face} .
4. The highest performance surfaces (AB-3,6) are closest to an equilateral triangle arrangement. The closer packed AB-6 requires either a larger frontal area or higher pumping power expenditure at comparable values of Q'' .
5. Volumetric performance curves, Q''' , depend almost exclusively on the surface area density α .

Figure 9 shows the following:

1. At a given S_t , a decrease in S_1 (J-B,E; J-C,D) either decreases Q'' at a given value of θ or increases θ for the same Q'' and G_{face} .

*Standard conditions used in this study were dry air at 1 atm and 500°F.

Figure 8

HEAT TRANSFER RATES FOR TUBE BANKS AB-1, 2, 3, 4, 5, 6
DESIGNATIONS FROM TABLE B-1

Figure 9
HEAT TRANSFER RATES FOR TUBE BANKS J-A, B, C, D, E
DESIGNATIONS FROM TABLE B-1

2. When S_1 is held constant, decreasing S_t (J-A,B,C) either increases Q'' and lowers G_{face} at a given θ , or increases both Q'' and θ at a given G_{face} .
3. The relative performance of the only tube tank with the minimum flow area in the diagonal spacings, J-D, was poor.
4. The volumetric performance curves, Q''' , were not strictly dependent on α . Arrangement J-A transferred more heat than J-D, even though the latter had a higher α .

Figure 10 shows the two close packed staggered arrangements (COX-2,3) to be higher performance than the widely spaced COX-1. The equilateral triangle arrangement, COX-2, appears to be slightly superior to the equi-velocity COX-3. The in-line arrangement, COX-1, has lower levels of Q'' and Q''' . At a given G_{face} , however, COX-1 has a much lower pumping power requirement.

The bare tube data in figure 11 shows that volumetric performance follows the same trend as the surface area density α . On an area basis, relative performance often changes with increasing θ . However, some trends are apparent:

1. If S_t is held constant, a decrease in S_1 (KL-5,7,8) increases Q'' but not θ at a given G_{face} .
2. If S_1 is held constant, a decrease in S_t (KL-5,6; KL-7,9) can increase Q'' , but it also requires either a decrease in G_{face} or an increase in θ .
3. In-line arrangements are low performance (KL-13,14). Closer packed KL-14 requires a smaller G_{face} for the same Q'' .
4. There is no distinct effect from A_{min} being in the diagonal tube spacings (KL-9,10). However, at the same α (KL-5,10) the tube bank with A_{min} in the diagonal spacings would require a smaller G_{face} at equal values of Q'' and θ .

The preceding comments indicate the tradeoffs required among heat transfer area, volume, pumping power, and frontal area in a final tube bank design. Close packed tube arrangements generally had higher curves for Q'' and Q''' . This corresponds to lower heat transfer area and volume requirements. If there existed no restrictions on frontal areas, then those curves would probably indicate the desired tube arrangements. However, if frontal area were fixed, the selection of *best* pitch might become more difficult. An arrangement with a lower performance curve might then save enough in pumping power to offset its increased area or volume requirement.

In general, the statements made thus far should be applicable for turbulent flow through most tube banks. However, the effect that tube bank depth has on performance was neglected. Neal and Hitchcock⁸ found row-to-row heat transfer for finned tubes to vary considerably with the tube pitch.

Figure 10

HEAT TRANSFER RATES FOR TUBE BANKS COX-1, 2, 3
DESIGNATIONS FOR SURFACES 4, 5, 13 IN TABLE 1

Figure 11

HEAT TRANSFER RATES FOR TUBE BANKS KL-5, 6, 7, 8, 9, 10, 13, 14
DESIGNATIONS FROM TABLE B-2

Kays, London, and Lo⁹ found the row-to-row effects for bare tubes to vary only mildly with flow rate and pitch. Since pressure drop also exhibits row-to-row variations,¹⁰ designers of shallow tube banks should exercise due caution.

COMMENTS

Several of the core samples that were tested had geometries or data results that are worth noting. One core sample emitted high-frequency noises.

The core sample designated surface 8 was retested several times in an attempt to resolve the anomalous heat transfer behavior discussed in reference 2. It had been felt that tube side fouling resulted in the low heat transfer coefficients. However, numerous acid cleanings failed to improve the heat transfer rate. New headers to improve flow distribution also had no effect. Similarly, surface 9 appeared to exhibit poor heat transfer behavior. Several possible answers can be offered to at least partially explain this.

Both surface 8 and surface 9 were in-line tubes expanded onto plate fins. An obvious possibility is the existence of an appreciable gap or bond resistance between fin and tube. A less obvious explanation is the inherent error in the method of data reduction.

For purposes of data reduction, it was assumed² that heat transfer coefficients were always uniform over the entire fin surface. Flow studies⁸ in tube banks similar to surface 6 have shown considerable variation in heat transfer coefficients and the existence of *dead* and reverse flow zones. With in-line tubes such as surfaces 8 and 9 these effects might be expected to become even more significant. The effects of heat transfer area on computed *j*-lines can be explained as follows.

Values for *h* come from *ch* which depend upon *U* which, in turn, varies inversely with heat transfer area. Plots of *h* versus *ch* are not linear. In fact, the slope increases as *ch* increases. Thus, the larger the numerical value for *ch*, the greater the effect of slight changes on calculated *h* and *j*. This means that data reduced from small overall *U*'s give *apparent* *h*'s and *j*'s higher than those from higher overall *U*'s for the same amount of *dead* heat transfer area. Whether experimental *U*'s were high or low depended upon whether the gas used in the experiments had a high or low thermal conductivity.

The two surfaces with spot welded, serrated helical fins had poor fin-to-tube bonding and poor uniformity of geometry. These surfaces, 11 and 12, had their data reduced and plotted using average geometric values and assuming no fin bond resistance.

Over the higher range of experimental Reynolds numbers, surface 13 emitted a high-frequency whistling noise. This same phenomena was reported earlier for surface 5. In neither case did any irregularities appear in the data. However, inspection of the petal fins for these surfaces showed that they had been flattened and in some cases broken. It is not known at what fluid velocity this damage occurred. There was no degradation in performance over the several weeks of testing.

