

The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIAL AND MANUFACTURING ENGINEERING

A LEVEL 3 MODULE, SPRING SEMESTER 2017-2018

ADVANCED HEAT TRANSFER MM3HTR

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 Part A and ONE question from Part 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 of Part A and ONE out of THREE questions in Part 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:

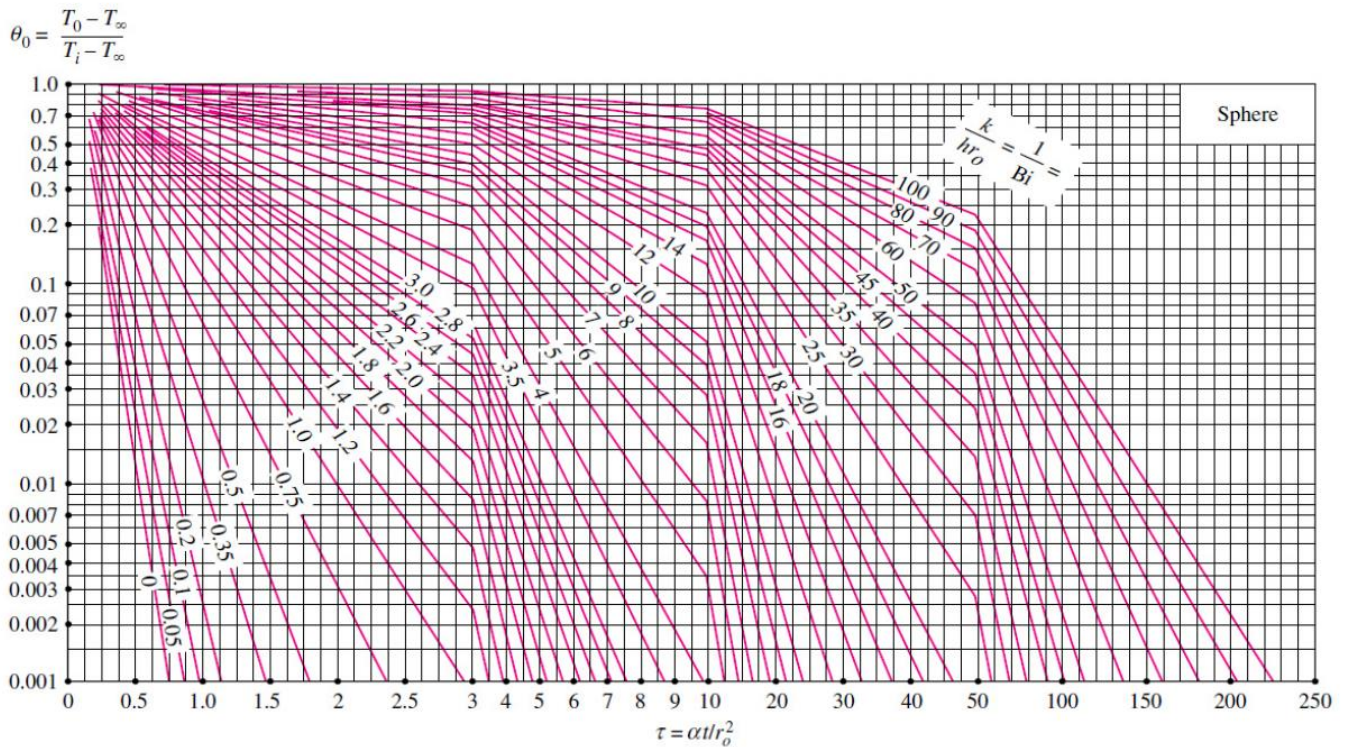
Formula sheet
Heisler charts
Thermodynamic and transport properties of fluids

INFORMATION FOR INVIGILATORS:

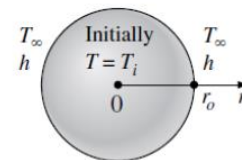
Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

