King Abdulaziz University

Mechanical Engineering Department

MEP 460 Heat Exchanger Design

Compact Heat Exchangers
Part 2

Ch. 10 of Kakac textbook

&

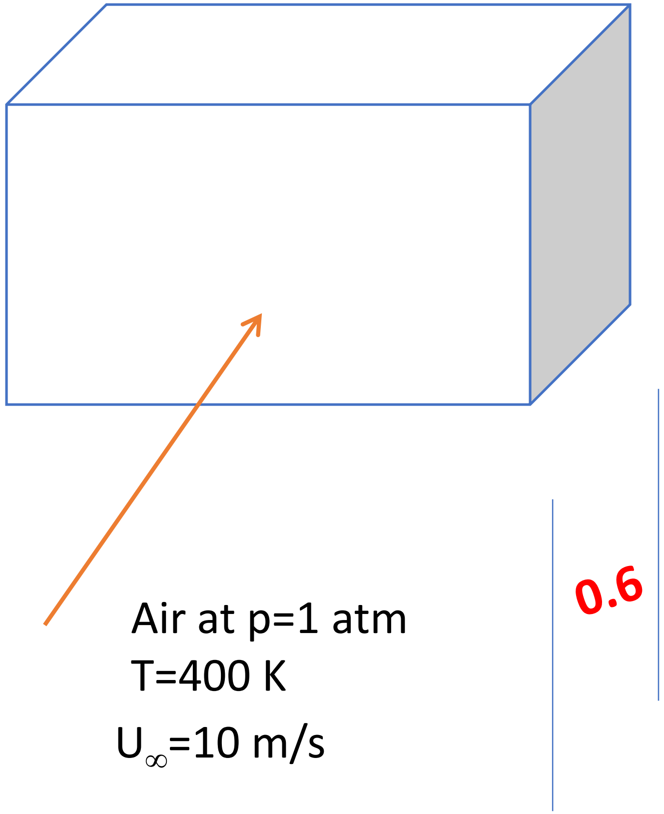
Kays & London textbook

Compact Heat Exchangers

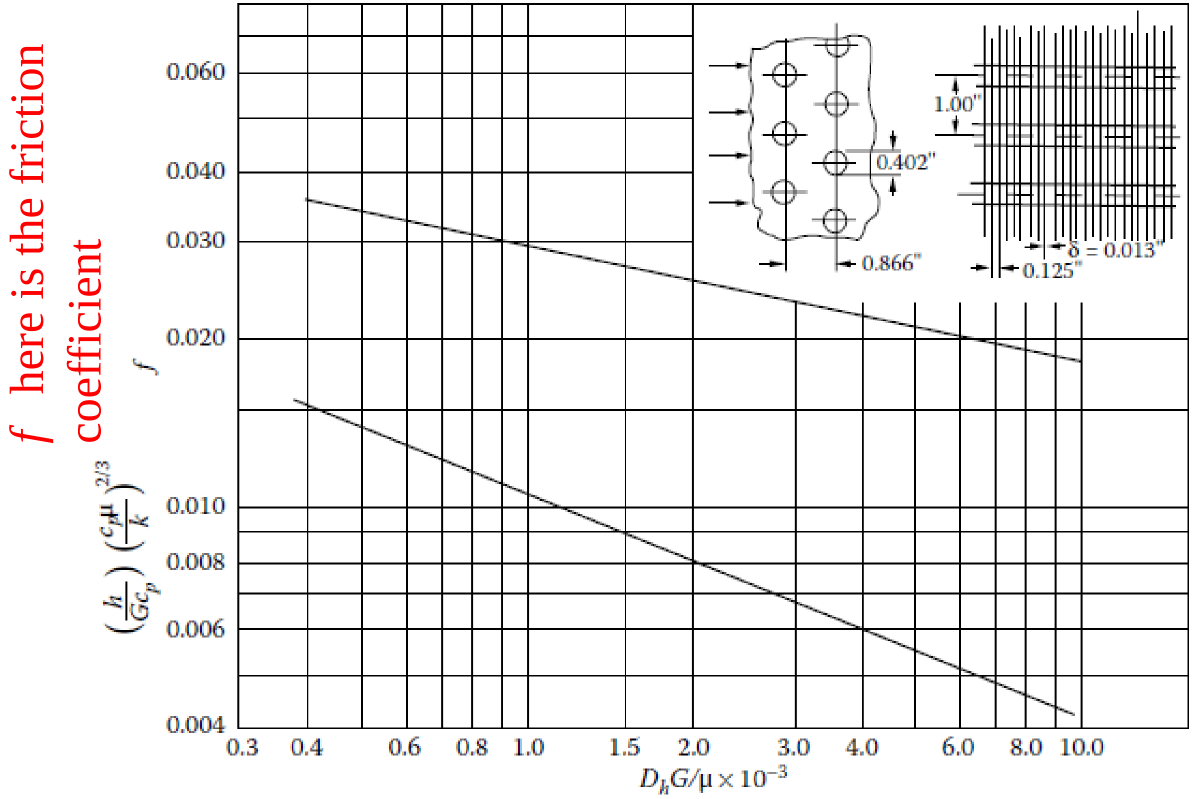
6-Examples
(Kakac Textbook)

Example 10.1

Air at 1 atm and 400 K and with a velocity of $U_\infty = 10$ m/s flows across a compact heat exchanger matrix having the configuration shown in Figure 10.4. Calculate the heat transfer coefficient, h, and frictional pressure drop for the air side. The length of the matrix is 0.6 m.



