Mark Scored:

KATHMANDU UNIVERSITY
End Semester Examination
February/March, 2019

Level : B. E.
Year : III

Course : CHEG 303
Semester: I

Exam Roll No. :

Time: 30 mins.

F. M. : 10

Registration No.:

Date FEB 2 4 2019

SECTION "A"
[20 Q.× 0.5= 10 marks]

Select the most appropriate answer.

1. Fourier's law applies to the heat transfer by
   a. Convection b. Conduction c. Radiation d. All of the above

2. Bulk of the convective heat transfer resistance from a hot tube surface to the fluid flowing in it, is
   a. In the central core of the fluid
   b. Mainly confined to a thin film of fluid near the surface
   c. Uniformly distributed throughout the fluid
   d. None of the above

3. In case of heat flow by conduction for a cylindrical body with an internal heat source, the nature of temperature distribution is
   a. Linear b. Parabolic c. Exponential d. None of the above

4. The rate of emission of radiation by a body does not depend upon the
   a. Shape and porosity of the body b. Surface temperature
   c. Nature of the surface d. Wavelength of radiation

5. Maximum heat transfer is obtained in ___________ flow.
   a. Turbulent b. Laminar c. Transition d. Creeping

6. In case of __________ boiling, the liquid temperature is below the saturation temperature and the boiling takes place in the vicinity of the heated surface.
   a. Nucleate b. Pool c. Local d. Saturated

7. Pick up the wrong case. Heat flowing from one side to the other directly depends on
   a. Face area b. Thermal conductivity
   c. Thickness d. Temperature difference

8. In free convection heat transfer, Nusselt number is a function of
   a. Grasshoff number and Prandtl number
   b. Prandtl number and Reynolds number
   c. Grasshoff number and Reynolds number
   d. Grasshoff number, Reynolds number and Prandtl number

9. Air is to be heated by condensing steam. Two heat exchangers are available (i) a shell and tube heat exchanger and (ii) a finned tube heat exchanger. Tube side heat transfer area are equal in both the cases. The recommended arrangement is

a. Finned tube heat exchanger with air inside and steam outside
b. Finned tube heat exchanger with steam inside and air outside
c. Shell and tube with air inside and steam outside
d. Shell and tube with steam inside and air outside

10. Fouling factor

a. Is a dimensionless quantity
b. Accounts for additional resistances to heat flow
c. Does not provide a safety factor for design
d. None of the above

11. Lubricating oil is being recycled continuously through a double-pipe counterflow heat exchanger for cooling. The oil is to be cooled from 70 °C to 40 °C at the rate of 5000 kg/h using water entering at 28 °C. The water temperature at the exit should not exceed 42 °C. The specific heat of oil is 2.05 kJ/kg °C and that of water is 4.17 kJ/kg °C. Calculate the required rate of flow of water.

a. 4200 kg/h   b. 5267 kg/h   c. 5550 kg/h   d. 6250 kg/h

12. Based on the data given in the above question (question 11), what is the log mean temperature difference for the heat exchanger ?

a. 28 °C   b. 12.8 °C   c. 18.9 °C   d. 19.4 °C

13. For the heat exchanger in problem 11, if the area of the heat exchanger is 3 m^2, what is the overall heat transfer coefficient ?

a. 1000 W/m^2 °C   b. 1300 W/m^2 °C   c. 1400 W/m^2 °C   d. 1500 W/m^2 °C

14. For radiation exchange between 10 surfaces, how many view factors need to be determined directly ?

a. 40   b. 45   c. 50   d. 35

15. Baffles in the shell side of a shell and tube heat exchanger

a. increase the cross-section of the shell side liquid
b. force the liquid to flow parallel to the bank
c. increase the shell side heat transfer coefficient
d. decrease the shell side heat transfer coefficient

16. A Biot number of less than 1 suggests

a. Higher resistance to heat transfer within the solid and higher resistance from solid to fluid
b. Lower resistance to heat transfer within the solid and lower resistance from solid to fluid
c. Lower resistance to heat transfer within the solid and higher resistance from solid to fluid
d. Higher resistance to heat transfer within the solid and lower resistance from solid to fluid

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17. The bottom of a copper pan 0.3 m in diameter is maintained at 118 °C by an electric heater. The heater supplies power at the rate of 836 kW/m^2 which causes the water to boil. If the latent heat of vaporization for water is 2257 kJ/kg, what is the evaporation rate ?

a. 100 kg/h b. 94 kg/h c. 82 kg/h d. 98 kg/h

18. Heat produced when a steady state current I passes through an electrical conductor having resistance R is

a. IR b. IR^2 c. I^2R d. I^2R^2

19. A perfect black body is one which

a. Is black in color
b. Absorbs heat radiations of all wavelengths falling on it
c. Reflects all the heat radiations
d. Transmits the heat radiations

20. The heat transfer takes place according to

a. Zeroth law of thermodynamics
b. First law of thermodynamics
c. Second law of thermodynamics
d. Third law of thermodynamics

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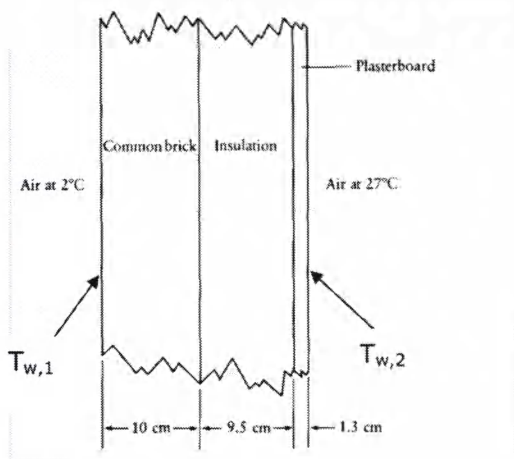
SECTION "B"
[4Q. × 10 = 40 marks]

