Program: BSc. in ME (6th Semester)/ BSc. TE (2S/2Y)

Date: 11 March, 2024
Time: 10AM to 11.30AM

ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

ORGANIZATION OF ISLAMIC COOPERATION (OIC)

DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING

Mid Semester Examination
Course Number: ME 4613
Course Title: Applied Heat Transfer

Summer Semester: 2022-2023
Full Marks: 75
Time: 1 Hour 30 Minutes

There are 3 (Three) questions. Answer all of them. Marks of each Question and the corresponding CO and PO are written in the brackets. The symbols have their usual meanings. All the necessary equations are attached afterward. Assume reasonable values for any missing data. Programmable calculators are not allowed. Do not write on this question paper.

1. a) Derive the temperature distribution in fully developed flow within a tube exposed to constant surface heat flux. Formulate that the temperature gradient remains constant with respect to the axial distance (x), indicating that the temperature profile retains its shape uniformly along the tube. Moreover, illustrate how the average fluid temperature along the tube, under constant temperature conditions, exhibits an exponential variation, with necessary derivation. (12) (CO2) (PO2) (P1,P2)

   b) Oil flow in a journal bearing can be treated as parallel flow between two large isothermal plates with one plate moving at a constant velocity of 10 m/s and the other stationary. Consider such a flow with a uniform spacing of 0.7 mm between the plates. The temperatures of the upper and lower plates are 40°C and 15°C, respectively. By simplifying and solving the continuity, momentum, and energy equations, determine (13) (CO2) (PO2) (P1,P2)
      (i) the velocity and temperature distributions in the oil, and
      (ii) the maximum temperature and where it occurs.

2. a) Engine oil enters a 1 cm diameter tube at 40°C and with a flow rate such that the Reynolds number is 80 at the entrance. Fully developed convective flow takes place in such a way that raises the fluid temperature to 43°C when the tube wall temperature is constant at 80°C. Calculate the following: (12) (CO4) (PO4) (P1,P4)
   (i) Mean Reynolds number, (ii) Average convection heat transfer coefficient, and
   (iii) Length of the tube

   b) Air at 1 atm and 300 K blows across a 50-cm-square flat plate at a velocity such that the Reynolds number at the downstream edge of the plate is 1.1×10^5. Heating does not begin until halfway along the plate and then the surface temperature is 400 K. Determine the heat transfer rate from the plate. (13) (CO4) (PO4) (P1,P4)

3. Air is to be heated by passing it over a bank of 3-m-long tubes inside which steam is condensing at 100°C. Air approaches the tube bank in the normal direction at 20°C and 1 atm with a mean velocity of 5.2 m/s. The outer diameter of the tubes is 1.6 cm, and the tubes are arranged staggered with longitudinal and transverse pitches of $S_L = S_T =$ 4 cm. If the outlet temperature is 30°C, determine (a) the number of tubes in the longitudinal direction, (b) pressure drop across the tube bank, (c) the rate of heat transfer, and (d) the rate of condensation of steam inside the tubes. (25) (CO3) (PO3) (P1,P2)

Property Table

Properties of liquids

Temp. T, °C	Density ρ, kg/m³	Specific Heat c_p, J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m²/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m²/s	Prandtl Number Pr	Volume Expansion Coeff. β, 1/K
				Engine Oil (unused)				
0	899.0	1797	0.1469	9.097×10^{-8}	3.814	4.242×10^{-3}	46,636	0.00070
20	888.1	1881	0.1450	8.680×10^{-8}	0.8374	9.429×10^{-4}	10,863	0.00070
40	876.0	1964	0.1444	8.391×10^{-8}	0.2177	2.485×10^{-4}	2,962	0.00070
60	863.9	2048	0.1404	7.934×10^{-8}	0.07399	8.565×10^{-5}	1,080	0.00070

Properties of air at 1 atm pressure

Temp. T, °C	Density ρ, kg/m³	Specific Heat c_p, J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m²/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m²/s	Prandtl Number Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-5}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
90	0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
100	0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
120	0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
140	0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
160	0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
180	0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
200	0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
250	0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
300	0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935

Necessary Equations

For flow across tube banks –

$$S_D = \sqrt{S_L^2 + (S_T/2)^2}$$

In-line and *Staggered* with $S_D < (S_T + D)/2$:

$$\mathcal{V}_{\max} = \frac{S_T}{S_T - D}\mathcal{V}$$

Staggered with $S_D < (S_T + D)/2$:

$$\mathcal{V}_{\max} = \frac{S_T}{2(S_D - D)}\mathcal{V}$$

TABLE 7–2

Nusselt number correlations for cross flow over tube banks for $N_L > 16$ and $0.7 < Pr < 500$ (from Zukauskas, 1987)