Part A
This section is worth 40 marks

1. Give an example of internal energy generation. [2]
2. For radiation, define and explain the concept of the view factor and a diffuse surface. [4]
3. Using the Heisler charts given, estimate the time (in minutes and seconds) for the centre temperature of a spherical meat dumpling of diameter 2 cm and initially at temperature -5 C, that is dropped into a pot of boiling water at 100 C to reach the 89.5C. Take the thermal diffusivity and thermal conductivity of the sphere to be 0.0012 cm²/s and 0.35W/mK respectively, and assume that the heat transfer coefficient is 175 W/m². [7]



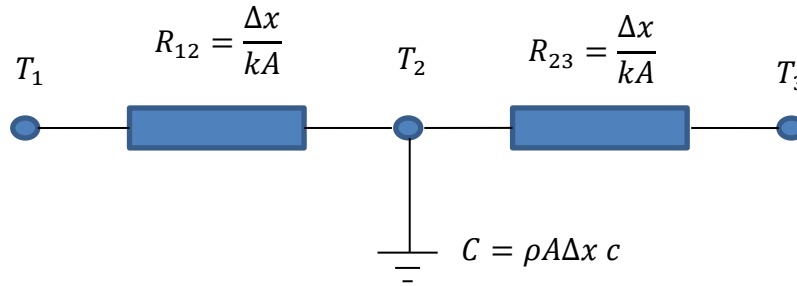
(a) Midpoint temperature (from M. P. Heisler, "Temperature Charts for Induction and Constant Temperature Heating," *Trans. ASME* 69, 1947, pp. 227-36. Reprinted by permission of ASME International.)



4. In my shower room, the water vapour in the air condenses on the cold mirror. If I wished to model the system as a mass transfer problem, what should be noted as the boundary condition at the surface of the mirror? [2]

5. Fig Q5 shows the resistance network for internal nodes in an unsteady problem. Eq. Q5 shows the balance of energy in this resistance network.

Fig Q5



$$\frac{kA}{\Delta x} (T_1^0 - T_2^0) + \frac{kA}{\Delta x} (T_3^0 - T_2^0) = \rho A \Delta x c \frac{T_2^1 - T_2^0}{dt} \quad (\text{Eq. Q5})$$

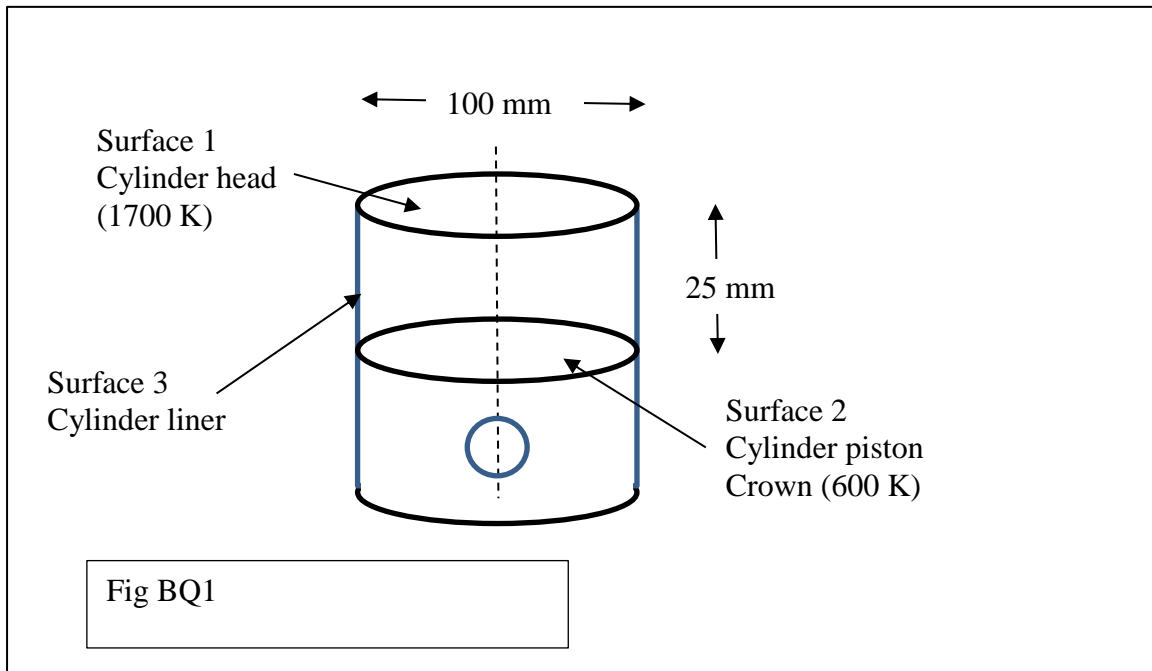
- (a) Are we using the explicit or implicit solution of the differential equation? [2]
- (b) Rearrange the equation in terms of the Fourier number and collect each temperature term. Show working. Marks are given for clarity of presentation. [3]
- (c) What is the criteria for stability for this internal node? [2]
6. A vertically mounted panel on a wall is electrically heated to keep a room at constant temperature. The room is kept at 20°C , and the panel is heated to a constant 84°C . The panel has dimensions 1 meter in the horizontal direction and 0.5 m in the vertical direction. Using the thermodynamic tables to get air properties, Calculate the Rayleigh number for the flow and state if the flow is laminar ($Ra_L < 10^{13}$) or turbulent ($Ra_L > 10^{13}$). [7]