1. The engine of my go-cart has circular fins, 3 mm thick, that are machined into the aluminum of the cylinder (k = 240 W/m·K) such that the outer diameter of the cylinder itself (not including the fins) is 10 cm and the fins stick out from the cylinder by 5 cm. The temperature of the cylinder cannot exceed 265 °C. I typically run my go-cart in on a 27 °C day under conditions such that the convective heat transfer coefficient h is 80 $W/m^2 \cdot K$.
   a. Estimate the amount of heat transferred by a single fin. [7]
   b. If the engine is 8.5 kW in size, is 30% efficient in transferring power (the other 70% is lost as heat) and 80% of the lost heat is transferred by the fins, how many fins are needed? [3]

2. A vertical plane wall is shown below. The outside brick is 10 cm thick, and the inside panel is 1.3 cm thick plaster board. The brick and the plaster board are separated by a 9.5 cm of glass fiber insulation. On the brick side is air at 2 °C, while on the plaster board side air is at 27 °C. The wall is 2.5 m tall. How much heat is transferred through wall per unit width? Also, find the wall temperatures $T_{w,1}$ and $T_{w,2}$. Assume $T_{w,1}$ and $T_{w,2}$ as 10 °C and 20 °C respectively for initial calculation and then find the corrected values. [10]

   Thermal conductivity value of the brick, glass-fiber and plaster are 0.45, 0.035 and 0.814 W/m.K respectively.



OR

A heat exchanger is to be designed to condense an organic vapor at a rate of 500 kg/min which is available at its saturation temperature of 355 K. Cooling water at 286 K is available at a flow rate of 60 kg/s. The overall heat transfer coefficient is 475 W/m^2C. Latent heat of condensation of organic vapor is 600 kJ/kg. Calculate
   a. The number of tubes required, if tubes of 25 mm outer diameter, 2 mm thickness and 4.87 m length are available, and [6]
   b. The number of tube passes, if cooling water velocity should not exceed 2 m/s. [4]

3. Two parallel plates of size 1.0 m by 1.0 m spaced 0.5 m apart are located in a very large room, the walls of which are maintained at a temperature of 27°C. One plate is maintained at a temperature of 900 °C and the other is maintained at 400 °C. Their emissivities are 0.2 and 0.5 respectively. If the plates exchange heat between themselves and the surroundings, find the net heat transfer to each plate and to the room. Consider only the plate surface facing each other. [10]

4. Consider an air heater consisting of a semicircular tube for which the plane surface is maintained at 1000 K and the other surface is well insulated. The tube radius is 20 mm and both surfaces have an emissivity of 0.8. If atmospheric air flows through the tube at 0.01 kg/s and T_m = 400 K, what is the rate at which heat must be supplied per unit length to maintain the plane surface at 1000 K? What is the temperature of the insulated surface? [10]

OR

A thin-walled concentric tube heat exchanger of 0.19 m length is to be used to heat deionized water from 40 to 60 °C at a flow rate of 5 kg/s. The deionized water flows through the inner tube of 30 mm diameter while saturated steam at 1 atm is supplied to the annulus formed with the outer tube of 60 mm diameter. The thermophysical properties of the deionized water are ρ = 982.3 kg/m^3, c_p = 4181 J/kg.K, k = 0.643 W/m.K, μ = 548 * 10^{-6} N.s/m^2, and Pr = 3.56. Estimate the convection coefficients for both sides of the tube and determine the inner tube wall outlet temperature. Does the condensation provide a fairly uniform inner tube wall temperature equal approximately to the saturation temperature of the steam? [10]

For a horizontal tube condensation, the convection coefficient is given by

$$\bar{h}_D = C\left[\frac{g\rho_l(\rho_l - \rho_v)k_l^3 h'_{fg}}{\mu_l(T_{sat} - T_s)D}\right]^{1/4}$$

where C = 0.729

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Useful Equations and graphs:

$$q_i = A_i(J_i - G_i) \qquad J_i = E_i + \rho_i G_i$$

$$q_i = \frac{E_{bi} - J_i}{(1-\varepsilon_i)/\varepsilon_i A_i} \qquad q_i = \sum_{j=1}^{N} \frac{J_i - J_j}{(A_i F_{ij})^{-1}}$$

$$q_i = \sum_{j=1}^{N} A_i F_{ij} \sigma (T_i^4 - T_j^4) \qquad \sigma = 5.67\ X\ 10^{-8}\ W/m^2.K^4$$

$$Ra = \frac{g\beta(T_s - T_\infty)L^3}{\nu\alpha} \qquad Ja = \frac{C_{p,l}(T_{sat} - T_s)}{h_{fg}}$$

$$h'_{fg} = h_{fg}(1 + 0.68Ja) \qquad Re_D = \frac{4\dot{m}}{\pi D \mu}$$

$$\varepsilon(T) = \frac{\int_0^\infty \varepsilon_\lambda(\lambda,T) E_{\lambda,b}(\lambda,T) d\lambda}{E_b(T)} \qquad F_{(0\to\lambda)} = \frac{\int_0^\lambda E_{\lambda,b} d\lambda}{\int_0^\infty E_{\lambda,b} d\lambda}$$