Arrangement	Range of Re_D	Correlation
In-line	0–100	$Nu_D = 0.9\,Re_D^{0.4}Pr^{0.36}(Pr/Pr_s)^{0.25}$
	100–1000	$Nu_D = 0.52\,Re_D^{0.5}Pr^{0.36}(Pr/Pr_s)^{0.25}$
	$1000–2 \times 10^5$	$Nu_D = 0.27\,Re_D^{0.63}Pr^{0.36}(Pr/Pr_s)^{0.25}$
	$2 \times 10^5–2 \times 10^6$	$Nu_D = 0.033\,Re_D^{0.8}Pr^{0.4}(Pr/Pr_s)^{0.25}$
Staggered	0–500	$Nu_D = 1.04\,Re_D^{0.4}Pr^{0.36}(Pr/Pr_s)^{0.25}$
	500–1000	$Nu_D = 0.71\,Re_D^{0.5}Pr^{0.36}(Pr/Pr_s)^{0.25}$
	$1000–2 \times 10^5$	$Nu_D = 0.35(S_T/S_L)^{0.2}Re_D^{0.6}Pr^{0.36}(Pr/Pr_s)^{0.25}$
	$2 \times 10^5–2 \times 10^6$	$Nu_D = 0.031(S_T/S_L)^{0.2}Re_D^{0.8}Pr^{0.36}(Pr/Pr_s)^{0.25}$

*All properties except Pr_s are to be evaluated at the arithmetic mean of the inlet and outlet temperatures of the fluid (Pr_s is to be evaluated at T_s).

$Nu_{D,N_L<16} = F\,Nu_D$

TABLE 7–3

Correction factor F to be used in $Nu_{D,N_L<16} = F\,Nu_D$ for $N_L > 16$ and $Re_D > 1000$ (from Zukauskas, 1987)

N_L	1	2	3	4	5	7	10	13
In-line	0.70	0.80	0.86	0.90	0.93	0.96	0.98	0.99
Staggered	0.64	0.76	0.84	0.89	0.93	0.96	0.98	0.99

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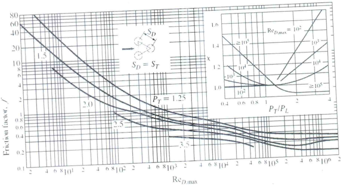

$A_s = N\pi DL \quad \dot{m} = \rho V(N_T S_T L)$

The pressure drop for a tube bank –

$$\Delta P = N_L f \chi \frac{\rho V_{max}^2}{2}$$

For parallel flow over a flat plate, the local friction and convection coefficients are –

Laminar: $C_{f,x} = \dfrac{0.664}{Re_x^{1/2}} \qquad Re_x < 5 \times 10^5$

$$Nu_x = \frac{h_x x}{k} = 0.332\, Re_x^{0.5}\, Pr^{1/3} \qquad Pr > 0.6$$

Turbulent: $C_{f,x} = \dfrac{0.0592}{Re_x^{1/5}}, \qquad 5 \times 10^5 \le Re_x \le 10^7$

$$Nu_x = \frac{h_x x}{k} = 0.0296\, Re_x^{0.8}\, Pr^{1/3} \qquad \begin{array}{l} 0.6 \le Pr \le 60 \\ 5 \times 10^5 \le Re_x \le 10^7 \end{array}$$

The average Nusselt number relations for flow over a flat plate are –

Laminar: $Nu = \dfrac{hL}{k} = 0.664\, Re_L^{0.5}\, Pr^{1/3} \qquad Re_L < 5 \times 10^5$

Turbulent:

$$Nu = \frac{hL}{k} = 0.037\, Re_L^{0.8}\, Pr^{1/3} \qquad \begin{array}{l} 0.6 \le Pr \le 60 \\ 5 \times 10^5 \le Re_L \le 10^7 \end{array}$$

For isothermal/isoflux surfaces with an unheated starting section of length ζ, the local Nusselt number –

Laminar: $Nu_x = \dfrac{Nu_{x\,(\text{for } \xi = 0)}}{[1 - (\xi/x)^{3/4}]^{1/3}}$

Turbulent: $Nu_x = \dfrac{Nu_{x\,(\text{for } \xi = 0)}}{[1 - (\xi/x)^{9/10}]^{1/9}}$

For isothermal/isoflux surfaces with an unheated starting section of length ζ, the average Nusselt number –

$$Nu_L = Nu_{L(\text{for } \xi=0)} \left(\frac{L}{L-\xi}\right)\left[1-\left(\frac{\xi}{L}\right)^{\frac{p+1}{p+2}}\right]^{\frac{p}{p+1}}$$

For laminar, p = 2, and for turbulent, p = 8

The End