$$Ra_L = \frac{g\beta(T_p - T_\infty)L^3}{\alpha\nu}, \alpha = \frac{k}{\rho c} \quad \text{Eq: Q6}$$

7. For what conditions is the Reynolds analogy valid? [2]
8. What is the maximum size of computational cells you can use if you are numerically modelling transient heat transfer for the case of convection into a surface with thermal conductivity $k=432\text{W/mK}$ and a heat transfer coefficient of $h=50\text{ W/m}^2\text{K}$ and wish a stable solution? [2]
9. What is thermal contact resistance and explain how the use of "thermal greases, pastes or gels" improves the performance over those of air. Use a diagram. [4]
10. Biot number and Nusselt number are both in the form $\frac{hL}{k}$. What are their physical significance and emphasise the differences between these in terms of the variables employed? [3]

Part B
Answer ONE question

11. Figure QB1 shows a schematic diagram, at a particular instant of the engine cycle, of a cylinder head (Surface 1), piston crown (Surface 2) and cylinder liner (Surface 3).
- (a) Using the dimensions indicated on the diagram, and given that $F_{12} = 0.6$, calculate all view factors. [8]
- (b) Draw the resistance network for this problem. Identify all temperatures, and resistances on the diagram. [6]
- (c) The cylinder head can be represented as a **black body** at the temperature $T_1 = 1700K$, the cylinder lining is well insulated so that it is **adiabatic** and the emissivity of the piston is $\epsilon_2 = 0.75$. What is the radiosity of the cylinder head using this information and why? [3]
- (d) If the surface temperature of the piston crown is, $T_2 = 600 K$, and using the conservation of heat flow, calculate the radiosity for the piston crown. [4]
- (e) Using the radiosity of the head and piston, calculate the temperature of the cylinder lining. [6]
- (f) Briefly explain how this analysis could be extended to make it more realistic. [3]



