Advanced Heat Transfer

23WSC801

Semester 1 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

<u>Help during the exam</u>

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

Answer **ALL THREE** questions.

All questions carry equal marks.

Use of a calculator is permitted - It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are not allowed).

Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/(m^{2}K^4)

Figures relating to questions can be found at the back of the paper.

1. Shown in **Figure Q.1** is a cross section of a long bar, which is subjected to convective cooling from the top by a stream with temperature 20 ºC. The convective heat transfer coefficient is 100 W/(m^2.ºC). Two vertical sides of this bar are insulated as shown in **Figure Q.1**. The bottom side of this bar is at a temperature of 500 ºC. Thermal conductivity k = 50 W/(m. ºC).

Also shown in **Figure Q.1** is a grid that is used to divide the cross-sectional geometry into small control volumes.

a) Considering symmetry, identify and name the nodes where equations can be derived using the energy balance method to solve for the temperature distribution. [2 marks]

b) Write a set of equations for the nodes identified in (a) that can be solved to obtain the temperature distribution in this bar [13 marks]

c) Rearrange the equations obtained in Part (b) to use the Jacobi iteration technique and describe briefly how the Jacobi iteration technique can be used to solve the resulting set of equations. [2 marks]

d) Using an initial temperature field of 0°C at all nodes where temperatures are unknown, illustrate two iterations of the Jacobi iteration method. [3 marks]

2. A simplified model of an electric oven is shown in **Figure Q.2(a)**. Heat is supplied by an electrical heater through surface 1, such that the temperature is maintained at 1000 K, surface emissivity $\varepsilon_1 = 0.8$. Surface 2 is a thin metal door exposed to the outside room temperature and its inside surface temperature is 300 K, surface emissivity $\varepsilon_2 = 0.8$. All other surfaces are well insulated and may be treated as one re-radiating surface (3).

a) Using **Figure Q.2(b)** and configuration factor algebra calculate F_{12}, F_{13}, F_{21}, F_{23} and F_{33}. [8 marks]

b) Construct an equivalent electrical network for the calculation of radiation exchange between surfaces. [2 marks]

c) Using the electrical network, calculate heat transfer from the heated surface to the door of this furnace. [5 marks]

d) If the surface temperature of surface 1 is maintained by an electrical heater, what is the current in the heater if the supply voltage is 240 V? [2 marks]

e) Calculate the temperature of the re-radiating surface. [3 marks]

Some useful view factor properties:

Reciprocal property

$$A_1 F_{1-2} = A_2 F_{2-1}$$

Summation rule, when a surface is completely enclosed by n surfaces

$$\sum_{j=1}^{n} F_{i-j} = 1, \quad i = 1,2,3,............n$$

For two surfaces, i and j; if the surface i is subdivided into areas A_1 and A_2 and the j surface is subdivided into areas A_3 and A_4.

$$A_{12} F_{12-34} = A_1 F_{1-3} + A_1 F_{1-4} + A_2 F_{2-3} + A_2 F_{2-4}$$

3. Shown in **Figure Q.3(a)** is a cross-section of long concentric cylinders. Diameters are marked in the figure. The outer surface of the small cylinder (surface 1) and the inner surface of the larger cylinder (surface 2) participate in radiative heat transfer, with the temperature of the small cylinder surface being T_1 and the temperature of the larger cylinder's inner surface being T_2. The emissivities of surface 1 and surface 2 are ε_1 and ε_2, respectively. No other surfaces are involved in radiative transfer.

a) In terms of d_1 and d_2 obtain expressions for configuration factors F_{12}, F_{21} and F_{22}. [2 marks]

b) Construct an electric network and derive an expression to calculate the heat transfer rate per unit length between surface 1 and 2. [3 marks]

c) The diameter of the small cylinder is $d_1 = 100$ mm, and the diameter of the larger cylinder is $d_2 =$ 500 mm. If $T_1 = 1000$ K, $T_2 = 300$ K, $\varepsilon_1 = 0.8$ and $\varepsilon_2 = 0.7$. Using the result obtained in (b) calculate heat transfer per unit length between 1 and 2. [2 marks]

d) For a case where $d_2 >> d_1$ simplify the expression obtained in (b) to calculate heat transfer from 1. Describe an example where this expression could be used to calculate radiative heat transfer. [3 marks]