Find h and Δp



Surface: 8.0-3/8 T

FIGURE 10.4
Heat transfer and friction factor for a circular tube continuous fin heat exchanger. Surface 8.0-3/8 T: tube OD = 1.02 cm; fin pitch = 3.15/cm; fin thickness = 0.033 cm; fin area/total area = 0.839; air-passage hydraulic diameter = 0.3633 cm; free-flow area/frontal area, $\sigma = 0.534$; heat transfer area/total volume = 587 m^2/m^3. (From Kays, W. M. and London, A. L., *Compact Heat Exchangers*, 3rd ed., McGraw-Hill, New York, 1984. With permission.)

Example 10.1

At 400 K and 1 atm, the properties of air from Appendix B are

$$\rho = 0.8825 \text{ kg/m}^3$$
$$\mu = 2.29 \times 10^{-5} \text{ kg/m} \cdot \text{s}$$
$$c_p = 1013 \text{ Jk/g} \cdot \text{K}$$
$$Pr = 0.719$$

$$G = \frac{\rho u_\infty A_{fr}}{A_{\min}} = \frac{\rho u_\infty}{\sigma} = \frac{0.8825 \times 10}{0.534} = 16.53 \text{ kg/}(\text{m}^2 \cdot \text{s})$$

$$Re = \frac{GD_h}{\mu} = \frac{16.53 \times 0.3633 \times 10^{-2}}{2.29 \times 10^{-5}} = 2622$$

Example 10.1

From Figure 10.4, for $Re = 2{,}622$, we can obtain

$$\frac{h}{Gc_p} Pr^{2/3} = 0.0071$$

$$h = 0.0071 \times \frac{Gc_p}{Pr^{2/3}} = 0.0071 \times \frac{16.53 \times 1013}{(0.719)^{2/3}}$$

$$h = 148.1 \text{ W/m}^2 \cdot \text{K}$$

For $Re = 2{,}622$, from Figure 10.4, $f = 0.025$ and so

f here is the friction coefficient

$$\Delta p_f = f \frac{G^2}{2\rho_a} \frac{A_t}{A_{min}}$$

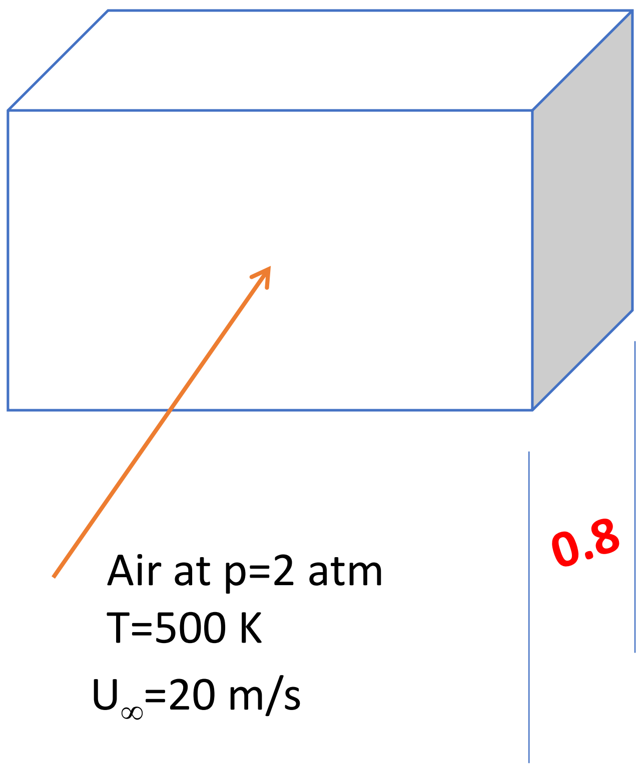
$$\frac{A_t}{A_{min}} = \frac{4 \times L}{D_h} = \frac{4 \times 0.6}{0.3633 \times 10^{-2}} = 660.6$$

Then,

$$\Delta p_f = 0.025 \times \frac{16.53^2}{2 \times 0.8825} \times 660.6 = 2556 \text{ Pa}$$

Example 10.2

Air at 2 atm and 500 K with a velocity of $U_\infty = 20$ m/s flows across a compact heat exchanger matrix having the configuration shown in Figure 10.8 (surface 11.32-0737-S-R). Calculate the heat transfer coefficient and the frictional pressure drop. The length of the matrix is 0.8 m.