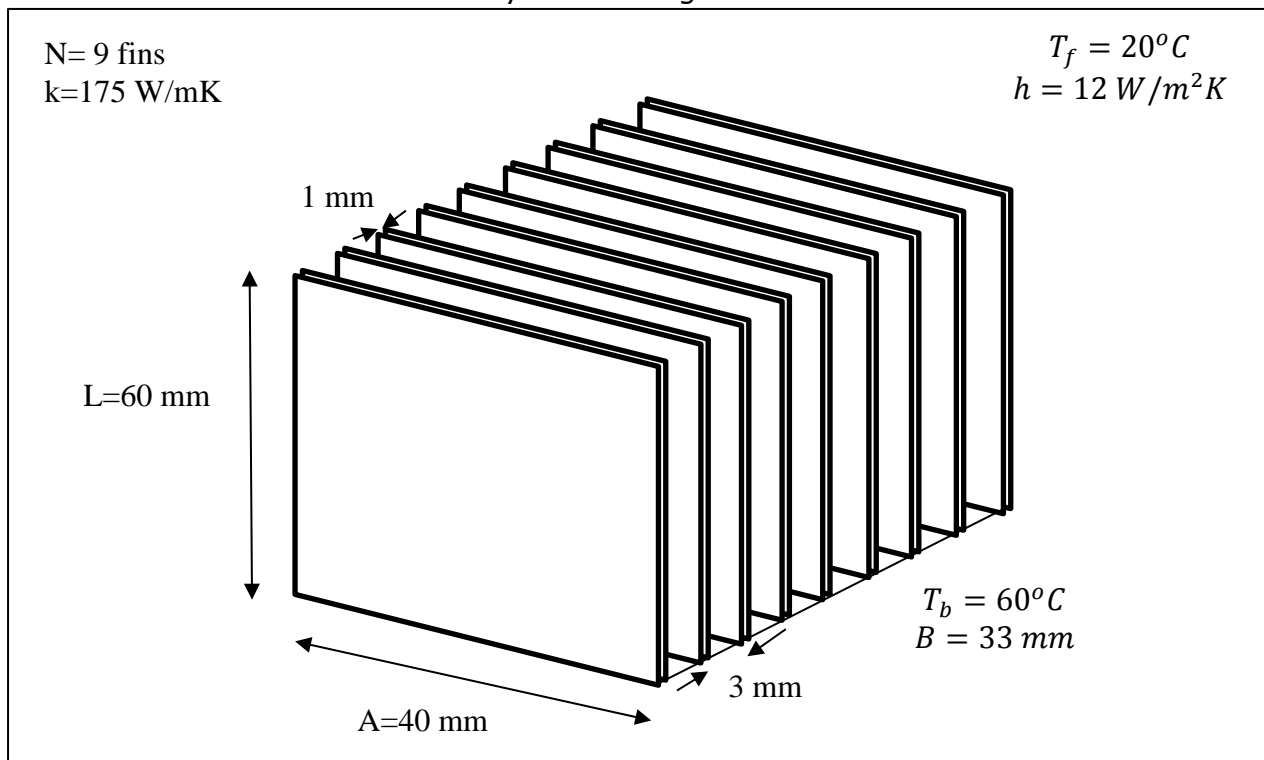
12. A diagram of a heat sink to be used in an electronic application is shown in fig QB2.

There are a total of 9 aluminium fins ($k = 175 \text{ W/mK}$, $C = 900 \text{ J/kgK}$, $\rho = 2700 \text{ kg/m}^3$) of rectangular cross-section, each 60 mm long, 40 mm wide and 1 mm thick. The spacing between adjacent fins, s , is 3 mm. The temperature of the base of the heat sink has a maximum design value of $T_b = 60^\circ\text{C}$, when the external air temperature T_f is 20°C . Under these conditions, the external heat transfer coefficient h is $12 \text{ W/m}^2\text{K}$. The fin may be assumed to be sufficiently thin so that heat transfer from the tip can be neglected, the surface temperature $T(x)$, at a distance x , from the base of the fin is given by:

$$\theta(x) = (T(x) - T_f) = \frac{(T_b - T_f) \cosh(m(L - x))}{\sinh(mL)},$$

$m^2 = \frac{hP}{kA_c}$ and A_c is the cross sectional area.

- (a) Calculate the convective heat that would be lost from the surface without the presence of the fins. [4]
- (b) Calculate the convective heat loss from a single fin and from the unfinned area between the fins. [10]
- (c) Calculate the fin effectiveness of the heat sink. Is this a good heat sink? Why? [6]
- (d) Calculate the fin efficiency of a single fin. [5]
- (e) In the question, it is assumed that the heat flow from the end of the fin is small. Is that true? Show your working. [5]



$$\frac{d}{dx} \left(\frac{\cosh(m(L - x))}{\sinh(mL)} \right) = -m \frac{\sinh(m(L - x))}{\cosh(mL)} \quad \text{EQ: B2}$$

13. The electronics in a wind turbine are mounted on a water cooled heat exchanger. The electronics emit $\dot{q} = 50W$ of heat that only exits through the heat exchanger which can be modelled by a series of 5 horizontal cylinders of length $L = 0.2 m$ in a semi-infinite medium with an isothermal surface temperature $T_s^\circ C$. The water in the cylinders is at $T_w = 25^\circ C$. The cylinders have a diameter of $r = 7 mm$, are spaced $l = 10 mm$ apart and are buried $H = 2.5 cm$ below the surface of the material. The electronics heat the surface T_s which must be less than $45^\circ C$ to avoid failure of the components. The resistance diagram is shown in Fig QB3. Follow the procedure below to estimate the flow rate needed to keep the electronics below its maximum allowable temperature.