CONCLUSIONS

1. Basic heat transfer and flow friction design data are presented for seven high-finned tube banks. Fanning friction factors and Colburn j-factors are tabulated in Appendix A and plotted versus Reynolds number in figures 1 through 7.
2. Based on the finned tube bank results displayed in figures 8, 9, and 10:
 - a. An equilateral triangle tube pitch is attractive based on surface heat transfer rates, but it requires a large frontal area for a given pumping power expenditure. A close-packed equilateral triangle pitch is attractive based on volumetric heat transfer rates.
 - b. In-line arrangements display a lower surface heat transfer rate, but at a given pumping power they can operate with smaller frontal areas than the staggered banks.
 - c. Decreasing the transverse tube spacing instead of the longitudinal spacing is more effective in achieving a high-performance, high-area density tube bank.
3. Based on the bare tube bank results in figure 11:
 - a. In-line tubes are low performance arrangements.
 - b. Decreasing the longitudinal tube spacing instead of the transverse spacing is more effective in achieving a high-performance, high-area density tube bank.
4. Since entrance effects vary with both the type of tube and the tube arrangement, design of shallow tube banks may be difficult.
5. The use of a fin efficiency, especially for plate finned tubes, is of questionable value. It can lead to serious errors, especially when trying to apply data from one fluid to another.

APPENDIX A

Geometric and Experimental Data

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APPENDIX A

GEOMETRIC AND EXPERIMENTAL DATA

Table A-1

CORE SAMPLE GEOMETRIC DATA

	Surface Number				
	9	10	11	12	13
k_f , Btu/hr-ft-°F	119	96	119	119	96
k_w , Btu/hr-ft-°F	119	96	119	119	96
L_h , ft	1.094	1.458	1.445	1.083	0.607
L_c , ft	1.00	1.00	1.00	1.00	1.00
$A_{min, h}$, sq ft	0.483	0.802	0.514	0.707	0.631
$A_{min, c}$, sq ft	0.151	0.0892	0.149	0.0386	0.0760
A_h , sq ft	195	174	115	31.0	54.8
A_c , sq ft	8.16	28.0	9.49	4.88	9.01
A_w , sq ft	9.64	24.05	11.3	6.74	11.2
A_{front} , sq ft	1.00	1.083	1.083	1.083	1.083
t , ft	0.00733	0.00292	0.00659	0.00707	0.00464
No. Rows Wide	5	10	6	7	9
No Rows Deep	7	7	8	7	10

SURFACE NUMBER 5

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.	660.9	589.7	570.5	572.1	2101.	2.360	1134.	128.0	1499.4	23.88	3543.	0.02659	0.00796
2.	662.8	588.3	570.7	572.0	2092.	1.940	1056.	128.0	1461.1	23.65	3304.	0.02522	0.00847
3.	666.0	585.5	571.1	572.2	2087.	1.350	842.	131.0	1259.7	20.60	2646.	0.02764	0.00925
4.	667.3	583.9	571.1	572.3	2119.	1.000	736.	130.0	1141.8	18.93	2319.	0.02731	0.00967
5.	664.6	584.6	570.9	572.0	2146.	1.130	800.	130.0	1188.6	19.68	2517.	0.02646	0.00931
6.	645.3	603.1	569.4	572.1	2132.	14.360	3368.	126.0	2638.0	51.74	10421.	0.01817	0.00580
7.	647.5	602.1	569.6	572.0	2128.	11.900	3045.	126.0	2566.9	48.52	9423.	0.01844	0.00602
8.	649.0	599.7	569.8	572.0	2122.	9.040	2583.	126.0	2366.5	43.75	8008.	0.01951	0.00640
9.	650.8	597.8	569.7	571.8	2116.	7.120	2238.	126.0	2203.8	39.28	6949.	0.02047	0.00663
10.	652.7	595.2	570.3	572.2	2103.	4.980	1814.	126.0	1937.5	33.69	5643.	0.02178	0.00702
11.	652.6	593.6	570.1	572.0	2098.	4.120	1632.	126.0	1820.3	31.30	5086.	0.02227	0.00724
12.	663.6	586.9	570.5	571.8	2144.	1.520	953.	126.0	1356.9	21.97	2987.	0.02495	0.00872
13.	651.0	597.2	569.2	571.8	2110.	4.960	1816.	82.0	1815.6	33.54	5639.	0.02164	0.00698
14.	651.1	596.7	569.6	572.1	2110.	4.960	1824.	96.0	1843.5	33.02	5667.	0.02148	0.00684
15.	653.3	595.7	570.2	572.2	2110.	4.930	1809.	118.5	1938.8	33.71	5624.	0.02173	0.00704
16.	653.6	594.5	570.4	572.1	2110.	4.970	1827.	160.0	2015.4	33.58	5688.	0.02152	0.00694
17.	654.5	593.5	570.8	572.1	2110.	4.950	1829.	212.0	2072.6	33.55	5699.	0.02144	0.00693
18.	656.2	592.6	570.8	571.9	2110.	4.970	1821.	296.0	2151.5	33.45	5679.	0.02174	0.00694
19.	657.6	591.8	570.6	572.1	2098.	3.490	1492.	158.0	1824.2	30.03	4653.	0.02267	0.00761
20.	659.6	590.6	570.5	572.1	2094.	3.010	1373.	158.0	1760.3	28.77	4286.	0.02309	0.00792
21.	666.1	585.9	570.9	572.2	2067.	1.400	858.	158.0	1280.1	19.88	2694.	0.02731	0.00876
22.	669.9	583.8	571.1	572.2	2083.	0.995	730.	156.0	1169.3	18.46	2299.	0.02718	0.00956
23.	670.6	583.2	571.0	572.1	2086.	0.990	700.	156.0	1137.4	18.02	2205.	0.02684	0.00974
24.	650.0	648.9*****			2175.	10.970	2808.	0.0*****			8393.	0.01916*****	
25.	650.0	648.7*****			2132.	7.120	2158.	0.0*****			6449.	0.02072*****	
26.	650.0	648.5*****			2107.	4.250	1588.	0.0*****			4748.	0.02258*****	
27.	650.0	648.1*****			2090.	2.060	1041.	0.0*****			3113.	0.02531*****	
28.	649.8	647.7*****			2085.	1.520	883.	0.0*****			2640.	0.02595*****	