Find h and Δp

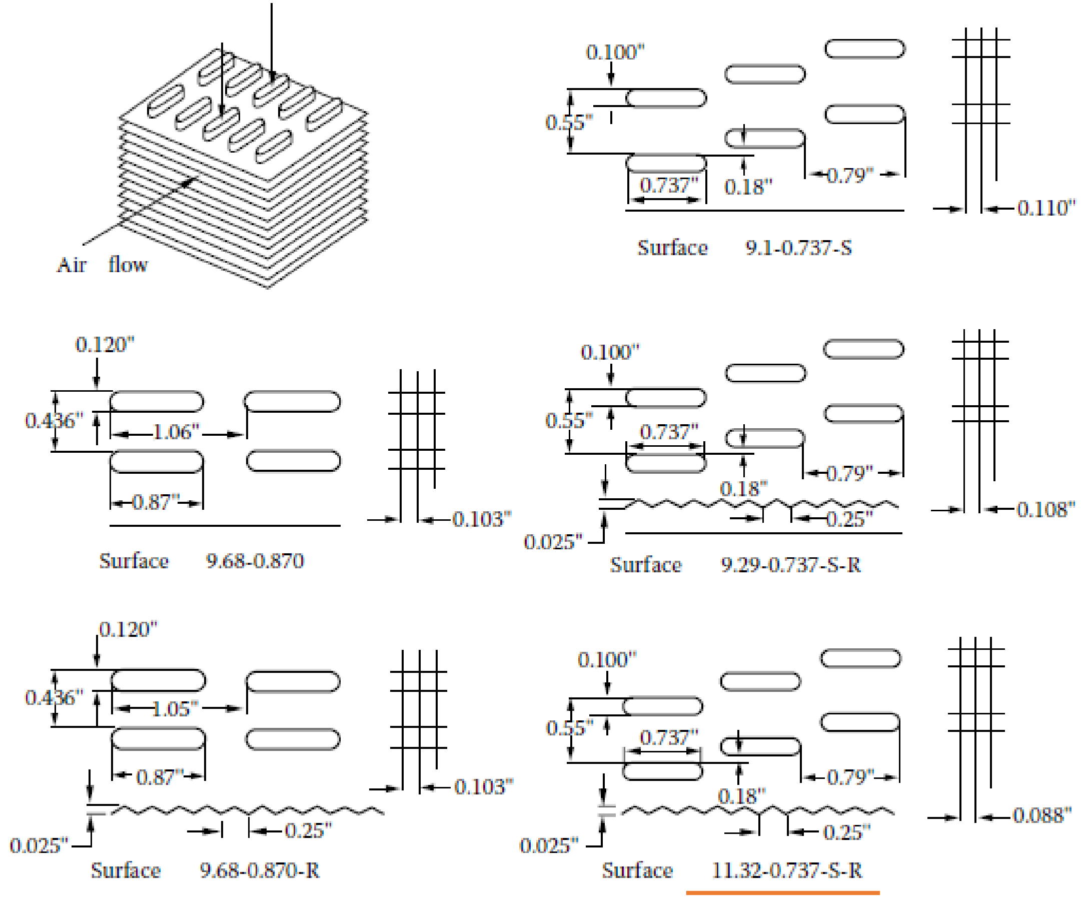


FIGURE 10.8
Various flattened tube-platefin compact surfaces for which test data are presented in Figure 10.7. (From Kays, W. M. and London, A. L., *Compact Heat Exchangers*, 3rd ed., McGraw-Hill, New York, 1984. With permission.)

Example 10.2

TABLE 10.1

Heat Transfer Matrix Geometries for Plate Plain-Fin and Fin Flat-Tube Types for Which Test Data are Presented in Figures 10.7 and 10.9

Surface Designation	Fins (per cm)	Hydraulic Diameter (D_h, cm)	Plate Spacing (b, cm)	Tube or Fin Thickness (cm)	Extended Area / Total Area	Area / Volume Between Plates (β, m²/m³)	Area / Core Volume (β, m²/m³)	Free Flow Area / Frontal Area (σ)
Plate plain-fin type								
5.30	13.46	0.051	1.194	0.0152	0.719	511.8		
11.10	28.19	0.257	0.635	0.0152	0.730	1095.8		
14.77	37.52	0.215	0.838	0.0152	0.831	1210.6		
19.86	50.44	0.152	0.635	0.0152	0.833	1493.0		
Fin flat-tube type								
9.68-0.870	24.587	0.2997		0.0102	0.795		751.3	0.697
9.68-0.870-R	24.587	0.2997		0.0102	0.795		751.3	0.697
9.1-0.737-S	23.114	0.3565		0.0102	0.813		734.9	0.788
9.29-0.737-S-R	28.753	0.3510		0.0102	0.845		885.8	0.788
11.32-0.737-S-R	23.596	0.3434		0.0102	0.814		748.0	0.780

Source: From Kays, W. M. and London, A. L., *Compact Heat Exchangers*, 3rd ed., McGraw-Hill, New York, 1984. With permission.