(a) What is the value of the thermal resistance R_1 ? [4]

(b) What will be the temperature T_p of the walls of the cylinders if the surface is at the maximum temperature allowed? [4]

(c) By noting conservation of heat flow, calculate the necessary value of R_2 . [4]

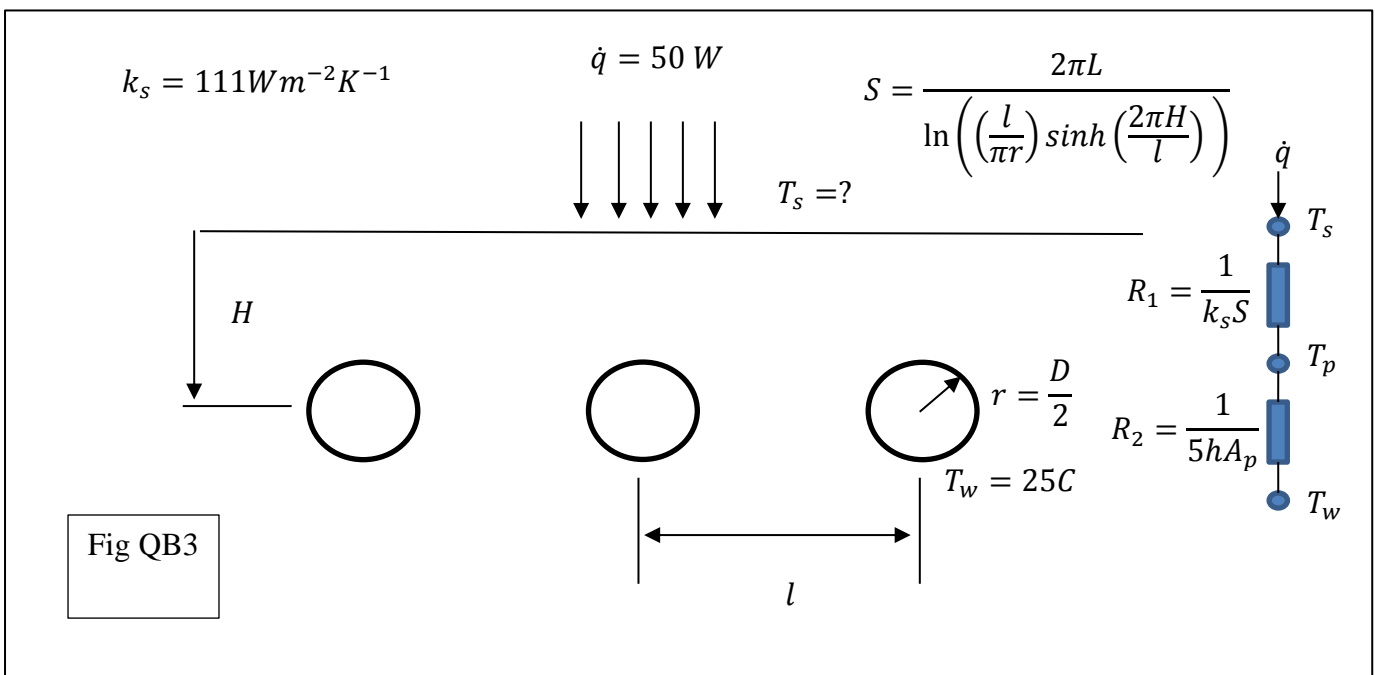
(d) Using the thermodynamic table to get water properties, estimate the Nusselt number $Nu = hD/k_w$ to obtain this value of R_2 . [8]

(e) The correlation for the flow down a pipe can be estimated as:

$$Nu = 0.2023 Re_D^{\frac{4}{5}} Pr^{\frac{1}{3}}, 2 \times 10^4 < Re_D < 10^6$$

Rearrange this equation and obtain the Re_D that is needed to obtain this heat loss along the pipe. [6]

(f) What flow rate in litres per minute does this correspond to? [4]



END