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Kafrelsheikh University
Faculty of Engineering
Dept. Mech. Engineering
Year: Second year
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انتقال الحرارة

Semester: 2nd Semester
Final Examination
Date: May 28th, 2016
Time allowed: 3 hours
Full Mark: 100

Subject: Heat and Mass Transfer (MEP2206)

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1. No. of pages: 10-No. of questions: 8.
2. You are permitted to use a heat transfer tables and a calculator. Extra pages, problem solutions, and class notes are **not** permitted.
3. Clear solutions are required. Marks will not be assigned for answers that require unreasonable effort for the instructor to decipher.
4. Whenever possible, solutions should include a schematic diagram that clearly indicates your nomenclature for temperatures and assumed directions of heat flows. Marks will be assigned for the schematic diagram.
5. Computations should include showing the work: the equation(s) in symbolic form, the substitution of values, and the final answer with appropriate units.
6. Ask for clarification if any problem statement is unclear to you.
7. The weight of each problem is indicated. The exam will be marked out of 100. There are 20 marks bonus. Try to collect 100 marks from the exam.

Question #1 (17 Marks)

Humans are able to control their heat production rate and heat loss rate to maintain a nearly constant core temperature of T_c=37°C under a wide range of environmental conditions. This process is called *thermoregulation*. From the perspective of calculating heat transfer between a human body and its surroundings, we focus on a layer of skin and fat, with its outer surface exposed to the environment and its inner surface at a temperature slightly less than the core temperature, T_i = 35 °C =308 K. Consider a person with a skin/fat layer of thickness L= 4 mm and effective thermal conductivity k = 0.4 W/m_ K. The person has a surface area A=2.1 m² and is dressed in a bathing suit. The emissivity of the skin is ε = 0.85.

1. Estimate the equivalent heat radiative heat transfer coefficient h_r with assuming (only for this step) T_s=303 K (Assuming σ=5.67×10⁻⁸ W/m².K) **(4 Marks)**
2. When the person is in still air at T_∞= 297 K, what is the skin surface temperature and rate of heat loss to the environment? Convection heat transfer to the air is characterized by a free convection coefficient of h = 5 W/m² . K. **(9 Marks)**
3. When the person is in water at T_∞= 297 K, what is the skin surface temperature and heat loss rate? Heat transfer to the water is characterized by a convection coefficient of h = 2000 W/m². K. **(4 Marks)**

B

Question #2 (12 Marks)

a. Write, without derivation, the general heat diffusion equation for Cartesian unsteady and 3D with heat generation. Simplify this equation for 1D unsteady without heat generation. State the boundary conditions for this equation at the surface (x=0) and sketch $T(x, t)$ for each state of boundary conditions. **(12 Marks)**

Solution

Question #3 (15 Marks)

The temperature distribution across a wall 2 m thick at a certain instant of time is given as:

$$T(x) = a + bx + cx^2$$

where T is in degrees Celsius and x is in meters, while a = 900°C, b=-300 °C /m, and c=-50 °C /m². A uniform heat generation, $\dot{q}$ =1500 W/m³, is present in the wall of area 20 m² having the properties ρ=1500 kg/m³, k =50 W/m.K, and c_p= 5 kJ/kg.K

1. Determine the rate of heat transfer entering the wall (x = 0) and leaving the wall (x = 2 m). **(3 Marks)**
2. Determine the rate of change of energy storage in the wall. **(7 Marks)**
3. Determine the time rate of temperature change at x= 0, 0.5, and 1 m. What is your comment? Also determine the time at which the temperature of wall changes by -20°C **(5 Marks)**

B

Question #4 (15 Marks)

A commercial grade cubical freezer, 3 m on a side, has a composite wall consisting of an exterior sheet of 6.35-mm-thick plain carbon steel, an intermediate layer of 100-mm-thick cork insulation, and an inner sheet of 6.35-mm-thick aluminum alloy (2024). Adhesive interfaces between the insulation and the metallic strips are each characterized by a thermal contact resistance of $R''_{t,c} = 2.5 \times 10^{-4}$ m²·K/W. What is the steady-state cooling load that must be maintained by the refrigerator under conditions for which the outer and inner surface temperatures are 22°C and -6°C, respectively?