SURFACE NUMBER 8

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.	652.7	651.6			2185.	12.100	2758.	0.0	0.0		4033.	0.00676	
2.	652.7	651.4			2148.	7.120	2009.	0.0	0.0		2938.	0.00740	
3.	653.2	651.5			2131.	4.740	1549.	0.0	0.0		2265.	0.00822	
4.	653.8	652.9			2118.	3.130	1193.	0.0	0.0		1743.	0.00909	
5.	654.4	652.1			2111.	1.980	863.	0.0	0.0		1260.	0.01097	
6.	678.0	607.7	569.7	571.7	2218.	16.620	3436.	121.0	1936.9	20.79	5216.	0.00644	0.00203
7.	638.8	605.1	570.1	571.9	2168.	12.270	2831.	120.5	1775.0	18.12	4305.	0.00689	0.00215
8.	640.3	601.4	570.4	572.0	2126.	7.930	2155.	120.5	1557.1	14.84	3286.	0.00759	0.00231
9.	644.3	597.0	570.7	572.0	2154.	4.150	1505.	120.5	1323.1	11.45	2301.	0.00832	0.00256
10.	647.2	593.2	570.4	571.7	2151.	2.750	1172.	120.5	1176.9	9.84	1797.	0.00914	0.00283
11.	651.6	587.5	570.7	571.7	2104.	1.610	843.	120.5	1004.9	8.70	1301.	0.01020	0.00348
12.	638.1	607.1	569.7	571.7	2225.	16.150	3388.	119.5	1952.8	22.07	5145.	0.00647	0.00219
13.	639.0	605.2	570.0	571.9	2211.	12.400	2891.	120.0	1819.1	19.17	4395.	0.00681	0.00223
14.	639.4	603.1	569.8	571.7	2178.	9.880	2540.	120.0	1714.4	17.49	3869.	0.00696	0.00232
15.	641.3	601.6	570.3	572.0	2170.	7.570	2160.	120.0	1591.1	15.22	3291.	0.00737	0.00237
16.	644.5	598.6	570.2	571.7	2159.	5.040	1683.	120.0	1434.2	12.60	2569.	0.00807	0.00252
17.	638.0	607.8	569.4	571.7	2226.	15.850	3356.	114.0	1885.8	20.15	5094.	0.00647	0.00202
18.	638.1	606.4	569.4	571.6	2205.	13.980	3090.	113.5	1916.8	19.16	4696.	0.00668	0.00208
19.	638.2	604.4	570.5	572.3	2180.	10.960	2674.	115.0	1679.2	17.40	4071.	0.00695	0.00219
20.	641.2	603.8	570.1	571.9	2184.	9.050	2386.	115.0	1657.5	15.91	3628.	0.00723	0.00224
21.	641.1	602.7	570.4	572.1	2160.	8.050	2221.	115.0	1585.1	15.09	3382.	0.00736	0.00228
22.	643.0	599.6	570.2	571.8	2131.	6.040	1871.	126.0	1509.4	13.58	2855.	0.00772	0.00244
23.	644.9	595.9	570.2	571.5	2116.	4.010	1464.	126.0	1332.6	11.36	2240.	0.00836	0.00261
24.	654.4	595.8	570.0	571.3	2136.	3.070	1262.	126.0	1375.9	10.53	1925.	0.00868	0.00281
25.	657.1	591.4	570.8	571.9	2112.	2.100	972.	126.0	1187.0	9.27	1490.	0.00997	0.00321
26.	640.2	605.0	569.8	571.3	2153.	15.950	3316.	174.0	2169.9	21.59	5040.	0.00647	0.00219
27.	641.6	602.6	570.6	572.0	2146.	11.080	2661.	174.0	1929.2	17.96	4051.	0.00700	0.00227
28.	643.5	599.2	570.8	572.0	2128.	7.120	2069.	174.0	1702.4	14.98	3158.	0.00743	0.00244
29.	645.3	594.7	571.3	572.2	2160.	4.050	1491.	174.0	1400.6	11.70	2284.	0.00834	0.00264
30.	639.8	600.6	570.1	572.0	2158.	5.988	1878.	89.0	1367.1	14.08	2867.	0.00768	0.00252
31.	640.2	599.8	570.3	572.0	2158.	5.995	1885.	105.0	1413.6	13.80	2879.	0.00764	0.00246
32.	641.5	599.6	570.4	571.9	2162.	5.997	1888.	118.0	1470.9	13.80	2882.	0.00764	0.00246
33.	642.5	598.7	570.5	571.9	2162.	5.997	1858.	139.0	1510.1	13.45	2838.	0.00790	0.00244
34.	643.1	597.6	570.9	572.0	2162.	6.003	1890.	169.0	1598.2	14.18	2889.	0.00766	0.00252
35.	643.9	596.7	571.2	572.1	2162.	6.009	1891.	222.0	1658.0	13.94	2893.	0.00766	0.00248
36.	644.6	596.8	570.5	571.7	2106.	4.990	1660.	150.0	1474.8	12.71	2539.	0.00804	0.00258
37.	636.6	592.4	570.5	571.5	2089.	2.520	1085.	150.0	1293.9	9.65	1661.	0.00948	0.00299
38.	659.8	589.0	570.5	571.5	2115.	1.860	896.	150.0	1178.9	8.92	1377.	0.01044	0.00335
39.	643.1	596.2	570.7	572.0	2132.	3.960	1460.	124.0	1273.1	10.94	2236.	0.00836	0.00252
40.	644.1	593.7	570.6	571.7	2127.	3.090	1261.	124.0	1182.1	10.11	1935.	0.00877	0.00270
41.	689.7	629.4	573.2	576.0	2138.	11.070	2576.	124.0	2891.4	16.87	3758.	0.00708	0.00219
42.	692.6	626.8	572.9	575.7	2132.	8.890	2284.	124.0	2756.3	15.78	3335.	0.00725	0.00231
43.	695.3	621.6	573.2	575.8	2120.	6.240	1814.	124.0	2488.4	13.27	2659.	0.00807	0.00245
44.	699.8	616.2	573.4	575.7	2109.	4.310	1439.	124.0	2239.4	11.38	2116.	0.00889	0.00265
45.	706.7	606.7	574.7	576.2	2100.	2.310	1001.	124.0	1863.0	9.56	1485.	0.00995	0.00320
46.	707.4	600.3	574.5	575.7	2164.	1.720	830.	124.0	1653.7	8.90	1241.	0.01121	0.00360
47.	650.2	589.7	571.0	572.0	2147.	2.000	951.	124.0	1069.0	9.06	1463.	0.01012	0.00321
48.	648.9	592.5	570.1	571.4	2145.	2.510	1108.	124.0	1160.5	9.35	1699.	0.00931	0.00284
49.	637.7	606.1	570.0	571.8	2216.	14.520	3199.	124.0	1881.7	20.24	4864.	0.00651	0.00213

