IIT Bombay

Department of Mechanical Engineering

2022–2023 Semester 1: PhD Qualifying Examination Paper

TFE2 : Heat Transfer : 05/08/2022 : 1430 – 1730

Total marks: 100. Passing marks: 40.

This is a closed-book examination, you are not allowed to bring any cribsheets either. Answer all questions. Make suitable assumptions if required and state them clearly. Simplify the answers to the extent possible. Please write neatly. **Please start the solution of each of the SIX problems below on a NEW page.** ***Good Luck and Enjoy the Examination!***

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1. A device is to be cooled by clamping an aluminium block to it and passing cooling air through small diameter holes in this block. The length of the block in the flow direction is fixed by practical consideration and the block can be assumed to be at a uniform temperature of Tw. The air enters the holes in the block at a known temperature of To and the total mass flow rate of air through the holes in the block may be considered to be fixed. You may assume the flow in the cooling holes to be laminar and fully developed. Through detailed heat transfer and fluid flow analysis, investigate the effect of the number of holes on the heat transfer rate from the block to the air passing through it. As part of this investigation, you may have to determine the maximum possible heat transfer between the walls of any given hole and the air flowing through it and the (ideal/theoretical) conditions under which this may be achieved. Finally, for a given requirement, it is desired to achieve 95% of the maximum possible heat transfer. Determine the expression for the number of holes that would fulfil the requirement. **[20 Marks]**

2. In a boiler, heat is radiated from the burning fuel bed to the side walls and the boiler tubes at the top, as shown in Figure 1. The temperature of the fuel and the tubes are T1 and T2 respectively and their areas are A1 and A2.
   a. Assume that the side walls are perfectly insulated. Determine the temperature of the side walls. (2 Marks)
   b. Derive an expression for the total radiative heat transfer to the tubes (Q2). (6 Marks)
   c. Calculate the radiative heat transfer to the tubes if T1 = 1,700°C, T2 = 300°C, A1 = A2 = 12 m^2 and the view factors are each 0.5. (2 Marks) **[12 Marks]**

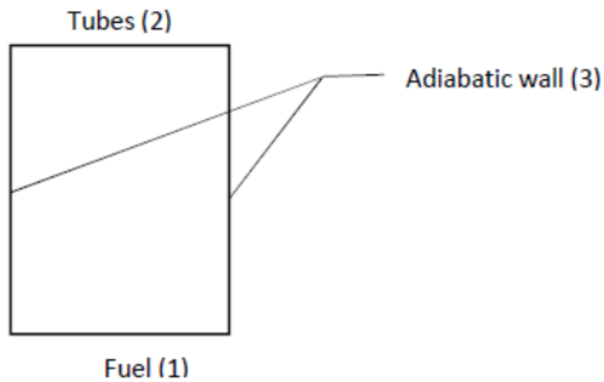


Figure 1

3. A solar water heater consists of a flat copper plate collector as shown in Figure 2. A series of parallel tubes are attached to one side of the plate. Water flows through the tubes and removes the heat. Under steady-state conditions, the net absorption of solar radiation on the plate is 800 W/m^2. Assume that the underside of the plate is perfectly insulated, the evacuated space prevents convection losses from the upper surface, radiation losses are accounted for in obtaining the above value of net absorption, and the temperature of the absorber plate directly above the tubes is 80^{o}C, equal to the temperature of the water in the tube. What is the maximum temperature on the collector panel of the thermal conductivity of the copper plate is 401 W/m.K? **[13 Marks]**

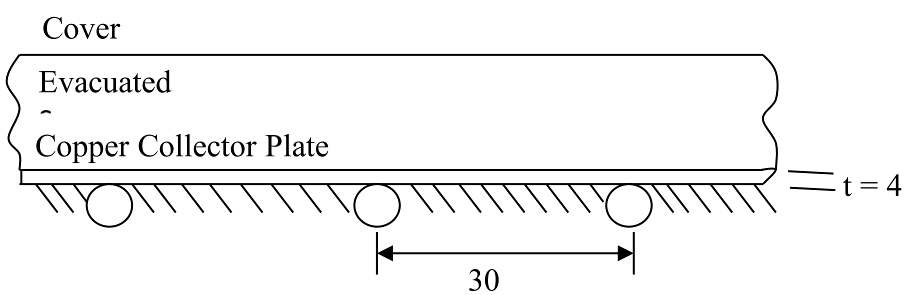


Figure 2

4. Sodium is used as a liquid coolant in a Nuclear reactor wherein it is made to flow through stainless steel tubes.
   a. Make appropriate assumptions and develop an expression for Nusselt Number
   b. Would Water be a better coolant? Assume a fully developed velocity profile for water