e) If the annulus between the cylinders is filled with a gaseous mixture with a pressure 100 kPa, containing 20% CO_2, 20% water vapour and 60% nitrogen (all by volumes), use Figures Q.3 (b) and Q.3(c) to calculate emissivity of the gaseous mixture. Assuming an initial gas temperature of 1000 K and take the pathlength to be $d_2 - d_1$. [3 marks]

f) Temperatures and emissivities of surfaces 1 and 2 remaining the same as in Part (c), construct an electrical network to calculate heat transfer including the gaseous mixture assuming a temperature of 1000 K. [3 marks]

g) If the gaseous mixture is allowed to reach its own equilibrium temperature, calculate the heat transfer between surfaces 1 and 2 while the gaseous mixture is present. [4 marks]

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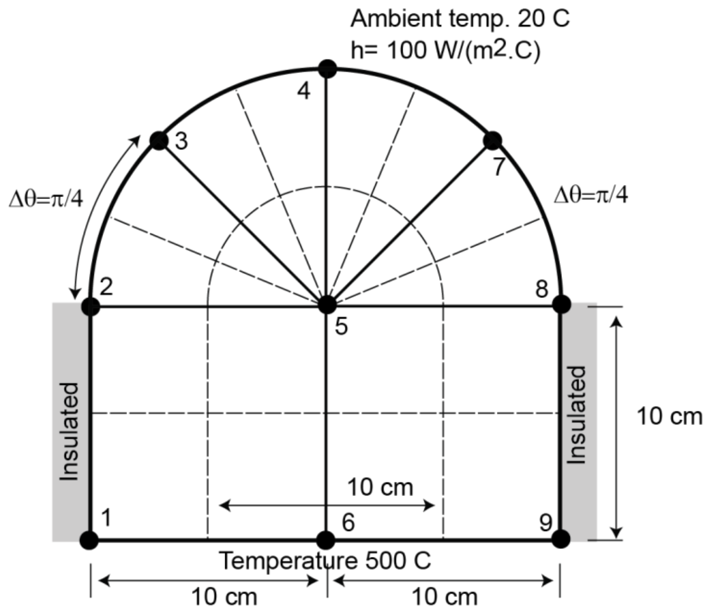