SURFACE NUMBER 9

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.	635.8	608.2	570.3	572.1	2211.	18.980	3013.	119.5	1545.1	18.74	6215.	0.01653	0.00214
2.	635.4	605.0	570.5	572.1	2188.	14.160	2543.	119.5	1438.7	17.95	5261.	0.01724	0.00243
3.	636.9	601.2	570.7	572.3	2170.	9.100	1984.	119.5	1314.9	16.64	4116.	0.01818	0.00288
4.	638.5	595.7	570.5	571.8	2157.	5.100	1437.	119.5	1142.3	14.70	2995.	0.01947	0.00352
5.	640.3	591.8	570.8	572.1	2150.	3.300	1094.	119.5	985.5	12.85	2288.	0.02181	0.00404
6.	662.7	588.5	570.9	572.2	2124.	1.660	755.	119.8	1041.0	11.90	1575.	0.02279	0.00542
7.	639.9	599.2	571.2	572.1	2170.	8.740	1931.	307.0	1461.3	15.68	4009.	0.01847	0.00279
8.	639.8	599.8	571.2	572.2	2169.	8.730	1938.	251.0	1439.6	15.72	4020.	0.01830	0.00279
9.	640.1	601.0	570.8	571.9	2169.	8.730	1937.	202.0	1406.9	15.22	4013.	0.01829	0.00270
10.	639.6	601.2	570.6	571.9	2168.	8.720	1936.	162.0	1382.8	15.63	4011.	0.01828	0.00278
11.	639.3	601.8	570.5	571.9	2168.	8.730	1935.	133.0	1349.8	15.74	4007.	0.01830	0.00280
12.	638.9	602.8	570.4	572.1	2168.	8.750	1933.	112.0	1294.4	15.31	4001.	0.01834	0.00272
13.	638.8	603.6	570.2	572.0	2147.	8.740	1932.	90.0	1263.3	15.67	3996.	0.01814	0.00279
14.	645.3	593.1	570.5	571.5	2105.	3.250	1097.	120.0	1062.8	12.77	2286.	0.02090	0.00401
15.	635.5	608.2	570.2	572.0	2219.	18.900	2994.	120.0	1516.7	18.07	6178.	0.01673	0.00207
16.	634.9	605.2	570.1	572.2	2163.	11.620	2260.	70.0	1245.7	17.81	4676.	0.01772	0.00271
17.	636.2	600.8	570.2	572.1	2136.	7.170	1726.	70.0	1135.4	16.39	3582.	0.01866	0.00327
18.	643.1	597.8	570.3	572.1	2118.	4.130	1264.	70.0	1064.1	14.23	2625.	0.01992	0.00387
19.	645.3	593.0	570.5	572.2	2125.	2.540	960.	70.0	933.0	12.69	2001.	0.02153	0.00455
20.	648.2	579.1	571.0	572.0	2163.	0.760	468.	100.0	601.0	9.68	996.	0.02823	0.00712
21.	643.9	582.8	570.8	571.9	2164.	1.220	635.	100.0	721.1	11.06	1344.	0.02445	0.00600
22.	639.8	586.6	570.6	571.8	2169.	1.870	825.	100.0	814.4	11.95	1737.	0.02214	0.00499
23.	623.4	602.9	570.5	572.2	2108.	20.700	3185.	100.0	1212.9	18.37	6638.	0.01553	0.00198
24.	625.7	601.3	570.2	571.8	2182.	14.760	2616.	100.0	1184.7	17.43	5454.	0.01707	0.00229
25.	627.4	599.9	570.5	572.1	2159.	11.040	2200.	100.0	1126.5	16.24	4587.	0.01792	0.00254
26.	636.9	636.0*****			2163.	13.300	2388.	0.0	0.0*****		4832.	0.01748*****	
27.	637.2	636.2*****			2141.	10.050	2021.	0.0	0.0*****		4087.	0.01829*****	
28.	637.2	636.1*****			2125.	7.470	1713.	0.0	0.0*****		3403.	0.01818*****	
29.	637.4	636.3*****			2111.	5.100	1370.	0.0	0.0*****		2787.	0.01971*****	
30.	639.7	638.3*****			2098.	2.800	991.	0.0	0.0*****		1999.	0.02073*****	
31.	641.8	639.5*****			2097.	2.660	948.	0.0	0.0*****		1909.	0.02147*****	