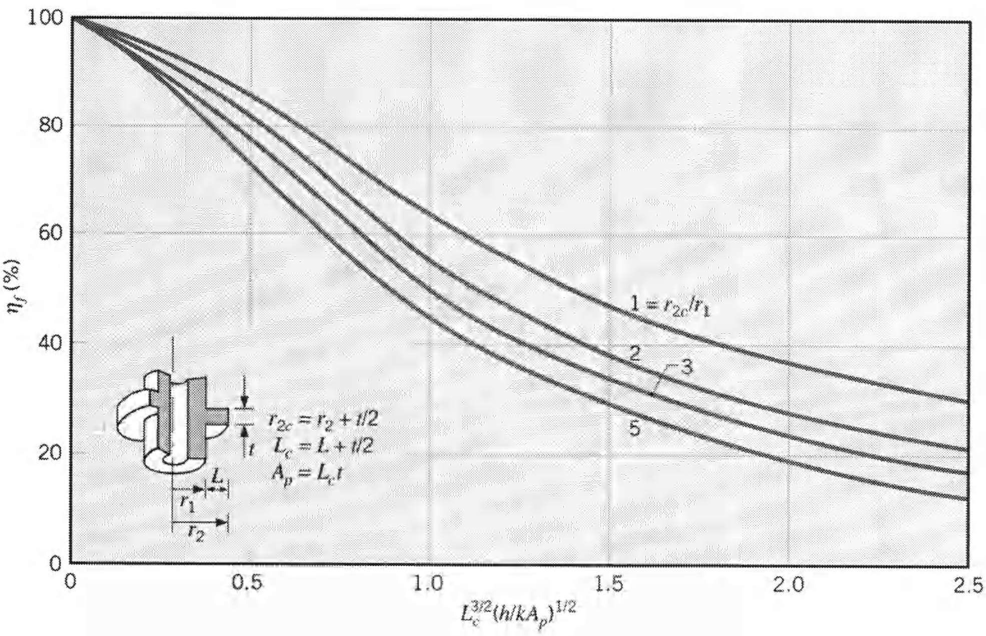

FIGURE 3.19 Efficiency of annular fins of rectangular profile.

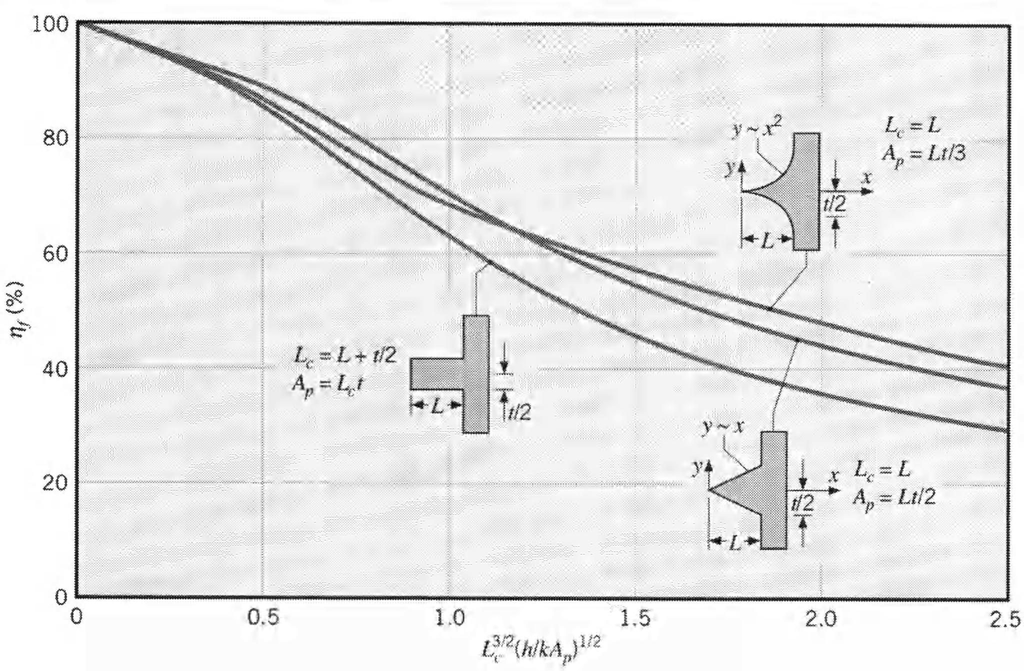

FIGURE 3.18 Efficiency of straight fins (rectangular, triangular, and parabolic profiles).

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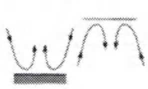
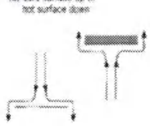
TABLE 3.3 One-dimensional, steady-state solutions to the heat equation with no generation

	Plane Wall	Cylindrical Wall[a]	Spherical Wall[a]
Heat equation	$\frac{d^2T}{dx^2}=0$	$\frac{1}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right)=0$	$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dT}{dr}\right)=0$
Temperature distribution	$T_{s,1}-\Delta T\frac{x}{L}$	$T_{s,2}+\Delta T\frac{\ln(r/r_2)}{\ln(r_1/r_2)}$	$T_{s,1}-\Delta T\left[\frac{1-(r_1/r)}{1-(r_1/r_2)}\right]$
Heat flux (q'')	$k\frac{\Delta T}{L}$	$\frac{k\,\Delta T}{r\ln(r_2/r_1)}$	$\frac{k\,\Delta T}{r^2[(1/r_1)-(1/r_2)]}$
Heat rate (q)	$kA\frac{\Delta T}{L}$	$\frac{2\pi Lk\,\Delta T}{\ln(r_2/r_1)}$	$\frac{4\pi k\,\Delta T}{(1/r_1)-(1/r_2)}$
Thermal resistance ($R_{t,\mathrm{cond}}$)	$\frac{L}{kA}$	$\frac{\ln(r_2/r_1)}{2\pi Lk}$	$\frac{(1/r_1)-(1/r_2)}{4\pi k}$

[a]The critical radius of insulation is $r_{cr}=k/h$ for the cylinder and $r_{cr}=2k/h$ for the sphere.