Flat tube 11.32-0.737S-R

(c) Flat tubes, continuous fins

Surface designation	Tube arrangement	Fin type	Tube length (parallel to flow)		Tube width (normal to flow)		Fins/in	Hydraulic diameter $4r_h$		Fin thickness δ		Free flow/frontal area σ	Heat transfer area/total volume α		Fin area/total area
			in	10^{-3}m	in	10^{-3}m		ft	10^{-3}m	in	10^{-3}m		ft^2/ft^3	m^2/m^3	
9.68−0.87	In-line	Plain	0.870	22.1	0.120	3.0	9.68	0.01180	3.60	0.004	0.102	0.697	229	751	0.795
9.1−0.737S	Staggered	Plain	0.737	18.7	0.100	2.5	9.1	0.01380	4.21	0.004	0.102	0.788	224	735	0.813
9.68−0.87R	In-line	Ruffled	0.870	22.1	0.120	3.0	9.68	0.01180	3.60	0.004	0.102	0.697	229	751	0.795
9.21−0.737SR	Staggered	Ruffled	0.737	18.7	0.100	2.5	9.29	0.01352	4.12	0.004	0.102	0.788	228	748	0.814
11.32−0.737SR	Staggered	Ruffled	0.737	18.7	0.100	2.5	11.32	0.01152	3.51	0.004	0.102	0.780	270	886	0.845

Kays and London

Compact Heat Exchangers, 3ed edition

Example 10.2

The mass flux G is

$$G = \frac{\dot{m}}{A_{\min}} = \frac{\rho u_\infty A_{fr}}{A_{\min}} = \frac{\rho u_\infty}{\sigma} = \frac{1.41 \times 20}{0.78} = 36.15 \text{ kg/m}^2 \cdot \text{s}$$

$$Re = \frac{G D_h}{\mu} = \frac{36.15 \times 0.3434 \times 10^{-2}}{2.69 \times 10^{-5}} = 4615$$

From Figure 10.7, for $Re = 4{,}615$, we get

$$\frac{h}{G c_p} \cdot Pr^{2/3} = 0.0058$$

$$h = 0.0058 \frac{G c_p}{Pr^{2/3}}$$

$$h = 0.0058 \times \frac{36.15 \times 1030}{(0.718)^{2/3}} = 278.7 \text{ W/m}^2 \cdot \text{K}$$

f here is the friction coefficient

$$\Delta p_f = f \frac{A_t}{A_{\min}} \frac{\rho_i}{\rho} \frac{G^2}{2\rho_i}$$

$$\frac{A_t}{A_{\min}} = \frac{4 \times L}{D_h} = \frac{4 \times 0.8}{0.3434 \times 10^{-2}} = 932$$

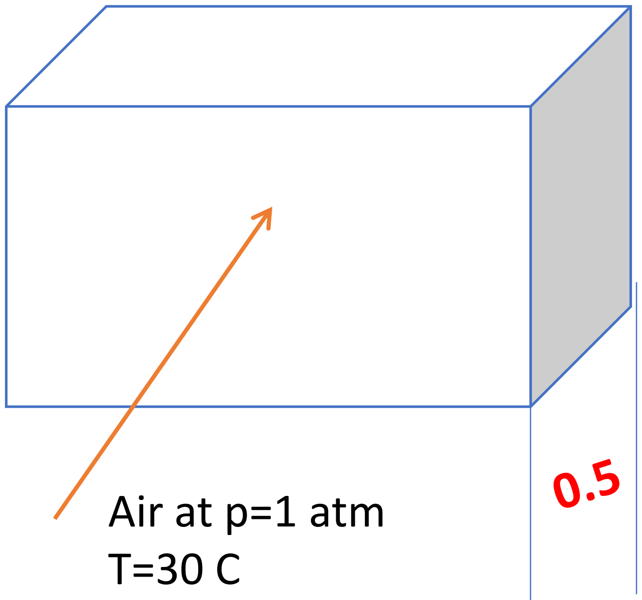
For $Re = 4{,}615$, from Figure 10.7, $f = 0.023$ and $\rho_i/\rho_o \approx 1$:

$$\Delta p_f = 0.023 \times 932 \times \frac{(36.15)^2}{2 \times 1.41} = 9934 \text{ N/m}^2$$

Example 10.3

Air enters the core of a finned-tube heat exchanger of the type shown in Figure 10.5 at 1 atm and 30°C. The air flows at a rate of 1,500°kg/h perpendicular to the tubes and exits with a mean temperature of 100°C. The core is 0.5 m long with a 0.25 m² frontal area. Calculate the total pressure drop between the air inlet and outlet and the average heat transfer coefficient on the air side.