SURFACE NUMBER 10

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	2079.	6.269	3705.	250.0	3264.5	40.53	11571.	0.01812	0.00624
2.	643.0	594.3	570.4	572.2	2080.	6.001	3639.	250.0	3289.5	40.02	11361.	0.01801	0.00628
3.	643.2	593.5	570.3	571.9	2083.	5.489	3455.	250.0	3187.6	38.73	10796.	0.01833	0.00640
4.	643.0	593.9	571.4	573.0	2086.	5.052	3291.	250.0	3004.8	36.91	10282.	0.01862	0.00640
5.	643.8	592.7	570.8	572.3	2090.	4.503	3116.	250.0	2958.1	36.02	9743.	0.01860	0.00660
6.	644.6	592.2	570.4	572.0	2091.	4.202	2989.	250.0	2915.3	35.08	9351.	0.01889	0.00670
7.	645.4	591.9	570.3	571.8	2092.	3.924	2868.	250.0	2850.7	33.85	8971.	0.01919	0.00674
8.	644.4	590.9	570.6	572.0	2107.	3.442	2658.	249.0	2642.3	31.98	8325.	0.01978	0.00687
9.	645.5	590.9	570.9	572.3	2108.	3.212	2555.	249.0	2592.7	31.18	8002.	0.01998	0.00697
10.	645.2	590.3	570.7	572.0	2109.	2.993	2475.	249.0	2526.3	30.44	7757.	0.01988	0.00703
11.	645.5	590.5	571.1	572.4	2109.	2.766	2391.	249.0	2440.6	29.26	7493.	0.01969	0.00699
12.	645.6	590.4	570.7	572.0	2110.	2.623	2358.	249.0	2419.3	28.62	7390.	0.01922	0.00693
13.	645.9	590.3	570.7	572.0	2111.	2.402	2255.	249.0	2328.6	27.13	7065.	0.01927	0.00687
14.	646.0	590.2	571.2	572.5	2112.	2.226	2165.	249.0	2241.6	26.33	6786.	0.01938	0.00695
15.	645.7	589.9	571.2	572.4	2085.	2.042	2057.	250.0	2134.3	25.04	6451.	0.01947	0.00695
16.	646.5	589.0	570.8	572.0	2086.	1.787	1915.	250.0	2046.4	23.79	6009.	0.01971	0.00710
17.	647.1	588.7	571.3	572.4	2087.	1.602	1797.	250.0	1946.9	22.73	5642.	0.02007	0.00722
18.	647.5	588.0	571.2	572.3	2087.	1.418	1679.	250.0	1854.9	21.66	5274.	0.02040	0.00737
19.	648.5	586.9	570.9	571.9	2088.	1.202	1516.	250.0	1733.7	20.08	4767.	0.02125	0.00757
20.	649.8	586.1	570.9	571.9	2088.	1.004	1377.	250.0	1627.9	18.72	4334.	0.02155	0.00777
21.	645.9	605.2	575.2	577.3	2079.	6.216	3671.	249.0	4143.4	40.26	11248.	0.01800	0.00625
22.	667.0	603.9	575.5	577.6	2086.	4.982	3263.	249.0	3825.0	36.91	10007.	0.01839	0.00645
23.	670.0	600.8	575.2	577.0	2095.	3.541	2675.	249.0	3443.2	32.85	8225.	0.01965	0.00700
24.	669.4	600.0	576.0	577.6	2100.	2.524	2272.	249.0	2932.0	27.80	6997.	0.01953	0.00697
25.	672.2	597.1	575.7	577.1	2104.	1.536	1745.	249.0	2435.1	22.62	5386.	0.02032	0.00730
26.	645.6	590.5	570.6	572.1	2097.	2.946	2441.	222.0	2457.9	29.87	7646.	0.01999	0.00699
27.	645.2	590.3	570.6	572.0	2097.	2.931	2441.	240.0	2427.1	29.85	7651.	0.01990	0.00698
28.	645.2	590.6	571.2	572.4	2096.	2.946	2444.	272.0	2479.8	29.84	7660.	0.01993	0.00697
29.	645.0	590.3	571.2	572.3	2096.	2.948	2443.	310.0	2482.7	29.84	7658.	0.01998	0.00698
30.	645.0	590.1	571.2	572.2	2096.	2.949	2452.	376.0	2501.0	29.92	7699.	0.01985	0.00697
31.	645.3	590.1	571.4	572.3	2096.	2.950	2446.	448.0	2507.4	29.85	7672.	0.01994	0.00697
32.	645.6	590.3	571.7	572.6	2096.	2.949	2447.	550.0	2513.8	29.84	7673.	0.01992	0.00696
33.	623.2	588.7	570.9	572.3	2059.	6.228	3714.	251.0	2381.2	39.61	11752.	0.01792	0.00610
34.	624.0	587.9	571.0	572.3	2067.	5.004	3290.	251.0	2210.6	36.37	10416.	0.01847	0.00632
35.	625.8	586.2	571.0	572.1	2075.	3.519	2604.	251.0	1978.7	32.13	8540.	0.01953	0.00682
36.	628.4	586.0	571.5	572.5	2077.	1.943	2046.	251.0	1612.6	24.55	6403.	0.01926	0.00686
37.	631.5	583.2	571.2	572.1	2083.	1.018	1390.	251.0	1247.0	18.51	4417.	0.02148	0.00762
38.	689.2	615.4	580.4	582.6	2062.	6.118	3576.	302.0	4913.8	39.41	10769.	0.01821	0.00627
39.	689.7	614.1	581.3	583.4	2068.	5.010	3220.	302.0	4526.6	36.62	9707.	0.01853	0.00647
40.	694.4	609.8	579.6	581.5	2078.	3.523	2629.	302.0	4135.6	32.42	7950.	0.01979	0.00702
41.	697.3	606.2	577.9	579.5	2085.	2.019	2009.	302.0	3403.6	25.17	6091.	0.01968	0.00713
42.	699.6	600.9	578.7	580.0	2088.	1.015	1361.	302.0	2498.5	18.92	4156.	0.02177	0.00791

SURFACE NUMBER 11.