Solution

Question #5 (15 Marks)

An electronic device, such as a power transistor mounted on a finned heat sink, can be modeled as a spatially isothermal object with internal heat generation and an external convection resistance.

a. Consider such a system of mass M, specific heat c, and surface area A_s, which is initially in equilibrium with the environment at T_∞. Suddenly, the electronic device is energized such that a constant heat generation $\dot{E}_g$ (W) occurs. Show that the temperature response of the device is

$$\frac{\theta}{\theta_i} = \exp\left(-\frac{1}{RC}\right)$$

where $\theta = T - T(\infty)$ and $T(\infty)$ is the steady-state temperature corresponding to $t \to \infty$; $\theta_i = T_i - T(\infty)$; T_i = initial temperature of device; R = thermal resistance $1/\bar{h}A_s$; and C = thermal capacitance Mc. **(10 Marks)**

b. An electronic device, which generates 60 W of heat, is mounted on an aluminum heat sink weighing 0.31 kg and reaches a temperature of 100°C in ambient air at 20°C under steady-state conditions. If the device is initially at 20°C, what temperature will it reach 5 min after the power is switched on? **(5 Marks)**

Solution

B

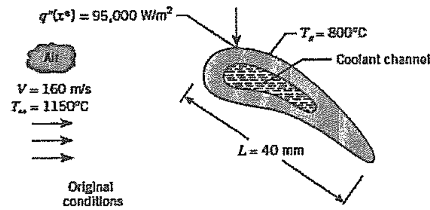
Question #6 (12 Marks)

a. Consider airflow over a flat plate of length L = 1m under conditions for which transition occurs at x_c= 0.5 m based on the critical Reynolds number, $Re_{x,c} = 5 \times 10^5$.

1. Evaluating the thermophysical properties of air at 350 K, determine the air velocity. **(2 Marks)**
2. In the laminar and turbulent regions, the local convection coefficients are, respectively, where, at T = 350 K, C_{lam} = 8.845 W/m$^{3/2}$. K, C_{turb} =49.75 W/m$^{1.8}$. K, and x has units of m. Develop an expression for the average convection coefficient, $\bar{h}_{lam}(x)$, as a function of distance from the leading edge, x, for the laminar region, $0 < x < x_c$. **(5 Marks)**
3. Develop an expression for the average convection coefficient, $\bar{h}_{turb}(x)$ as a function of distance from the leading edge, x, for the turbulent region, $x_c < x < L$.
4. On the same coordinates, plot the local and average convection coefficients, h_x and $\bar{h}_x$, respectively, as a function of x for $0 < x < L$. **(5 Marks)**

Solution

Question #7 (14 Marks)



Experimental tests using air as the working fluid are conducted on a portion of the turbine blade shown in the sketch. The heat flux to the blade at a particular point (x^*) on the surface is measured to be q''= 95,000 W/m^2. To maintain a steady-state surface temperature of 800°C, heat transferred to the blade is removed by circulating a coolant inside the blade.

1. Determine the heat flux to the blade at x^* if its temperature is reduced to $T_{s,1}$ = 700°C by increasing the coolant flow. **(7 Marks)**
2. Determine the heat flux at the same dimensionless location x^* for a similar turbine blade having a chord length of L = 80 mm, when the blade operates in an airflow at T_∞=1150°C and V = 80 m/s, with T_s = 800°C. **(7 Marks)**

Solution

B

Question #8 (20 Marks)

Pressurized water is often available at elevated temperatures and may be used for space heating or industrial process applications. In such cases it is customary to use a tube bundle in which the water is passed through the tubes, while air is passed in cross flow over the tubes. Consider a staggered arrangement for which the tube outside diameter is 16.4 mm and the longitudinal and transverse pitches are S_L = 34.3 mm and S_T = 31.3 mm. There are seven rows of tubes in the airflow direction and eight tubes per row. Under typical operating conditions the cylinder surface temperature is at 70°C, while the air upstream temperature and velocity are 15°C and 6 m/s, respectively. Determine the air-side convection coefficient and the rate of heat transfer for the tube bundle. What is the air-side pressure drop?

Note that $Nu_D = 0.323_1 \mathrm{Re}_{D,\max}^{0.6} \mathrm{Pr}^{0.36} \left(\frac{\mathrm{Pr}}{\mathrm{Pr}_s} \right)^{1/4}$, $\mathrm{Re}_{D,\max} = \rho V_{\max} D / \mu$,

$$V_{\max} = \begin{cases} \dfrac{S_T}{2(S_D - D)} V & \text{if} \quad S_D = \left[S_L^2 + (S_T/2)^2 \right]^{1/2} < (S_T + D)/2 \\ \dfrac{S_T}{S_T - D} V & \text{if} \quad S_D = \left[S_L^2 + (S_T/2)^2 \right]^{1/2} > (S_T + D)/2 \end{cases}$$

if

Solution