To=100 C

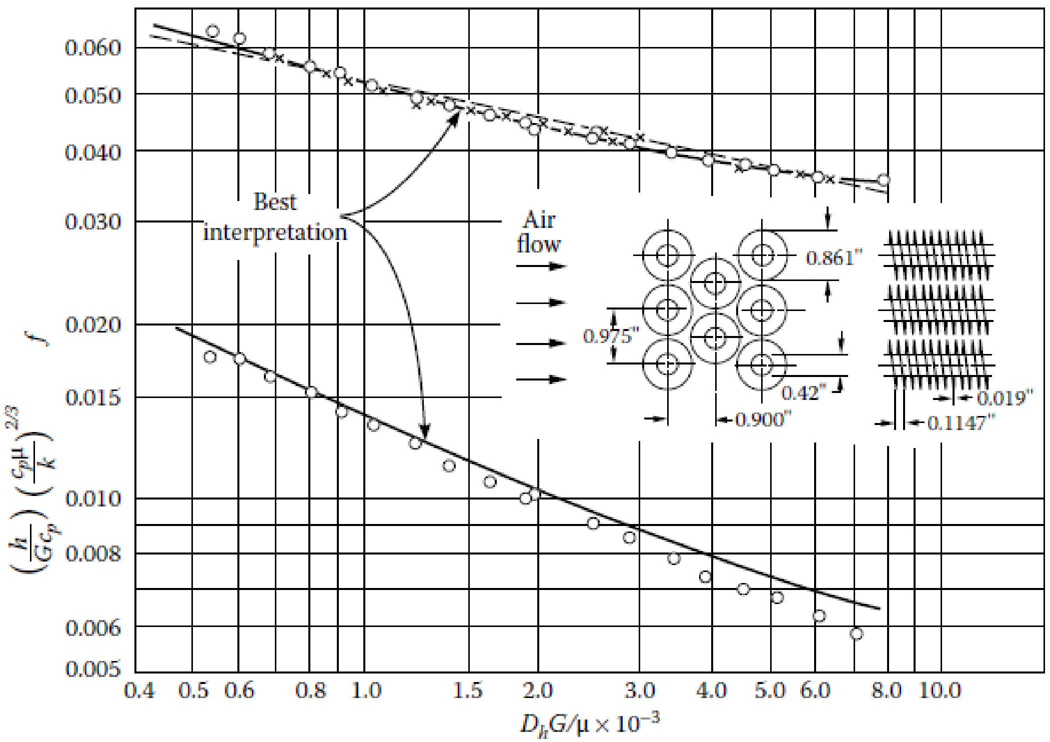


Air at p=1 atm
T=30 C

m=1500 kg/h
A_{fr}=0.25 m^2

Find h and Δp

f here is the friction coefficient



Surface: CF-8.72C

FIGURE 10.5
Heat transfer and friction factor for flow across circular finned-tube matrix. Surface CF-8.72(c): tube OD = 1.07 cm; fin pitch = 3.43/cm; fin thickness = 0.048 cm; fin area/total area = 0.876; air-passage hydraulic diameter, d_h = 0.443 cm; free-flow area/frontal area, σ = 0.494; heat transfer area/total volume = 446 m²/m³. (From Kays, W. M. and London, A. L., *Compact Heat Exchangers*, 3rd ed., McGraw-Hill, New York, 1984. With permission.)

Example 10.3

$$\rho_i = 1.177 \text{ kg/m}^3$$
$$\rho_o = 0.954 \text{ kg/m}^3$$

$$\frac{A_t}{A_{\min}} = \frac{4L}{D_h} = \frac{4 \times 0.5}{0.00443} = 451.5$$

$$A_{\min} = \sigma A_f = 0.494 \times 0.25 = 0.124 \text{ m}^2$$

$$G = \frac{\dot{m}}{A_{\min}} = \frac{1500}{3600} \times \frac{1}{0.124} = 3.36 \text{ kg/m}^2 \cdot \text{s}$$

$$Re = \frac{GD_h}{\mu} = \frac{3.36 \times 0.00443}{2.04 \times 10^{-5}} = 729$$

Example 10.3

$$\Delta p = (3.36)^2 \frac{1}{2 \times 1.177}\left[0.057 \times 451.5 \times \frac{1.177}{1.038} + (1 + 0.494^2)\left(\frac{1.177}{0.954} - 1\right)\right]$$

$$= 141.3 \text{ N/m}^2$$

For the heat transfer coefficient, the Colburn modulus $(h/Gc_p)\, Pr^{2/3}$ can be read from Figure 10.5 for $Re = 729$ as 0.0165.

$$\frac{h}{Gc_p} Pr^{2/3} = 0.0165$$

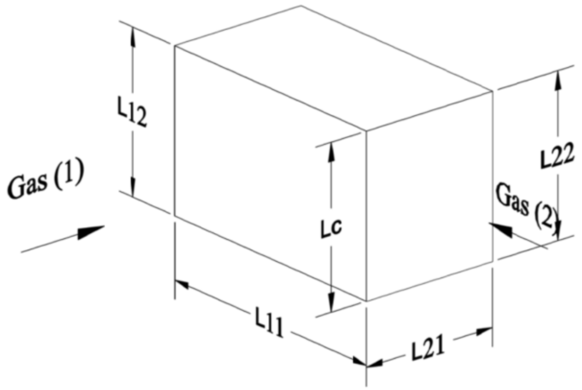
$$h = 0.0165 \times 3.36 \times 1.007 \times 10^3 \times (0.719)^{-2/3}$$

