

The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 3 MODULE, SPRING SEMESTER 2016-2017

ADVANCED HEAT TRANSFER

Time allowed TWO Hours

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced

Answer ALL questions in section A and ONE question in section B

Only silent, self-contained calculators with a Single-Line Display or Dual-Line Display are permitted in this examination.

Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

DO NOT turn examination paper over until instructed to do so

In this examination candidates are required to answer ALL questions in Section A and ONE out of THREE questions in Section B. If a candidate answers more than the required number of questions, all questions will be marked and the highest marks will be used in the final examination mark.

ADDITIONAL MATERIAL: Tables of Thermodynamic and Transport Properties of Fluids, formula and charts sheet

INFORMATION FOR INVIGILATORS:

Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

SECTION A
Answer ALL questions

1. Describe what happens in film boiling during a pool boiling process. How does this affect the heat transfer? [3]

2. A grain of rice can be approximated by a cylinder that measures approximately 15 mm long and 3 mm diameter. It needs to be heated to 70 °C to initiate the breakdown of the starches so it can begin to expand as it absorbs water. If you drop the grain into a pan of boiling water at sea level, how long will it take for the centre of the rice grain to reach 70 °C, if it was stored in a dark cupboard at 15 °C prior to being dropped into the pan. Since length is much longer than the radius, use the Heisler chart for an infinite cylinder.

Thermal heat capacity $c_{rice} = 1.5 \text{ kJ/kgK}$, Thermal conductivity $k_{rice} = 0.1 \text{ W/mK}$
Thermal diffusivity $\alpha_{rice} = 9.2 \times 10^{-8} \text{ m}^2/\text{s}$, Heat transfer coefficient: $h = 67 \text{ W/m}^2\text{K}$ [6]

3. Wien's displacement law states that the wavelength with maximum intensity in the black body radiation spectrum is relate to the Temperature by:

$$\lambda T = 2.898 \times 10^{-3} \text{ m.K}$$

If a heating element is glowing with a predominant colour with a wavelength of 650 nm, what will be the temperature of the element? [2]

4. In the case of a turbulent boundary layer flow over a flat surface, the overall Nusselt number correlation is:

$$\overline{Nu}_L = 0.037 Pr^{\frac{1}{3}} \left(Re_L^{\frac{4}{5}} - 23550 \right). \quad Pr \geq 0.5, 5 \times 10^5 < Re_L < 10^8$$

- (a) What will be the correlation from mass transfer relating the Sherwood number $\overline{Sh}_L = \frac{\overline{h}_m L}{D_c}$, and the Schmidt Number $Sc = \frac{\nu}{D_c}$, where D_c is the mass diffusivity of the situation? [3]

- (b) The mass diffusivity of water to air is $D_c = 3.29 \times 10^{-5} \text{ m}^2/\text{s}$. A flat plate of length 1 meter is covered with water. Air blows over at a speed of 20 m/s. The water and air are at the same temperature of 27C. What will be the overall mass transfer coefficient in this situation? [5]

5. Draw and clearly label a resistance network that can be used to solve the radiation heat transfer between three surfaces at different temperatures. All surfaces are grey bodies. [8]

6. Explain the term "radiosity" and "view factors". [4]

Continued on next page

7. Define Biot number and explain its physical meaning. If a hot solid body that is plunged into a cold liquid remains hot at the centre and cools down quickly at the surface, in what range is the Biot number; smaller than 1 or larger than 1. [3]
8. Briefly, state the relationship between the absorption and emission of radiation through Kirchoff's Law. [3]
9. What is thermal contact resistance and explain the use of "thermal greases, pastes or gels" improves the performance over those of air. [3]

SECTION B
Answer ONE question

10. A vacuum flask contains water at 100 °C. The inner wall is at the water temperature and the outer wall is cooled by convection with a heat transfer coefficient of 20 W/m²K. The inner wall has a Diameter of 100mm and the outer wall has a diameter of 110 mm. There is a vacuum between the two walls. The vessel is 15 cm in height. The temperature of the air in the room is 20 °C.
- (a) State the expected heat transfer rate due to conduction and convection in the space between walls and explain why. [4]
- (b) Calculate all the view factors for radiation between the two walls, assuming that they are infinite cylinders so ends can be neglected. [6]
- (c) Assuming that both walls have an emissivity of 0.2, and that the outer wall has negligible conduction,
- i) Estimate the air properties of the film of air near the flask wall (($\alpha, k, \nu, \beta, Pr$)) [6]
 - ii) Estimate the heat transfer coefficient for the convection on the outer wall. [7]
 - iii) Derive an iterative equation to estimate the outer wall temperature by using the heat transfer coefficient calculated in ii). [5]
 - iv) Show the working of the first iteration for the solution and explain how the second iteration should be completed. [8]
 - v) If a thermal resistance term is added to account for the temperature gradient across the outer wall, would this increase decrease or have no effect on the heat flow from the flask. Why? [4]

The correlation for the Wall averaged Nusselt number for isothermal vertical plate or large diameter cylinder is:

$$\overline{Nu}_L = \left\{ 0.825 + \frac{\left(0.387 Ra_L^{\frac{1}{4}} \right)}{\left[1 + \left(\frac{0.492}{Pr} \right)^{\frac{9}{16}} \right]^{\frac{8}{27}}} \right\}^2$$

Where $Ra_L = \frac{g\beta(T_w - T_\infty)L^3}{\alpha\nu}$, and L is the height of the cylinder.