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.	636.6	610.5	569.5	571.8	2206.	10.320	3192.	87.5	1546.7	26.02	14405.	0.01603	0.00298
2.	637.1	609.2	569.6	571.7	2180.	8.060	2783.	79.0	1443.1	24.70	12571.	0.01633	0.00324
3.	639.1	608.9	570.1	572.0	2165.	6.430	2461.	88.0	1384.5	22.14	11110.	0.01657	0.00329
4.	638.3	608.3	570.1	572.0	2155.	6.370	2437.	85.5	1355.7	22.09	11011.	0.01668	0.00331
5.	640.5	606.2	570.2	572.0	2133.	4.000	1901.	85.5	1209.6	18.94	8594.	0.01712	0.00364
6.	641.4	604.7	570.2	571.9	2123.	3.010	1623.	84.0	1107.8	17.11	7347.	0.01763	0.00385
7.	644.0	602.7	570.3	571.8	2113.	1.980	1304.	84.0	1000.9	15.00	5905.	0.01796	0.00421
8.	645.0	599.3	571.0	572.3	2158.	1.008	947.	84.0	803.9	12.06	4300.	0.01784	0.00466
9.	629.2	598.1	560.2	562.1	2125.	5.100	2174.	84.0	1254.7	20.02	9943.	0.01683	0.00337
10.	631.1	596.1	560.5	562.1	2110.	3.460	1758.	84.0	1142.6	17.85	8045.	0.01743	0.00372
11.	633.6	593.3	560.6	562.0	2099.	2.050	1326.	84.0	990.8	14.97	6076.	0.01815	0.00413
12.	636.2	589.9	560.8	561.9	2127.	1.000	915.	83.0	786.9	11.50	4204.	0.01894	0.00460
13.	634.0	593.1	560.6	562.0	2109.	1.900	1267.	84.0	962.2	14.43	5809.	0.01849	0.00417
14.	635.0	591.0	560.8	562.1	2142.	1.200	1017.	85.0	831.7	12.23	4670.	0.01849	0.00440
15.	640.7	586.3	560.7	561.7	2140.	0.500	629.	84.0	635.6	8.99	2895.	0.02028	0.00523
16.	628.0	598.8	559.9	562.0	2159.	5.725	2334.	74.0	1268.3	21.16	10674.	0.01664	0.00332
17.	628.2	598.2	560.0	561.8	2159.	5.710	2323.	83.0	1295.2	21.18	10627.	0.01677	0.00334
18.	628.4	597.8	560.3	562.0	2159.	5.685	2330.	100.0	1325.1	20.96	10663.	0.01660	0.00329
19.	629.7	597.9	560.4	562.0	2159.	5.690	2320.	119.0	1369.4	20.75	10607.	0.01677	0.00328
20.	629.5	597.0	560.9	562.1	2159.	5.720	2337.	150.0	1412.0	21.16	10698.	0.01663	0.00331
21.	630.6	596.8	560.9	562.0	2159.	5.700	2323.	179.0	1459.8	21.23	10628.	0.01678	0.00335
22.	632.0	591.4	560.7	561.8	2158.	1.508	1150.	85.0	889.3	13.57	5293.	0.01829	0.00432
23.	636.0	589.6	560.7	561.8	2154.	0.990	912.	84.0	785.4	11.52	4192.	0.01912	0.00463
24.	637.6	589.5	561.0	562.0	2152.	0.800	927.	84.5	738.7	10.57	3798.	0.01879	0.00468
25.	639.4	587.2	560.9	561.9	2151.	0.600	710.	84.5	687.6	9.89	3265.	0.01920	0.00511
26.	627.1	600.2	560.1	561.8	2180.	9.780	3100.	114.0	1550.3	24.69	14165.	0.01620	0.00292
27.	628.4	599.0	560.4	562.1	2149.	7.200	2628.	114.0	1439.1	22.41	12012.	0.01641	0.00312
28.	640.1	585.5	561.1	561.8	2121.	0.500	620.	114.0	637.2	8.96	2845.	0.02029	0.00523
29.	641.8	584.2	561.3	562.0	2130.	0.400	552.	114.0	591.2	8.34	2546.	0.02105	0.00554
30.	643.6	582.2	561.3	562.0	2124.	0.300	428.	114.0	488.3	6.87	1979.	0.02613	0.00588
31.	647.0	580.0	561.1	561.7	2123.	0.200	372.	114.0	462.2	6.55	1721.	0.02326	0.00646
32.	635.7	579.9	555.8	556.7	2142.	0.400	582.	80.5	604.4	8.82	2702.	0.01919	0.00555
33.	636.2	579.0	555.7	556.6	2142.	0.360	542.	80.5	575.5	8.39	2516.	0.01995	0.00567
34.	637.4	578.6	555.6	556.6	2141.	0.320	513.	80.5	559.9	8.08	2381.	0.01984	0.00578