$$h \approx 70 \text{ W/m}^2 \cdot \text{K}$$

Input data sheet for rating Gas-to-Gas compact heat exchanger

Solved example. Reference: Kays & London 3ed edition

#	Symbol	Meaning	Value	Unit	Remarks
1	Fluid 1	Gas side (1) fluid	Air	-	
2	L11	Length 1 of HE ⊥ to flow 1	0.91	m	
3	L12	Length 2 of HE ⊥ to flow 1	2.29	m	
4	$\dot{m}_1$	mass flow rate of flow 1	24.3	kg/s	Either the mass flow rate
5	$\dot{\forall}_1$	volumetric flow rate in side (1)	--	m^3/s	or volume flow rate is given
6	$P_{i,1}$	inlet pressure of flow (1)	$9.1*10^5$	Pa	
7	$T_{i,1}$	inlet temperature of flow (1)	175	ºC	
8	mat1$	matrix designation for side (1)	3/8-6.06	-	Louvered fin
9	k_{f1}	fin side (1) thermal conductivity of	21.24	W/m.K	
10	a	plate thickness	$0.3*10^{-3}$	m	
11	Fluid 2	Gas side (2) fluid	gas (Air)	-	
12	L21	Length 1 of HE ⊥ to flow 2	1.83	m	
13	L22	Length 2 of HE ⊥ to flow 2	2.29	m	
14	$\dot{m}_2$	mass flow rate of flow 2	24.7	kg/s	
15	$\forall_2$	volumetric flow rate in side (2)	--	m^3/s	
16	$P_{i,2}$	inlet pressure of flow (2)	$103.*10^3$	Pa	
17	$T_{i,2}$	inlet temperature of flow (2)	430	ºC	
18	mat2$	matrix designation for side (2)	11.1	-	
19	k_{f2}	fin side (2) thermal conductivity of	21.24	W/m.K	
20	k_p	thermal conductivity of the plate	190	W/m.K	



Calculation sheet for rating Gas_to_Gas compact heat exchangers

Solved example. Reference: Kays & London 3ed edition

#	Symbol	Description	Source	Value	Units
1	Fluid 1	Gas side (1) fluid	Input data	Air	-
2	L11	Length 1 of HE ⊥ to flow 1	Input data	0.91	m
3	L12	Length 2 of HE ⊥ to flow 1	Input data	2.29	m
4	$\dot{m}_1$	mass flow rate of flow 1	Input data	24.3	kg/s
5	$\dot{\forall}_1$	volumetric flow rate into side (1)	Input data	-	m^3/s
6	$P_{i,1}$	inlet pressure of flow (1)	Input data	$9.1*10^5$	Pa
7	$T_{i,1}$	inlet temperature of flow (1)	Input data	175	ºC
8	mat1$	surface designation for side (1)	Input data	3/8-6.06	-
9	k_{f1}	fin side (1) thermal conductivity of	Input data	21.24	W/m.K
10	a	plate thickness	Input data	$0.3*10^{-3}$	m
					m
11	b_1	Plate spacing (1)	surface data	$6.35*10^{-3}$	m
12	Dh_1	Hydraulic diameter (1)	surface data	$4.453*10^{-3}$	m
13	δ_{f1}	fin (1) thickness	surface data	$0.15*10^{-3}$	m^2/m^3
14	β_1	heat transfer area/volume between the plates=$A_1/\forall_{p1}$	surface data	840	m^2/m^2
15	ω_1	fin (1) area / heat transfer area=A_{f1}/A_1	surface data	0.640	m
16	l_{f1}	fin (1) length	surface data (b_1/2)	$3.175*10^{-3}$	m
17	Fluid 2	Gas side (2) fluid	Input data	Gas (Air)	
18	L21	Length 1 of HE ⊥ to flow 2	Input data	1.83	m
19	L22	Length 2 of HE ⊥ to flow 2	Input data	2.29	m
20	$\dot{m}_2$	mass flow rate of flow 2	Input data	24.7	kg/s
21	$\dot{\forall}_2$	volumetric flow rate in side (2)	Input data	--	m^3/s
22	$P_{i,2}$	inlet pressure of flow (2)	Input data	$103*10^3$	Pa
23	$T_{i,2}$	Inlet temperature of gas into side (2)	Input data	430	C
24	mat2$	Surface (2) designation	Input data	11.1	-
25	k_{f2}	fin (2) thermal conductivity	Input data	21.24	W/m.K
26	k_p	plate thermal conductivity	Input data	190	W/m.K
27	b_2	Plate spacing (2)	surface data	$6.35*10^{-3}$	m
28	Dh_2	Hydraulic diameter (2)	surface data	$3.085*10^{-3}$	m
29	δ_{f2}	fin (2) thickness	surface data	$0.15*10^{-3}$	m
30	β_2	heat transfer area/volume between the plates=$A_2/\forall_{p2}$	surface data	1204	m^2/m^3
31	ω_2	fin (2) area / heat transfer area=A_{f2}/A_2	surface data	0.756	m^2/m^2
32	l_{f2}	fin (2) length	surface data	$3.175*10^{-3}$	m