NATURAL CONVECTION CORRELATIONS

Geometry	Recommended Correlation	Restrictions
1. Vertical plates[a] 	Equation 9.26	None
2. Inclined plates Cold surface up or hot surface down 	Equation 9.26 $g \rightarrow g\cos\theta$	$0 \le \theta \le 60°$
3. Horizontal plates (a) Hot surface up or cold surface down 	Equation 9.30 Equation 9.31	$10^4 \le Ra_L \le 10^7$ $10^7 \le Ra_L \le 10^{11}$
(b) Cold surface up or hot surface down 	Equation 9.32	$10^5 \le Ra_L \le 10^{10}$
4. Horizontal cylinder 	Equation 9.34	$Ra_D \le 10^{12}$
5. Sphere 	Equation 9.35	$Ra_D \le 10^{11}$ $Pr \ge 0.7$

[a]The correlation may be applied to a vertical cylinder if $(D/L) \ge (35/Gr_L^{1/4})$.

$$\overline{Nu}_L=\left\{0.825+\frac{0.387Ra_L^{1/6}}{[1+(0.492/Pr)^{9/16}]^{8/27}}\right\}^2 \quad (9.26)$$

For horizontal plates $\quad L \equiv \frac{A_s}{P} \quad (9.29)$

Upper Surface of Hot Plate or Lower Surface of Cold Plate:

$$\overline{Nu}_L=0.54Ra_L^{1/4} \quad (10^4 \lesssim Ra_L \lesssim 10^7) \quad (9.30)$$

$$\overline{Nu}_L=0.15Ra_L^{1/3} \quad (10^7 \lesssim Ra_L \lesssim 10^{11}) \quad (9.31)$$

Lower Surface of Hot Plate or Upper Surface of Cold Plate:

$$\overline{Nu}_L=0.27Ra_L^{1/4} \quad (10^5 \lesssim Ra_L \lesssim 10^{10}) \quad (9.32)$$

$$\overline{Nu}_D=\left\{0.60+\frac{0.387\,Ra_D^{1/6}}{[1+(0.559/Pr)^{9/16}]^{8/27}}\right\}^2 \quad Ra_D \lesssim 10^{12} \quad (9.34)$$

$$\overline{Nu}_D=2+\frac{0.589Ra_D^{1/4}}{[1+(0.469/Pr)^{9/16}]^{4/9}} \quad (9.35)$$

TABLE 8.4 **Summary of convection correlations for flow in a circular tube**[a,b,e]

Correlation		Conditions
$f = 64/Re_D$	(8.19)	Laminar, fully developed
$Nu_D = 4.36$	(8.53)	Laminar, fully developed, uniform q''_s
$Nu_D = 3.66$	(8.55)	Laminar, fully developed, uniform T_s
$\overline{Nu}_D = 3.66 + \dfrac{0.0668(D/L)Re_D\,Pr}{1 + 0.04[(D/L)Re_D\,Pr]^{2/3}}$	(8.56)	Laminar, thermal entry (or combined entry with $Pr \gtrsim 5$), uniform T_s
or		
$\overline{Nu}_D = 1.86\left(\dfrac{Re_D\,Pr}{L/D}\right)^{1/3}\left(\dfrac{\mu}{\mu_s}\right)^{0.14}$	(8.57)	Laminar, combined entry, $0.6 \lesssim Pr \lesssim 5$, $0.0044 \lesssim (\mu/\mu_s) \lesssim 9.75$, uniform T_s
$f = 0.316 Re_D^{-1/4}$	(8.20a)[c]	Turbulent, fully developed, $Re_D \lesssim 2 \times 10^4$
$f = 0.184 Re_D^{-1/5}$	(8.20b)[c]	Turbulent, fully developed, $Re_D \gtrsim 2 \times 10^4$
or		
$f = (0.790 \ln Re_D - 1.64)^{-2}$	(8.21)[c]	Turbulent, fully developed, $3000 \lesssim Re_D \lesssim 5 \times 10^6$
$Nu_D = 0.023 Re_D^{4/5}\,Pr^n$	(8.60)[d]	Turbulent, fully developed, $0.6 \lesssim Pr \lesssim 160$, $Re_D \gtrsim 10{,}000$, $(L/D) \gtrsim 10$, $n = 0.4$ for $T_s > T_m$ and $n = 0.3$ for $T_s < T_m$
or		
$Nu_D = 0.027 Re_D^{4/5}\,Pr^{1/3}\left(\dfrac{\mu}{\mu_s}\right)^{0.14}$	(8.61)[d]	Turbulent, fully developed, $0.7 \lesssim Pr \lesssim 16{,}700$, $Re_D \gtrsim 10{,}000$, $L/D \gtrsim 10$
or		
$Nu_D = \dfrac{(f/8)(Re_D - 1000)Pr}{1 + 12.7(f/8)^{1/2}(Pr^{2/3} - 1)}$	(8.62)[d]	Turbulent, fully developed, $0.5 \lesssim Pr \lesssim 2000$, $3000 \lesssim Re_D \lesssim 5 \times 10^6$, $(L/D) \gtrsim 10$
$Nu_D = 4.82 + 0.0185(Re_D\,Pr)^{0.827}$	(8.64)	Liquid metals, turbulent, fully developed, uniform q''_s, $3.6 \times 10^3 \lesssim Re_D \lesssim 9.05 \times 10^5$, $10^2 \lesssim Pe_D \lesssim 10^4$
$Nu_D = 5.0 + 0.025(Re_D\,Pr)^{0.8}$	(8.65)	Liquid metals, turbulent, fully developed, uniform T_s, $Pe_D \gtrsim 100$