SURFACE NUMBER 12

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.	616.8	601.5	555.4	556.7	2155.	2.430	2978.	76.0	843.6	43.96	38251.	0.04252	0.00743
2.	616.7	600.6	555.3	556.4	2142.	2.000	2666.	76.0	797.5	41.14	34264.	0.04342	0.00777
3.	630.3	616.4	570.3	571.7	2203.	3.260	3459.	76.0	894.0	47.88	43651.	0.04202	0.00696
4.	632.6	614.7	570.6	571.6	2131.	1.480	2241.	76.0	746.0	37.69	28273.	0.04429	0.00846
5.	633.6	613.1	570.9	571.8	2096.	0.965	1771.	76.0	674.6	33.81	22369.	0.04564	0.00960
6.	634.4	610.0	571.1	571.8	2081.	0.485	1162.	76.0	527.9	25.78	14704.	0.05312	0.01116
7.	636.8	609.2	571.2	571.9	2074.	0.270	858.	76.0	439.7	20.58	10854.	0.05417	0.01206
8.	637.8	608.7	564.4	565.2	2093.	0.395	1162.	76.0	628.6	27.00	14690.	0.04394	0.01169
9.	638.9	607.8	564.6	565.3	2090.	0.300	948.	76.0	548.3	23.03	11985.	0.05000	0.01222
10.	639.4	607.4	564.5	565.1	2088.	0.240	846.	76.0	504.6	20.86	10700.	0.05022	0.01240
11.	639.2	606.2	564.6	565.4	2087.	0.220	821.	76.0	504.0	21.28	10390.	0.04907	0.01304
12.	631.5	616.1	563.8	565.2	2211.	3.400	3498.	76.0	999.8	47.20	44172.	0.04303	0.00678
13.	631.8	615.1	563.9	565.2	2173.	2.550	3009.	76.0	934.9	43.62	37975.	0.04302	0.00729
14.	632.9	614.4	563.8	565.1	2145.	1.880	2538.	76.0	873.0	39.74	32033.	0.04413	0.00787
15.	634.4	612.6	564.2	565.4	2117.	1.085	1882.	76.0	763.4	33.96	23756.	0.04598	0.00908
16.	608.7	594.0	553.3	554.4	2127.	1.704	2456.	49.0	666.5	39.62	31852.	0.04379	0.00814
17.	608.8	594.0	553.5	554.5	2128.	1.708	2464.	65.0	674.6	38.85	31966.	0.04359	0.00795
18.	608.8	593.7	553.7	554.6	2127.	1.700	2455.	82.0	677.2	38.45	31852.	0.04374	0.00790
19.	608.9	593.8	553.7	554.4	2127.	1.700	2461.	100.0	689.3	38.32	31924.	0.04353	0.00785
20.	609.2	593.6	553.8	554.4	2128.	1.707	2461.	130.0	709.7	38.99	31928.	0.04372	0.00799
21.	609.0	593.3	554.2	554.7	2128.	1.701	2474.	140.0	720.5	39.52	32106.	0.04315	0.00805
22.	635.1	611.1	559.7	560.8	2105.	1.000	1812.	79.0	806.1	33.31	22891.	0.04559	0.00925
23.	636.5	610.9	559.9	561.0	2098.	0.795	1609.	79.0	767.7	31.16	20315.	0.04590	0.00974
24.	636.1	609.9	560.1	561.1	2095.	0.705	1508.	78.0	734.1	30.00	19056.	0.04635	0.01001
25.	636.7	609.7	560.2	561.2	2092.	0.605	1378.	79.0	692.2	27.67	17418.	0.04755	0.01010
26.	635.2	611.4	559.6	560.8	2110.	1.000	1821.	70.0	804.3	33.42	22995.	0.04526	0.00923
27.	635.2	611.4	559.6	560.7	2110.	1.050	1821.	80.0	806.0	33.05	23002.	0.04744	0.00912
28.	635.6	611.6	559.9	560.9	2110.	1.000	1813.	90.0	809.2	32.88	22888.	0.04564	0.00912
29.	635.6	611.4	559.9	560.8	2110.	1.000	1813.	104.0	817.0	32.98	22897.	0.04564	0.00915
30.	635.7	611.6	560.1	560.9	2110.	1.000	1821.	120.0	816.0	32.55	22988.	0.04524	0.00899

SURFACE NUMBER 13

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.	643.7	604.0	563.2	566.4	2139.	15.290	3185.	80.0	2348.7	75.37	12040.	0.08525	0.01062
2.	653.4	594.7	564.2	566.5	2137.	3.575	1462.	80.0	1595.0	46.73	5554.	0.09600	0.01436
3.	651.9	595.5	565.3	567.4	2154.	3.790	1532.	80.0	1606.0	48.42	5820.	0.09334	0.01419
4.	656.4	593.4	565.8	567.7	2149.	2.475	1208.	80.0	1415.1	41.29	4592.	0.09814	0.01535
5.	658.1	591.2	565.6	567.5	2148.	1.900	1039.	80.0	1291.5	37.61	3958.	0.10206	0.01626
6.	662.6	588.7	566.0	567.6	2146.	1.235	833.	80.0	1144.5	33.04	3181.	0.10342	0.01781
7.	653.9	594.4	565.2	567.3	2161.	3.010	1358.	80.0	1503.6	44.45	5163.	0.09476	0.01470
8.	655.9	592.4	565.8	567.7	2159.	2.220	1149.	80.0	1357.6	40.13	4376.	0.09786	0.01568
9.	659.6	590.3	565.8	567.4	2158.	1.590	968.	80.0	1246.5	36.23	3691.	0.09901	0.01681
10.	629.9	573.2	560.4	561.1	2124.	0.695	609.	120.0	640.3	25.69	2390.	0.11170	0.01903
11.	628.9	573.4	560.3	561.0	2123.	0.800	669.	120.0	689.6	28.09	2626.	0.10653	0.01893
12.	628.4	574.3	560.3	561.0	2124.	0.995	754.	120.0	757.6	30.61	2958.	0.10405	0.01829
13.	626.2	576.6	560.1	560.9	2127.	1.493	941.	120.0	867.3	34.21	3681.	0.09998	0.01638
14.	622.1	581.0	559.4	561.0	2127.	3.090	1384.	71.0	1058.1	44.59	5393.	0.09492	0.01451
15.	622.4	580.8	559.5	561.0	2127.	3.085	1384.	80.0	1068.5	44.09	5394.	0.09481	0.01435
16.	622.6	580.5	559.8	561.1	2127.	3.060	1385.	100.0	1084.3	43.48	5399.	0.09401	0.01414
17.	623.5	580.1	560.1	561.2	2126.	3.090	1385.	130.0	1117.0	43.51	5400.	0.09496	0.01415
18.	623.4	579.5	560.4	561.3	2126.	3.080	1385.	160.0	1127.0	43.70	5406.	0.09467	0.01421
19.	631.0	573.7	559.9	560.7	2122.	0.807	668.	120.0	711.0	27.77	2619.	0.10749	0.01874
20.	631.8	572.9	560.0	560.7	2121.	0.700	608.	120.0	665.7	26.27	2398.	0.11249	0.01946
21.	632.8	572.2	560.0	560.6	2120.	0.600	583.	120.0	655.5	26.03	2290.	0.10526	0.02013
22.	639.6	589.3	559.9	561.9	2161.	4.050	1601.	80.5	1497.4	48.11	6145.	0.09274	0.01351
23.	635.8	592.3	560.7	563.0	2172.	6.110	2015.	80.0	1630.1	54.73	7722.	0.08843	0.01221
24.	634.4	594.0	560.9	563.3	2182.	8.050	2347.	80.0	1762.9	60.69	8985.	0.08606	0.01162
25.	632.5	596.2	561.0	563.7	2205.	11.450	2809.	80.8	1858.4	66.20	10740.	0.08600	0.01059
26.	632.2	597.0	560.9	563.6	2218.	13.100	3030.	80.0	1984.3	70.38	11581.	0.08490	0.01044
27.	634.1	594.8	563.9	565.7	2168.	9.570	2533.	120.0	1850.4	62.12	9694.	0.08715	0.01102
28.	636.1	592.6	565.4	566.8	2143.	5.650	1953.	120.0	1578.6	53.48	7485.	0.08601	0.01231
29.	637.5	591.4	565.3	566.9	2136.	4.470	1695.	120.0	1450.6	48.36	6507.	0.09013	0.01283
30.	646.7	583.1	563.4	564.4	2135.	1.300	980.	120.0	1038.7	32.89	3397.	0.10455	0.01681
31.	648.7	581.0	562.9	563.8	2138.	1.015	752.	120.0	946.6	29.94	2910.	0.10558	0.01790