#	Symbol	Description	Source	Value	Units
33	ΔT_o	Inlet temperature difference	T_{hi}-T_{ci} =<7>-<23>	255	ºC
34	L_{p1}	HX length // to flow (1)	Input data	1.83	m
35	L_{p2}	HX length // to flow (2)	Input data	0.91	m
35a	L_c	Common edge length	Input data	2.29	m
36	A_{fr1}	frontal area of side (1)	L11*L12=<2>*<3>	2.0839	m^2
37	A_{fr2}	frontal area of side (2)	L21*L22=<18>*<19>	4.1807	m^2
38	N_p	Number of plates $(L_c - b_1 - 2a)/(b_1 + b_2 + 2a)$	$\frac{<35a> - <11> - 2<10>}{<11> + <27> + 2<10>}$	172	-
39	$\forall_{p1}$	volume between the plates (1)	L11*L21*b_1*N_p=<2>*<18>*<11>*<38>	1.815	m^3
40	$\forall_{p2}$	volume between the plates (2)	L11*L21*b_2*(N_p+1)=(<3>*<18>*<27>*(<38>+1))	1.825	m^3
41	A_1	heat transfer area of side (1)	$\beta_1 * \forall_{p1}$=<14><39>	1536.7	m^2
42	A_2	heat transfer area of side 2)	$\beta_2 * \forall_{p2}$=<30><40>	2198.3	m^2
43	S_1=$A_{min,1}$	min. flow area of side (1) $Dh_1 * A_1/4L_{p1}$	$(<12><41>)/(4<34>)$	0.9276	m^2
44	S_2=$A_{min,2}$	min. flow area of side (2) $Dh_2 * A_2/4L_{p2}$	$(<28><42>)/(4<35>)$	1.8675	m^2
45	$\forall$	Heat exchanger volume= L11*L12*L_{p1}	<2><3><34>	3.8135	m^3
45a	A_1/A_2	heat transfer area ratio	(<41>/<42>)	0.699	-
46	α_1	heat transfer area (1)/HX volume	<41>/<45>	399.8	m^2/m^3
47	α_2	heat transfer area (2)/HX volume	<42>/<45>	577.76	m^2/m^3
48	σ_1	side (1) min. flow area/frontal area (1)	<43>/<36>	0.4451	m^2/m^2
49	σ_2	side (2) min. flow area/frontal area (2)	<44>/<37>	0.444	m^2/m^2
50	ρ_1	density of gas (1) based on $P_{i,1}$ and $T_{i,1}$	Use $\rho = P_{i,1}/RT_{i,1}$	7.0775	kg/m^3
51	ρ_2	density of gas (2) based on $P_{i,2}$ and $T_{i,2}$	Use $\rho = P_{i,2}/RT_{i,2}$	0.5105	kg/m^3
52	$\dot{m}_1$	side (1) gas flow rate	Given or $\dot{\forall}_1\rho_1$ <5><50>	24.3	kg/s
53	$\dot{m}_2$	side (2) gas flow rate	Given or $\dot{\forall}_2\rho_2$ <21><51>	24.7	kg/s
54	C_{p1}	assumed specific heat side (1)	Interpolation for assumed average T_1	1020.7	J/kg.K
55	C_{p2}	assumed specific heat side (2)	Interpolation for assumed average T_2	1075.7	J/kg.K
56	C_1	mass capacity rate (1)	$\dot{m}_1 C_{p1} = <52><54>$	24803	W/K
57	C_2	mass capacity rate (2)	$\dot{m}_2 C_{p2} = <53><55>$	26569.8	W/K
58	C_{min}	min. mass capacity rate	Smallest of C_1 and C_2	24803	W/K
59	C_r	ratio of C_{min}/C_{max}	C_{min}/C_{max}	0.9335	-
60	U_1	Overall heat transfer coeff. base on side (1)	Estimated.	--	W/m^2K
			You can either assume U_1 or ε	--	
61	NTU_1	Number of transfer unit based on side (1)	$U_1A_1/C_{min} = <60><41>/<58>$	--	-
62	ε	initial guess for the HX effectiveness	Assumed or calculated	0.75	-
63	Q_{max}	Max. heat rate for the HX	$C_{min} * \Delta T_o = <58><33>$	6324765	W
63a	Q	Heat rate	ϵQ_max = <62><63>	4743573	
64	T_{o1}	outlet temperature for flow in side (1)	$T_{o1} = T_{i1} + Q/C_1 = \; = <7> + <63a>/<56>$	366.25	ºC
65	T_{o2}	outlet temperature for flow in side (2)	$T_{o2} = T_{i2} - Q/C_2 = <23> - <63a>/<57>$	251.5	ºC