Figure Q.1

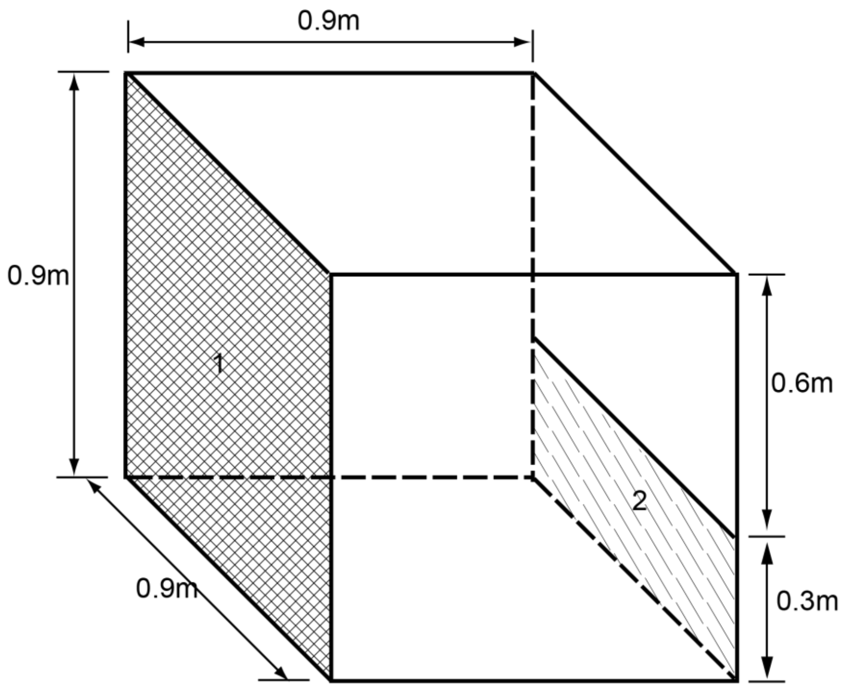
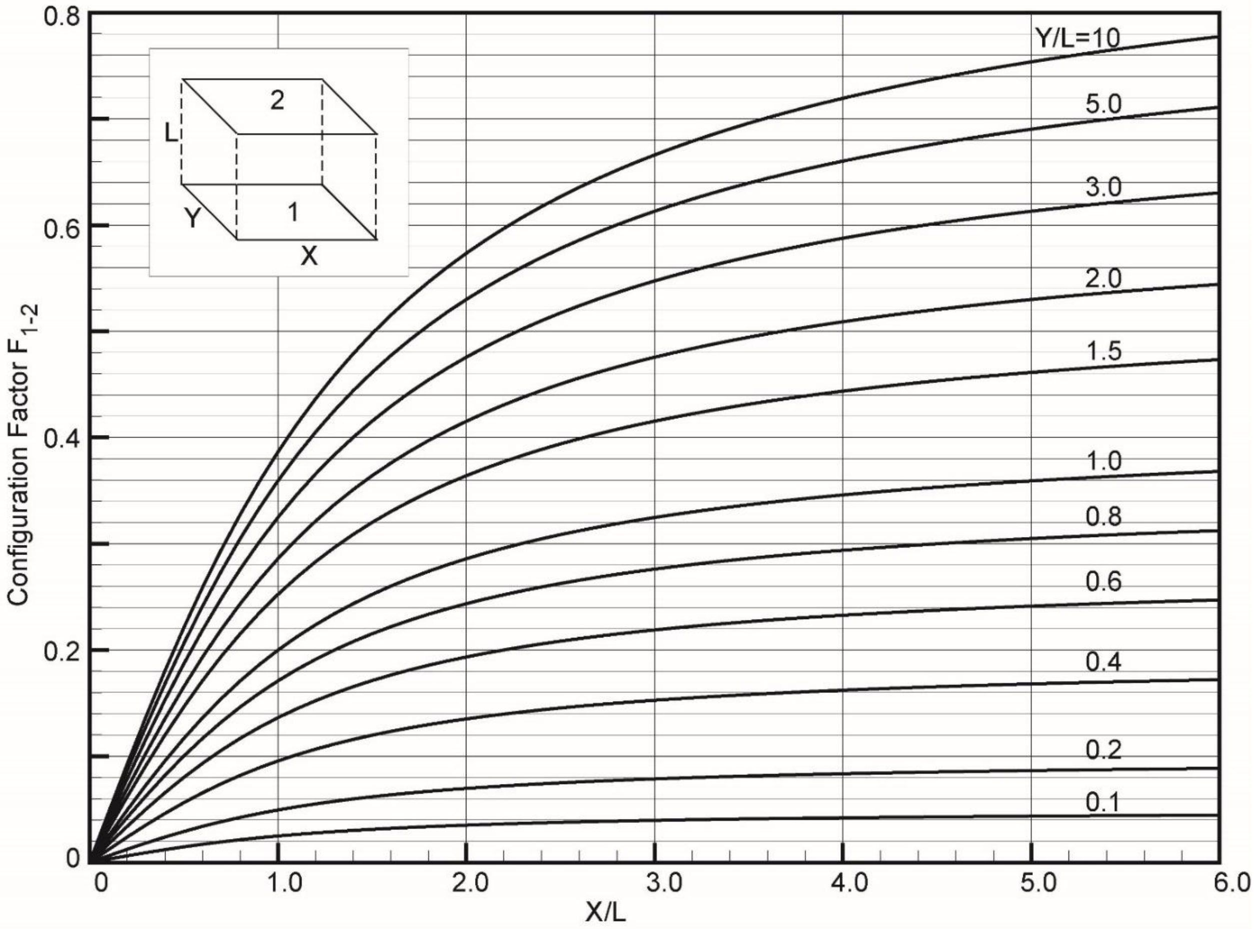


Figure Q.2(a)



Configuration Factor F_{1-2}
X/L
Y/L=10
5.0
3.0
2.0
1.5
1.0
0.8
0.6
0.4
0.2
0.1
0
0.2
0.4
0.6
0.8
1.0
2.0
3.0
4.0
5.0
6.0
L
Y
X
1
2

Figure Q.2(b)