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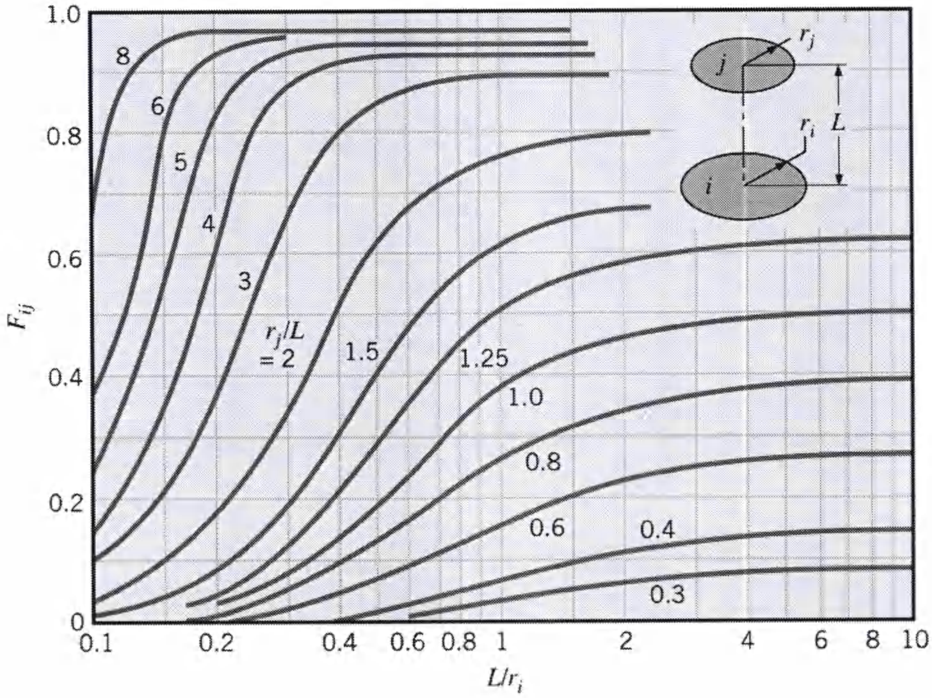

FIGURE 13.5 View factor for coaxial parallel disks.

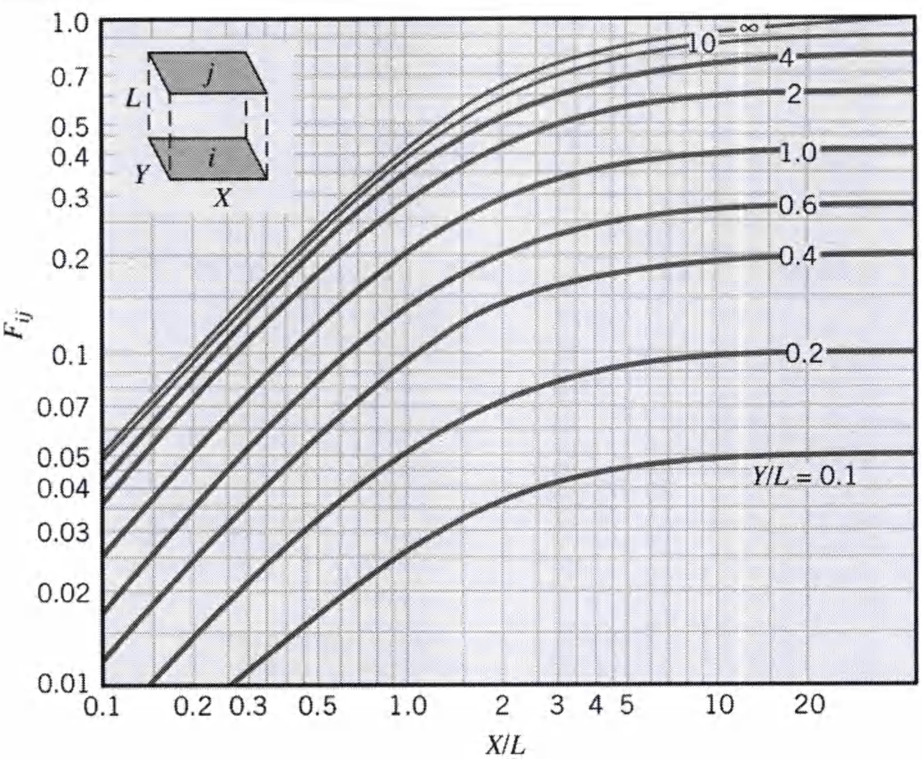

FIGURE 13.4 View factor for aligned parallel rectangles.

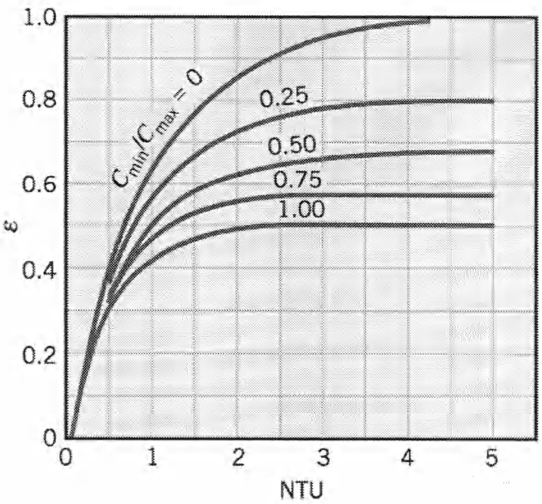

Figure 11.10 Effectiveness of a parallel-flow heat exchanger (Equation 11.28).

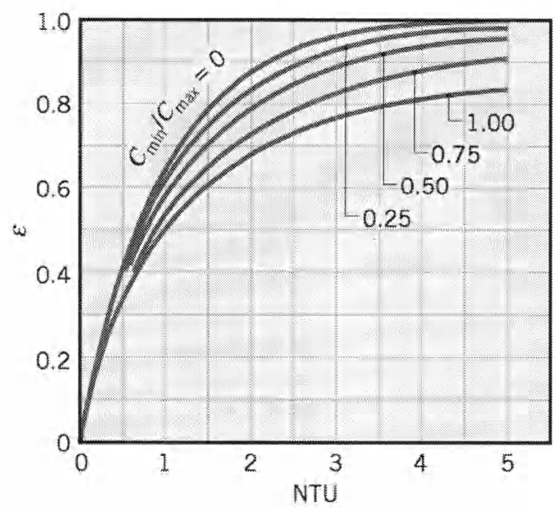

Figure 11.11 Effectiveness of a counterflow heat exchanger (Equation 11.29).