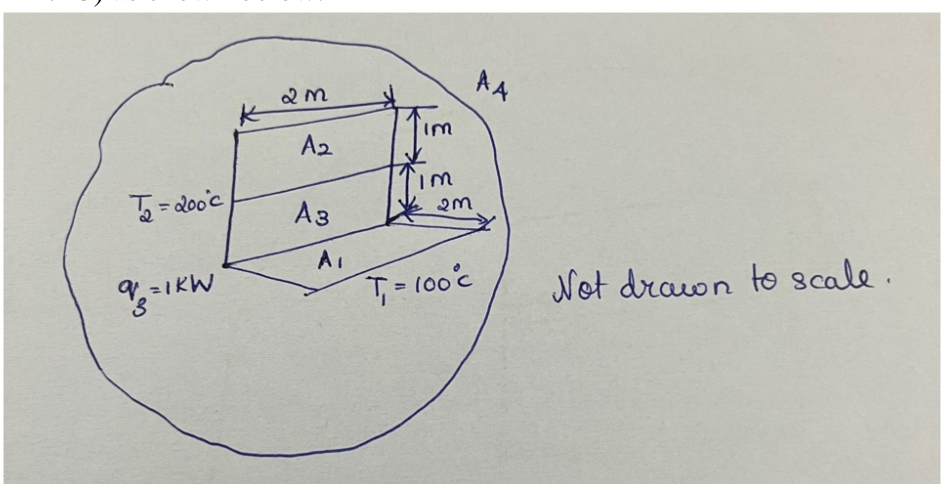
   Properties: $Pr_{water} = 10$; $K_{liq\_sodium}/K_{water} = 117.3$

   <u>Hint</u>: Since sodium has a very low Prandtl number, the thermal BL develops more rapidly than the velocity boundary layer. Thus, assume thermal BL to be fully developed whereas velocity BL to be uniform velocity across the cross-section. Since this is inside a reactor, one can assume that the influx of heat to sodium is at constant heat flux. **[20 Marks]**

5. Consider an insulated electrical wire where the radius of the wire including insulation is ‘r’.

a. For this system, derive and show that $\frac{d^2 R\prime}{dr^2} > 0$ at r = $\frac{k}{h}$. Here, R'_{tot} is the total resistance per unit length of the circuit, and h is the heat transfer coefficient.
b. Explain what this implies regarding this specific radius location with regards to the physics
c. An uninsulated electrical wire of 0.5 mm radius produces electrical heating at the rate of 2 W/m. If plastic insulation with k = 0.15 W/(m.K)) is to be provided, calculate the critical radius of insulation. The heat transfer coefficient on the surface of the insulation is 25 W/(m^2.K).
d. After adding insulation if r_{outer} = 1 mm, will it cause a heat transfer augmentation effect or insulation effect. Support your theory by estimating the heat loss rate. The temperature difference between the surface of the electrical wire (under the insulation) and the atmosphere is 25°C. **[15 Marks]**

6. Consider 3 blackbody plates located inside another large blackbody enclosure (which is at T = 27°C) as shown below.



The back side of each plate is insulated and 1 kW of heat is electrically generated in Plate A_3.
a. Sketch the thermal radiation network for this system
b. Determine the temperature of surface A_3
c. Rate of radiation heat transfer between plates A_1 and A_3
Necessary values can be obtained from the given plot of the Radiation Shape Factors.

Assume that there is no contact between adjoining plates. **[20 Marks]**

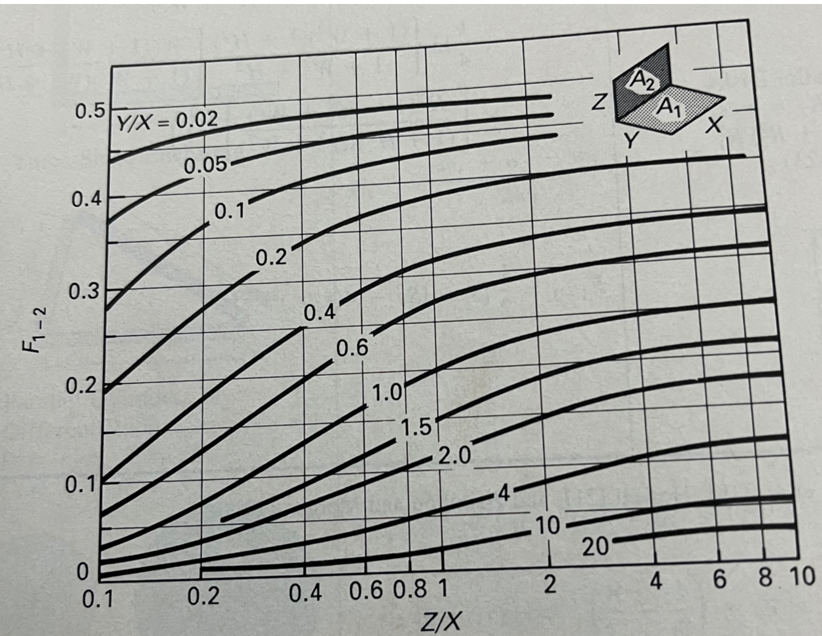


FIGURE 5–22 Radiation shape factor for perpendicular rectangles with a common edge.