#	Symbol	Description	Source	Value	Units
66	$T_{av,1}$	Average temp. side (1) $(T_{i,1}+T_{o,1})/2$	(<7>+<64>)/2	270.5	ºC
67	$T_{av,2}$	Average temp. side (2) $(T_{i,2}+T_{o,2})/2$	(<23>+<65>)/2	340.75	ºC
68	ρ_1	Density side (1)	$\rho_1 = P_{i,1}/RT_{av,1}$	5.834	kg/m^3
69	C_{p1}	Specific heat side (1)	Interpolation	1038.7	J/kg.K
70	k_1	Thermal conductivity side (1)	Interpolation	$43.5*10^{-3}$	W/m.K
71	μ_1	Viscosity side (1)	Interpolation	$286*10^{-7}$	Pa,s
72	Pr_1	Prandtl number side (1)	Interpolation	0.6831	-
73	ρ_2	Density side (2)	$\rho_2 = P_{i,2}/RT_{av,2}$	0.5847	kg/m^3
74	C_{p2}	Specific heat side (2)	Interpolation	1053.82	J/kg.K
75	k_2	Thermal conductivity side (2)	Interpolation	$47.6*10^{-3}$	W/m.K
76	μ_2	Viscosity side (2)	Interpolation	$309.7*10^{-7}$	Pa.s
77	Pr_2	Prandtl number side (2)	Interpolation	0.6862	-
78	G_1	Mass velocity of side (1) $G_1 = \dot{m}_1/S_1$	<52>/<43>	26.19	$kg/s.m^2$
79	Re_1	Reynold's number side (1) $Re_1 = D_{h1}G_1/\mu_1$	<78><12>/<71>	4128.7	-
80	J_1	Heat transfer factor side (1)	Surface data	0.007317	-
81	fc_1	friction coefficient side (1)	Surface data	0.0372	-
82	G_2	Mass velocity of side (2) $G_2 = \dot{m}_2/S_2$	<53>/<44>	13.257	$kg/s.m^2$
83	Re_2	Reynold's number side (2) $Re_2 = D_{h2}G_2/\mu_2$	<82><28>/<76>	1335.7	-
84	J_2	Heat transfer factor side (2)	Surface data	0.00457	-
85	fc_2	friction coefficient side (2)	Surface data	0.01591	-
86	h_1	Heat transfer coeff. side (1) $h_1 = J_1G_1C_{p1}Pr_1{}^{-2/3}$	<80><78><69><72$^{-2/3}$>	257.3	W/m^2K
87	h_2	Heat transfer coeff. side (2) $h_2 = J_2G_2C_{p2}Pr_2{}^{-2/3}$	<84><82<74><77$^{-2/3}$>	82.95	W/m^2K
88	M_1	Fin factor (1) $\sqrt{2h_1/k_{f1}\delta_{f1}}$	$\sqrt{2<86>/(<9><13>)}$	401.54	1/m
89	M_1l_{f1}	Fin factor (1) * fin (1) length	<88><16>	1.275	-
90	η_{f1}	Fin efficiency (1) $\eta_{f1} = \tanh(M_1l_{f1})/M_1l_{f1}$	tanh(<89>)/<89>	0.6707	-
91	η_{01}	Overall surface efficiency side (1)	$1-\omega_1(1-\eta_{f1})$ 1-<15>(1-<90>)	0.790	-
92	M_2	Fin factor (2) $\sqrt{2h_2/k_{f2}\delta_{f2}}$	$\sqrt{2<87>/(<25><29>)}$	227.45	1/m
93	M_2l_{f2}	Fin factor (2) * fin (2) length	<92><32>	0.7221	-
94	η_{f2}	Fin efficiency (2) $\eta_{f2} = \tanh(M_2l_{f2})/M_2l_{f2}$	tanh(<93>)/<93>	0.856	-
95	η_{02}	Overall surface efficiency side (2)	$1-\omega_2(1-\eta_{f2})$ 1-<31>(1-<94>)	0.89	-

#	Symbol	Description	Source	Value	Units
95a	A_w	Wall area of all plates	L11*L21*2(N_p+1) <2><18>*2(<38>+1)	576.2	m^2
96	R_w	Wall thermal resistance	a/k_pA_w <10>/(<26><95a>)	$2.74*10^{-8}$	
97	U_1	Overall heat transfer Coeff. based on side (1)	$1/U_1 = 1/h_1\eta_{01} + R_wA_1 + (A_1/A_2)/h_2\eta_{02}$ $1/U_1 = 1/(<86><91>) + <96><41> + <45a>/(<87><95>)$	69.1	W/m^2K
98	C_1	Heat capacity rate for side (1)	<52><69>	25240	W/K
99	C_2	Heat capacity rate for side (2)	<53><74>	26029	W/K
100	C_{min}	Min. heat capacity rate	Smallest of C_1 & C_2	25240	W/K
101	C_r	Ratio C_{min}/C_{max}	C_{min}/C_{max}	0.9696	-
102	NTU_1	Number of transfer units based on side (1)	$NTU_1 = U_1A_1/C_1$ NTU_1=<97>*<41>/<98>	4.207	-
103	ε	HX effectiveness calculated or found from graph	Appropriate figure or expression	0.7388	-
104	Q_{max}	Max. heat rate	$C_{min}\Delta T_o = <100><33>$	6436200	W
105	Q	Heat rate	$Q = \epsilon Q_{max}$=<103><104>	4755064	W
106	T_{o1}	Outlet temperature for side (1)	$T_{o1} = T_{i1} + Q/C_1 = <7> + <105>/<98>$	363.4	ºC
107	T_{o2}	Outlet temperature for side (2)	$T_{o2} = T_{i2} - Q/C_2 = <23> - <105>/<99>$	247.3	ºC
108	ΔP_1	Pressure drop for flow in side (1)	$\Delta P_1 = 4fc_1\ (L_{p1}/D_{h1})\ G_1^2/(2\rho_1)$ $4<81>(<34>/<12>)<78>^2/(2<68>)$	3591.6	Pa
109	ΔP_2	Pressure drop for flow in side (2)	$\Delta P_2 = 4fc_2\ (L_{p2}/D_{h2})\ G_2^2/(2\rho_2)$ $4<85>(<35>/<28)<82>^2/(2<73>)$	2844.2	Pa