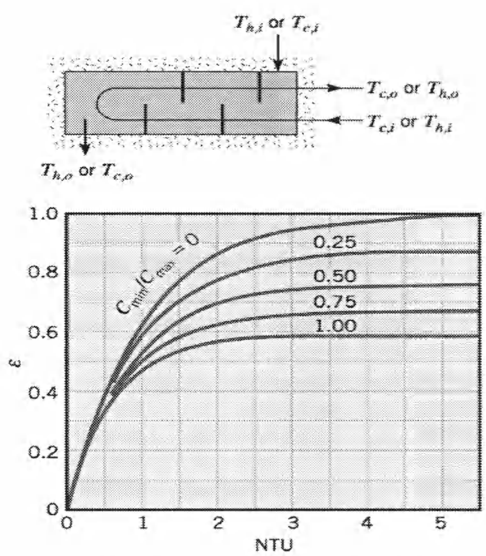

Figure 11.12 Effectiveness of a shell-and-tube heat exchanger with one shell and any multiple of two tube passes (two, four, etc. tube passes) (Equation 11.30).

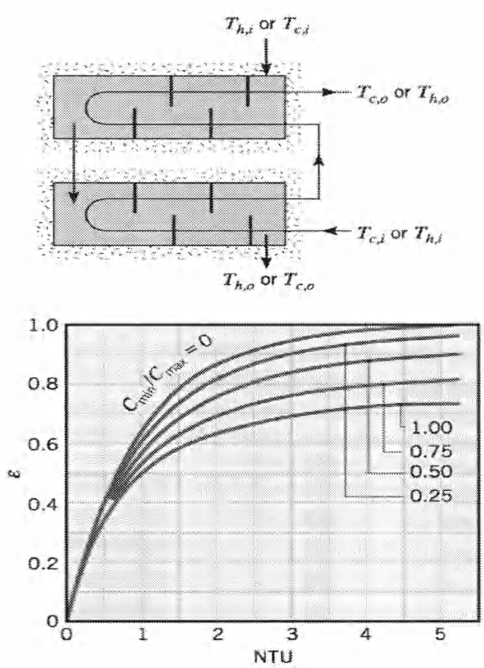

Figure 11.13 Effectiveness of a shell-and-tube heat exchanger with two shell passes and any multiple of four tube passes (four, eight, etc. tube passes) (Equation 11.31 with $n = 2$).

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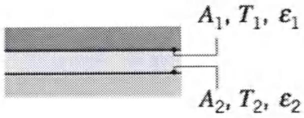
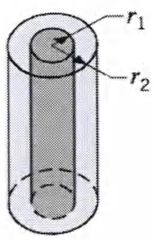
TABLE 13.3 Special Diffuse, Gray, Two-Surface Enclosures

Large (Infinite) Parallel Planes



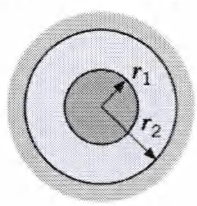
$$A_1 = A_2 = A \qquad F_{12} = 1 \qquad q_{12} = \frac{A\sigma(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1} \tag{13.19}$$

Long (Infinite) Concentric Cylinders



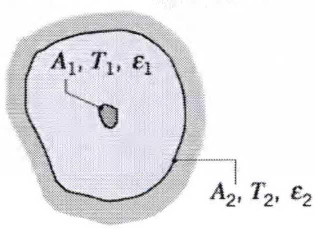
$$\frac{A_1}{A_2} = \frac{r_1}{r_2} \qquad F_{12} = 1 \qquad q_{12} = \frac{\sigma A_1(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1-\varepsilon_2}{\varepsilon_2}\left(\dfrac{r_1}{r_2}\right)} \tag{13.20}$$

Concentric Spheres



$$\frac{A_1}{A_2} = \frac{r_1^2}{r_2^2} \qquad F_{12} = 1 \qquad q_{12} = \frac{\sigma A_1(T_1^4 - T_2^4)}{\dfrac{1}{\varepsilon_1} + \dfrac{1-\varepsilon_2}{\varepsilon_2}\left(\dfrac{r_1}{r_2}\right)^2} \tag{13.21}$$

Small Convex Object in a Large Cavity



$$\frac{A_1}{A_2} \approx 0 \qquad F_{12} = 1 \qquad q_{12} = \sigma A_1 \varepsilon_1 (T_1^4 - T_2^4) \tag{13.22}$$

TABLE A.4 Thermophysical Properties of Gases at Atmospheric Pressure[a]

T (K)	ρ (kg/m^3)	c_p (kJ/kg · K)	$\mu \cdot 10^7$ (N · s/m^2)	$\nu \cdot 10^6$ (m^2/s)	$k \cdot 10^3$ (W/m · K)	$\alpha \cdot 10^6$ (m^2/s)	Pr
Air							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683
600	0.5804	1.051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1.063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1.075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1.087	354.6	76.37	54.9	109	0.702
800	0.4354	1.099	369.8	84.93	57.3	120	0.709
850	0.4097	1.110	384.3	93.80	59.6	131	0.716
900	0.3868	1.121	398.1	102.9	62.0	143	0.720
950	0.3666	1.131	411.3	112.2	64.3	155	0.723
1000	0.3482	1.141	424.4	121.9	66.7	168	0.726
1100	0.3166	1.159	449.0	141.8	71.5	195	0.728
1200	0.2902	1.175	473.0	162.9	76.3	224	0.728
1300	0.2679	1.189	496.0	185.1	82	238	0.719
1400	0.2488	1.207	530	213	91	303	0.703
1500	0.2322	1.230	557	240	100	350	0.685
1600	0.2177	1.248	584	268	106	390	0.688
1700	0.2049	1.267	611	298	113	435	0.685
1800	0.1935	1.286	637	329	120	482	0.683
1900	0.1833	1.307	663	362	128	534	0.677
2000	0.1741	1.337	689	396	137	589	0.672
2100	0.1658	1.372	715	431	147	646	0.667
2200	0.1582	1.417	740	468	160	714	0.655
2300	0.1513	1.478	766	506	175	783	0.647
2400	0.1448	1.558	792	547	196	869	0.630
2500	0.1389	1.665	818	589	222	960	0.613
3000	0.1135	2.726	955	841	486	1570	0.536