APPENDIX B

Literature Tube Bank Results

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APPENDIX B

LITERATURE TUBE BANK RESULTS

Three sets of data were taken from the open literature to help determine the effects that tube pitch had on tube bank performance. Two sets of data were for finned tube banks, and one set was for bare tube banks.

Ackerman and Brunsvold⁵ reported results with six arrangements of studded tubes. There were 6 studs per row on a 0.25-in. staggered pitch, tube OD = 1.875-in. and $A_f/A_t = 0.878$. The results were transformed to f and j curves using tube material and free flow areas described by Worley and Ross.⁷ Tube bank designations and basic design data equations are listed in table B-1. In all cases, the minimum free flow area was in the transverse spacing between tubes.

Jameson⁶ reported results with a number of arrangements of helically finned tubes. The data listed in table B-1 are an interpretation of Jameson's results and figure 10-81 in reference 4. The tabulated results assumed 9.05 fins per inch, a 0.774-in. tube OD and $A_f/A_t = 0.912$. The minimum free flow area was in the transverse tube spacings for all banks except J-D, where the minimum was in the diagonal spacings.

Bare tube bank data results were taken from reference 4. Curves of basic design data plus pertinent geometric information for 8 arrangements of 0.375-in.-OD bare tubes were given in reference 4: figures 10-5, 10-6, 10-7, 10-8, 10-9, 10-10, 10-13, and 10-14. These arrangements are designated KL-5, KL-6, KL-7, KL-8, KL-9, KL-10, KL-13, and KL-14, respectively. Transverse and longitudinal spacings for these tube banks are listed in table B-2.

Table B-1

FINNED TUBE BANK PERFORMANCE DATA

Tube Bank	S_t	S_l	Type*	D	α	Re Range	a	m	b	n	Reference
AB-1	5.0	3.5	S	0.0853	24.6	7600-27000	0.2375	-0.202	0.520	-0.453	5
AB-2	6.0	3.25	S	0.1094	22.1	9800-35000	0.360	-0.202	0.627	-0.453	5
AB-3	5.0	4.5	S	0.1097	19.1	9800-35000	0.234	-0.202	0.595	-0.453	5
AB-4	5.0	4.5	I	0.1097	19.1	9800-35000	0.0392	-0.069	0.490	-0.453	5
AB-5	5.0	3.25	S	0.0792	26.5	7000-25000	0.240	-0.202	0.513	-0.453	5
AB-6	4.0	3.5	S	0.0528	30.8	4700-17000	0.128	-0.202	0.391	-0.453	5
J-A	1.557	1.75	S	0.01681	108.2	1100-7100	0.198	-0.25	0.105	-0.319	6
J-B	1.982	1.75	S	0.02689	85.1	1700-11000	0.287	-0.25	0.121	-0.319	6
J-C	2.725	1.75	S	0.04453	61.8	2800-19000	0.400	-0.25	0.143	-0.319	6
J-D**	2.725	0.80	S	0.01587	135.3	1300-8500	0.222	-0.25	0.0866	-0.319	6
J-E	1.982	1.375	S	0.02113	108.2	1350-9000	0.284	-0.25	0.112	-0.319	6

*S = staggered, I = in-line.

**Minimum free-flow area in diagonal spacings.

Table B-2

BARE TUBE BANK ARRANGEMENTS

<u>Tube Bank</u>	<u>St</u>	<u>S₁</u>	<u>Type*</u>	<u>Reference</u>
KL-5	0.5625	0.4688	S	4
KL-6	0.4688	0.4688	S	4
KL-7	0.5625	0.375	S	4
KL-8	0.5625	0.5625	S	4
KL-9**	0.750	0.375	S	4
KL-10**	0.9375	0.2812	S	4
KL-13	0.563	0.469	I	4
KL-14	0.469	0.469	I	4

*S = staggered, I = in-line.

**Minimum free-flow area in diagonal spacings.

ACKNOWLEDGMENTS

The author gratefully acknowledges the contributions of R. R. Uglow and Dr. G. J. Kidd to this study.

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Zeek, R. M.</p> <p>65-66. <u>ORNL</u>
Fee, G. G.
Hoffman, H. W.</p> <p>67-74. <u>Paducah Plant</u>
Bernstein, S.
Clifford, W. R.
Golliher, W. R.
Hopkins, C. C.
Levin, R. W.
Loveland, C. W.
Merriman, J. R.
Riepe, R. C.</p> <p>75-79. <u>Y-12 Plant</u>
Case, J. M.
Griffin, J. D.
Horde, G. W.
Jasny, G. R.
Jordan, R. G.</p> |
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EXTERNAL

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