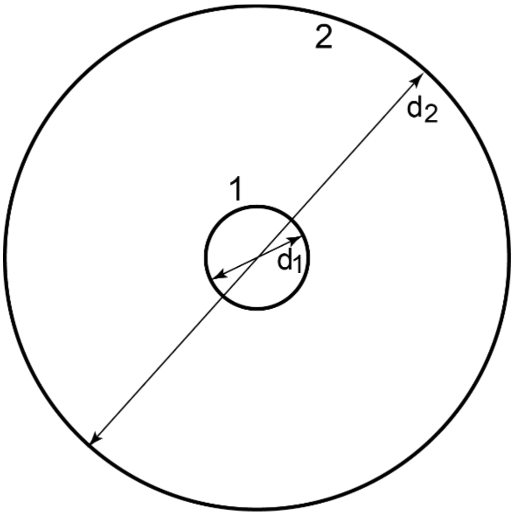


Figure Q.3(a)

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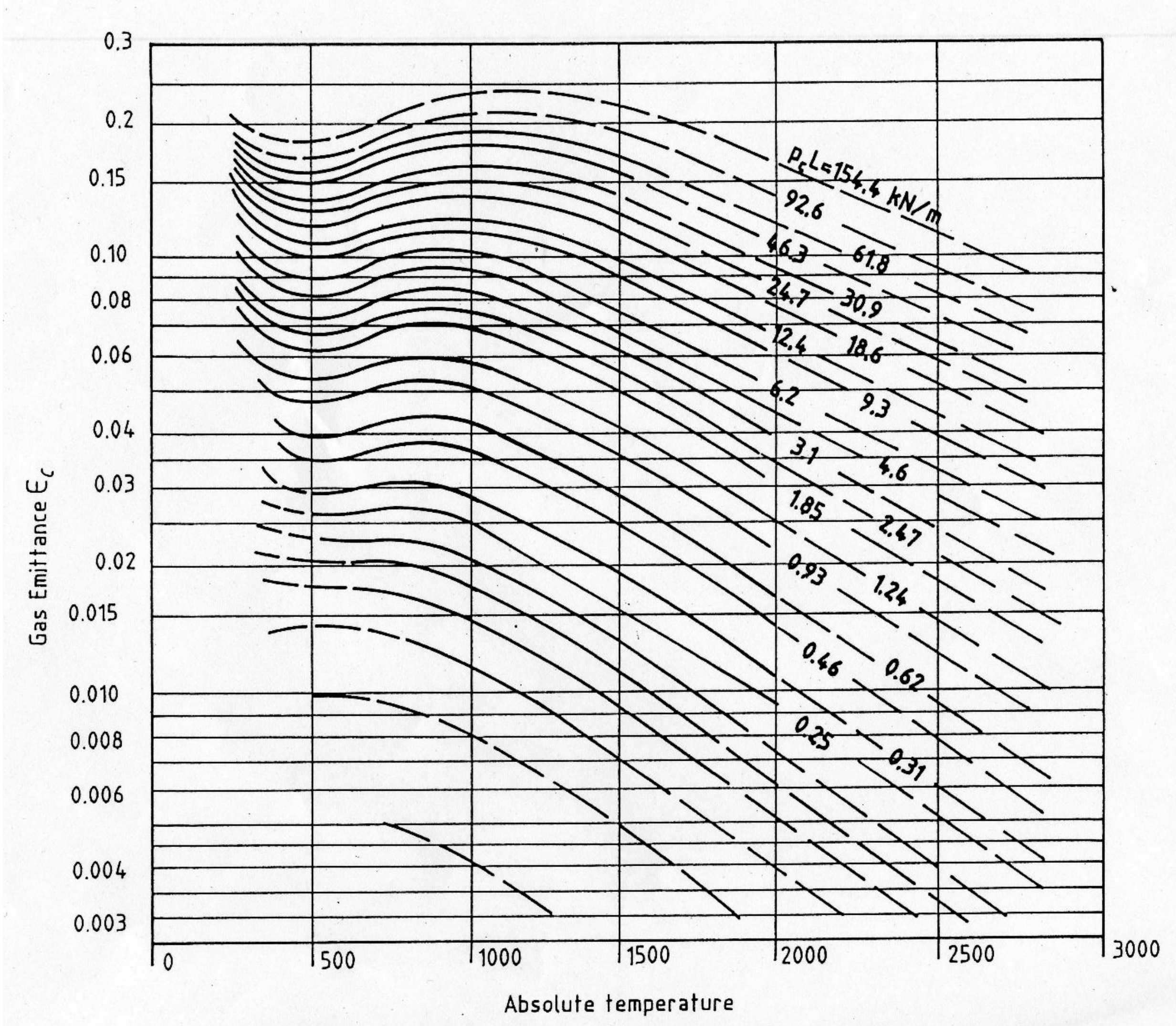