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TABLE 12.1 Blackbody Radiation Functions

λT $(\mu m \cdot K)$	$F_{(0 \rightarrow \lambda)}$	$I_{\lambda,b}(\lambda, T)/\sigma T^5$ $(\mu m \cdot K \cdot sr)^{-1}$	$\frac{I_{\lambda,b}(\lambda, T)}{I_{\lambda,b}(\lambda_{max}, T)}$
200	0.000000	0.375034×10^{-27}	0.000000
400	0.000000	0.490335×10^{-13}	0.000000
600	0.000000	0.104046×10^{-8}	0.000014
800	0.000016	0.991126×10^{-7}	0.001372
1,000	0.000321	0.118505×10^{-5}	0.016406
1,200	0.002134	0.523927×10^{-5}	0.072534
1,400	0.007790	0.134411×10^{-4}	0.186082
1,600	0.019718	0.249130	0.344904
1,800	0.039341	0.375568	0.519949
2,000	0.066728	0.493432	0.683123
2,200	0.100888	0.589649×10^{-4}	0.816329
2,400	0.140256	0.658866	0.912155
2,600	0.183120	0.701292	0.970891
2,800	0.227897	0.720239	0.997123
2,898	0.250108	0.722318×10^{-4}	1.000000
3,000	0.273232	0.720254×10^{-4}	0.997143
3,200	0.318102	0.705974	0.977373
3,400	0.361735	0.681544	0.943551
3,600	0.403607	0.650396	0.900429
3,800	0.443382	0.615225×10^{-4}	0.851737
4,000	0.480877	0.578064	0.800291
4,200	0.516014	0.540394	0.748139
4,400	0.548796	0.503253	0.696720
4,600	0.579280	0.467343	0.647004
4,800	0.607559	0.433109	0.599610
5,000	0.633747	0.400813	0.554898
5,200	0.658970	0.370580×10^{-4}	0.513043
5,400	0.680360	0.342445	0.474092
5,600	0.701046	0.316376	0.438002
5,800	0.720158	0.292301	0.404671
6,000	0.737818	0.270121	0.373965
6,200	0.754140	0.249723×10^{-4}	0.345724
6,400	0.769234	0.230985	0.319783
6,600	0.783199	0.213786	0.295973
6,800	0.796129	0.198008	0.274128
7,000	0.808109	0.183534	0.254090
7,200	0.819217	0.170256×10^{-4}	0.235708
7,400	0.829527	0.158073	0.218842
7,600	0.839102	0.146891	0.203360
7,800	0.848005	0.136621	0.189143
8,000	0.856288	0.127185	0.176079
8,500	0.874608	0.106772×10^{-4}	0.147819
9,000	0.890029	0.901463×10^{-5}	0.124801

TABLE A.6 Continued

Temperature, T (K)	Pressure, p (bars)[b]	Specific Volume (m^3/kg) $v_f \cdot 10^3$	v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	$c_{p,g}$	Viscosity (N · s/m^2) $\mu_f \cdot 10^6$	$\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	$k_g \cdot 10^3$	Prandtl Number Pr_f	Pr_g	Surface Tension, $\sigma_f \cdot 10^3$ (N/m)	Expansion Coefficient, $\beta_f \cdot 10^6$ (K^{-1})	Temperature, T (K)
440	7.333	1.110	0.261	2059	4.36	2.46	162	14.50	682	31.7	1.04	1.12	45.1		440
450	9.319	1.123	0.208	2024	4.40	2.56	152	14.85	678	33.1	0.99	1.14	42.9		450
460	11.71	1.137	0.167	1989	4.44	2.68	143	15.19	673	34.6	0.95	1.17	40.7		460
470	14.55	1.152	0.136	1951	4.48	2.79	136	15.54	667	36.3	0.92	1.20	38.5		470
480	17.90	1.167	0.111	1912	4.53	2.94	129	15.88	660	38.1	0.89	1.23	36.2		480
490	21.83	1.184	0.0922	1870	4.59	3.10	124	16.23	651	40.1	0.87	1.25	33.9	—	490
500	26.40	1.203	0.0766	1825	4.66	3.27	118	16.59	642	42.3	0.86	1.28	31.6	—	500
510	31.66	1.222	0.0631	1779	4.74	3.47	113	16.95	631	44.7	0.85	1.31	29.3	—	510
520	37.70	1.244	0.0525	1730	4.84	3.70	108	17.33	621	47.5	0.84	1.35	26.9	—	520
530	44.58	1.268	0.0445	1679	4.95	3.96	104	17.72	608	50.6	0.85	1.39	24.5	—	530
540	52.38	1.294	0.0375	1622	5.08	4.27	101	18.1	594	54.0	0.86	1.43	22.1	—	540
550	61.19	1.323	0.0317	1564	5.24	4.64	97	18.6	580	58.3	0.87	1.47	19.7	—	550
560	71.08	1.355	0.0269	1499	5.43	5.09	94	19.1	563	63.7	0.90	1.52	17.3	—	560
570	82.16	1.392	0.0228	1429	5.68	5.67	91	19.7	548	76.7	0.94	1.59	15.0	—	570
580	94.51	1.433	0.0193	1353	6.00	6.40	88	20.4	528	76.7	0.99	1.68	12.8	—	580
590	108.3	1.482	0.0163	1274	6.41	7.35	84	21.5	513	84.1	1.05	1.84	10.5	—	590
600	123.5	1.541	0.0137	1176	7.00	8.75	81	22.7	497	92.9	1.14	2.15	8.4	—	600
610	137.3	1.612	0.0115	1068	7.85	11.1	77	24.1	467	103	1.30	2.60	6.3	—	610
620	159.1	1.705	0.0094	941	9.35	15.4	72	25.9	444	114	1.52	3.46	4.5	—	620
625	169.1	1.778	0.0085	858	10.6	18.3	70	27.0	430	121	1.65	4.20	3.5	—	625
630	179.7	1.856	0.0075	781	12.6	22.1	67	28.0	412	130	2.0	4.8	2.6	—	630
635	190.9	1.935	0.0066	683	16.4	27.6	64	30.0	392	141	2.7	6.0	1.5	—	635
640	202.7	2.075	0.0057	560	26	42	59	32.0	367	155	4.2	9.6	0.8	—	640
645	215.2	2.351	0.0045	361	90	—	54	37.0	331	178	12	26	0.1	—	645
647.3[c]	221.2	3.170	0.0032	0	∞	∞	45	45.0	238	238	∞	∞	0.0	—	647.3[c]