11. An Aluminium Plate placed on top of a computer processor has a surface area of 100 mm X 100 mm. The processor must be at a temperature below 180°C. Considering all heat generated is leaving from the top surface of the processor and taking the ambient air temperature as 20°C:

(a) State the length that should be used for the empirical correlation in this case and why? [6]

(b) Estimate the air properties for this problem. ($\alpha, k, \nu, \beta, Pr$) [6]

(c) Estimate the heat transfer coefficient for horizontal top surface plate, [6]

$$\overline{Nu}_L = 0.54 Ra_L^{\frac{1}{4}}, \quad (10^4 < Ra_L < 10^7)$$

$$\overline{Nu}_L = 0.15 Ra_L^{\frac{1}{3}}, \quad (10^7 < Ra_L < 10^9)$$

(d) What is the worst case rate of heat transfer from the surface? [4]

(e) Assuming that this heat transfer coefficient is a constant, estimate the thermal resistance of the heat loss from the plate if 4 fins of length 10 cm and diameter 2 cm are added to the surface of the plate. The fin efficiency can be assumed to be 90%. [8]

(f) Assuming that we will dissipate the same heat as the no-fin case, what will be the temperature of the surface with the fins attached. [4]

(g) Discuss the effect of increasing the length of the fins on the overall heat loss from the surface. Consider the effect of the length on the efficiency and area of the fins. Use figure QB2 to aid your discussion. [6]

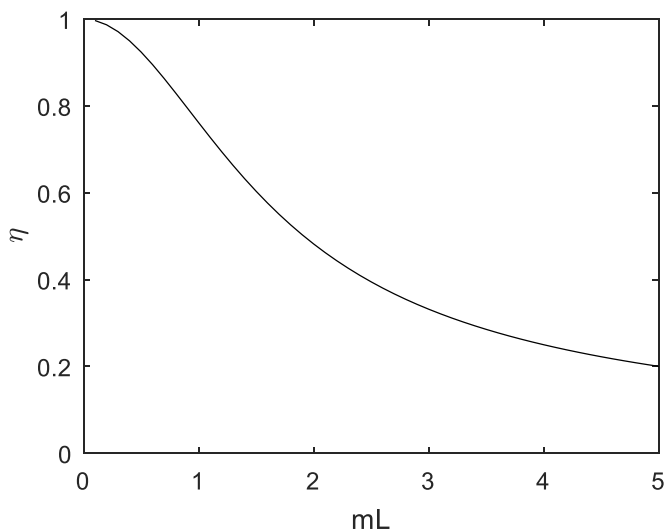


Figure QB2

12. A stainless ball ($\rho=8055 \text{ kg/ m}^3$, $c_p = 480 \text{ J/kgK}$, $k_{ball} = 33 \text{ W/mK}$, $\alpha=0.555 \times 10^{-5} \text{ m}^2/\text{s}$) with diameter of $D=25 \text{ cm}$ is subjected to the flow of air at 1 atm pressure and 27°C with a velocity of 4 m/s , as shown in Figure QB3a. The surface temperature of the ball is maintained at 127°C due to an internal heat source. The Nusselt number is determined from:

$$\text{Nu}_D = 2 + \left[0.4\text{Re}_D^{1/2} + 0.06\text{Re}_D^{2/3} \right] \text{Pr}^{0.4} \left(\frac{\mu_\infty}{\mu_s} \right)^{1/4}$$

Where μ_∞ and μ_s are the viscosity of the fluid and surface respectively.

- (a) Determine the rate of heat transfer between the ball and air. [16]
- (b) How much heat must be internally generated to maintain this temperature and why? [3]
- (c) If the internal heat source is shut down with an initial ball surface temperature of 127°C and eventually it drops to 47°C , estimate approximately how long this cooling process will take in minutes. For Lumped Capacity approach, one has:

$$\frac{\theta}{\theta_0} = \exp\left(-\frac{hA}{\rho C_p V} t\right)$$
 [7]

- (d) Is the lumped capacitance model valid in this case? [4]
- (e) Assume the ball has an isothermal temperature of 47°C now and is then put into water of 7°C , taking convection heat transfer coefficient $h_{water}=88 \text{ W/m}^2\text{k}$, use the Heisler charts given in figure QB3b to estimate how long in minutes and seconds it will take for the centre temperature of the ball drops to 27°C . [10]

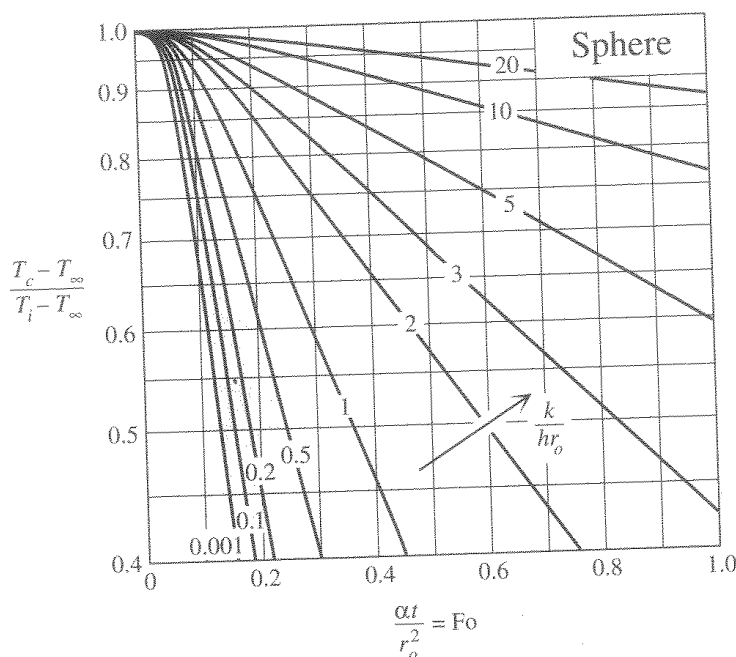


Fig QB3b