Figure Q.3(b) – Emissivity of CO_2 at a total pressure of 100 kPa

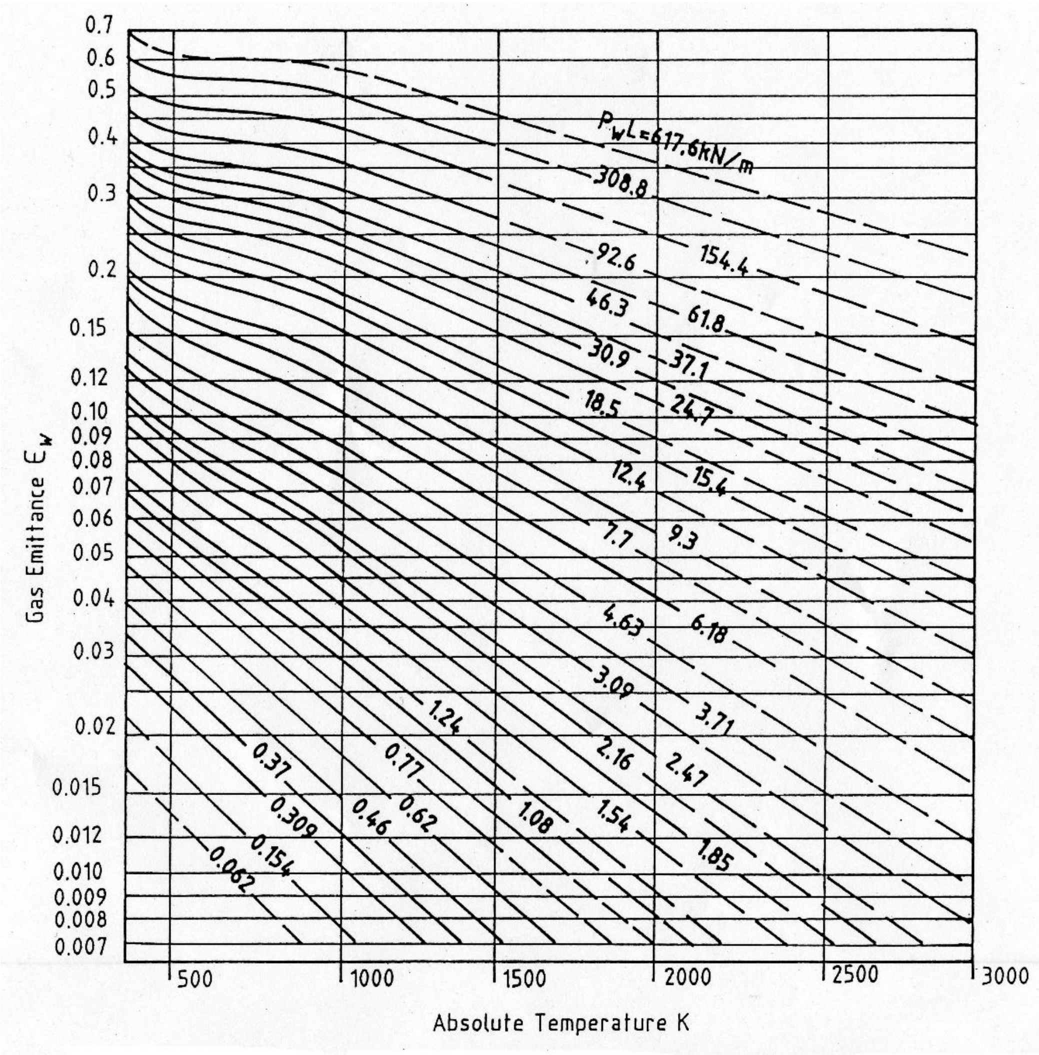

Figure Q.3(c) – Emissivity of H_2O at a total pressure of 100 kPa