[a]Adapted from Reference 22.
[b]1 bar = 10^5 N/m^2.
[c]Critical temperature.

TABLE A.6 Thermophysical Properties of Saturated Water[a]

Temperature, T (K)	Pressure, p (bars)[b]	Specific Volume (m³/kg) $v_f \cdot 10^3$	v_g	Heat of Vaporization, h_{fg} (kJ/kg)	Specific Heat (kJ/kg · K) $c_{p,f}$	$c_{p,g}$	Viscosity (N · s/m²) $\mu_f \cdot 10^6$	$\mu_g \cdot 10^6$	Thermal Conductivity (W/m · K) $k_f \cdot 10^3$	$k_g \cdot 10^3$	Prandtl Number Pr_f	Pr_g	Surface Tension, $\sigma_f \cdot 10^3$ (N/m)	Expansion Coefficient, $\beta_f \cdot 10^6$ (K⁻¹)	Temperature, T (K)
273.15	0.00611	1.000	206.3	2502	4.217	1.854	1750	8.02	569	18.2	12.99	0.815	75.5	−68.05	273.15
275	0.00697	1.000	181.7	2497	4.211	1.855	1652	8.09	574	18.3	12.22	0.817	75.3	−32.74	275
280	0.00990	1.000	130.4	2485	4.198	1.858	1422	8.29	582	18.6	10.26	0.825	74.8	46.04	280
285	0.01387	1.000	99.4	2473	4.189	1.861	1225	8.49	590	18.9	8.81	0.833	74.3	114.1	285
290	0.01917	1.001	69.7	2461	4.184	1.864	1080	8.69	598	19.3	7.56	0.841	73.7	174.0	290
295	0.02617	1.002	51.94	2449	4.181	1.868	959	8.89	606	19.5	6.62	0.849	72.7	227.5	295
300	0.03531	1.003	39.13	2438	4.179	1.872	855	9.09	613	19.6	5.83	0.857	71.7	276.1	300
305	0.04712	1.005	29.74	2426	4.178	1.877	769	9.29	620	20.1	5.20	0.865	70.9	320.6	305
310	0.06221	1.007	22.93	2414	4.178	1.882	695	9.49	628	20.4	4.62	0.873	70.0	361.9	310
315	0.08132	1.009	17.82	2402	4.179	1.888	631	9.69	634	20.7	4.16	0.883	69.2	400.4	315
320	0.1053	1.011	13.98	2390	4.180	1.895	577	9.89	640	21.0	3.77	0.894	68.3	436.7	320
325	0.1351	1.013	11.06	2378	4.182	1.903	528	10.09	645	21.3	3.42	0.901	67.5	471.2	325
330	0.1719	1.016	8.82	2366	4.184	1.911	489	10.29	650	21.7	3.15	0.908	66.6	504.0	330
335	0.2167	1.018	7.09	2354	4.186	1.920	453	10.49	656	22.0	2.88	0.916	65.8	535.5	335
340	0.2713	1.021	5.74	2342	4.188	1.930	420	10.69	660	22.3	2.66	0.925	64.9	566.0	340
345	0.3372	1.024	4.683	2329	4.191	1.941	389	10.89	668	22.6	2.45	0.933	64.1	595.4	345
350	0.4163	1.027	3.846	2317	4.195	1.954	365	11.09	668	23.0	2.29	0.942	63.2	624.2	350
355	0.5100	1.030	3.180	2304	4.199	1.968	343	11.29	671	23.3	2.14	0.951	62.3	652.3	355
360	0.6209	1.034	2.645	2291	4.203	1.983	324	11.49	674	23.7	2.02	0.960	61.4	697.9	360
365	0.7514	1.038	2.212	2278	4.209	1.999	306	11.69	677	24.1	1.91	0.969	60.5	707.1	365
370	0.9040	1.041	1.861	2265	4.214	2.017	289	11.89	679	24.5	1.80	0.978	59.5	728.7	370
373.15	1.0133	1.044	1.679	2257	4.217	2.029	279	12.02	680	24.8	1.76	0.984	58.9	750.1	373.15
375	1.0815	1.045	1.574	2252	4.220	2.036	274	12.09	681	24.9	1.70	0.987	58.6	761	375
380	1.2869	1.049	1.337	2239	4.226	2.057	260	12.29	683	25.4	1.61	0.999	57.6	788	380
385	1.5233	1.053	1.142	2225	4.232	2.080	248	12.49	685	25.8	1.53	1.004	56.6	814	385
390	1.794	1.058	0.980	2212	4.239	2.104	237	12.69	686	26.3	1.47	1.013	55.6	841	390
400	2.455	1.067	0.731	2183	4.256	2.158	217	13.05	688	27.2	1.34	1.033	53.6	896	400
410	3.302	1.077	0.553	2153	4.278	2.221	200	13.42	688	28.2	1.24	1.054	51.5	952	410
420	4.370	1.088	0.425	2123	4.302	2.291	185	13.79	688	29.8	1.16	1.075	49.4	1010	420
430	5.699	1.099	0.331	2091	4.331	2.369	173	14.14	685	30.4	1.09	1.10	47.2		430

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