ADVANCED HEAT TRANSFER

22WSC801

Semester 1 2022 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.

You may use a calculator for this exam. 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).

ADVANCED HEAT TRANSFER

(22WSC801)

January 2023 2 Hours

Any approved University calculator is permitted.

Answer **ALL QUESTIONS**

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.

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1. **Figure Q.1** shows a symmetrical quarter of the cross-section of a tall chimney stack. In usual notations, two-dimensional transient heat transfer in this situation is governed by:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+g=\rho C\frac{\partial T}{\partial t}$$

In this problem generation $g = 0$. The thermal conductivity of the material of this chimney is $k = 10$ W/(m°C). Thermal diffusivity of the material is $\alpha = 1\times10^{-6}$ m^2/s. At time $t = 0$, the chimney is at a temperature of 10 ºC. Suddenly $(t > 0)$ the inside of this chimney is exposed to an exhaust gas stream which flows at a temperature of 500 ºC, and the inside surface convective heat transfer coefficient is 100 W/(m^2 ºC). The outside of the chimney is exposed to an ambient temperature of 10 ºC with a convective heat transfer coefficient of 50 W/(m^2 ºC). A suitable grid for the calculation of temperature of this cross-section is also shown in **Figure Q.1**. Nodal spacing is equal in x and y directions.

a) Using appropriate symmetry considerations, determine the minimum number of nodes required to calculate the transient temperature distribution of this chimney. [2 marks]

b) Using the explicit method, write minimum number of equations required to calculate transient temperature development in the cross section. [14 marks]

c) Use the equations derived in (b) to determine the stability criterion for the analysis. [2 marks]

d) By selecting an appropriate time step according to the stability criterion, write a set of equations that could be used to calculate temperature at time $t = 10$ s. [2 marks]

2. **Figure Q.2** shows a two-dimensional equilateral triangular geometry whose surfaces are numbered 1, 2 and 3 as shown. All sides are 1 m in length. The blackbody emissive power of surfaces 1, 2 and 3 are E_{b1}, E_{b2} and E_{b3} respectively. For an enclosure with n grey surfaces, the radiosity of the ith surface is linked to other radiosities via the equation:

$$J_i - (1-\varepsilon_i)\left[\sum_{j=1}^{n} F_{ij} J_j\right] = \varepsilon_i E_{bi}$$

a) If all three surfaces (1, 2 and 3) of the triangular geometry are grey with emissivities ε_1 , ε_2 and ε_3 respectively, show how you apply the above radiosity equation to write 3 equations that could be solved to obtain radiosities J_1, J_2 and J_3. [2 marks]

b) For a triangular geometry with surface areas A_1, A_2 and A_3, the configuration factor F_{12} is given by $F_{12} = (A_1 + A_2 - A_3)/2A_1$. Using this formula and other relevant configuration factor properties, calculate all necessary configuration factors required for the equations obtained in (a) and simplify the set of equations. Leave the blackbody emissive powers in their symbolic form. [4 marks]

c) For a special case where surface 3 of the above geometry is a re-radiating surface $(\rho_3 = 1)$ and emissivity values of the other two surfaces are equal to 0.5, simplify the equations obtained in (b) and write a set of equations to obtain radiosities in terms of blackbody emissive powers. [2 marks]

d) Use simple elimination to solve the equations obtained in (c) and write an expression for radiosity J_1 (in terms of blackbody emissive powers of surfaces 1 and 2). [6 marks]

e) Use the expression obtained in (d) for J_1 to write an expression for heat transfer at surface 1. [2 marks]

f) Draw an equivalent electrical circuit for the case described in (c) and obtain an expression for heat transfer at surface 1 to verify your result obtained in (e). [4 marks]

3. Hot combustion products containing 37.2% of CO_2 and 24.7% of water vapour pass through a heat transfer arrangement as shown in **Figure Q.3(a).** The distance between the parallel plates is 0.139 m. The top plate, which has an emissivity of 0.8, is at a temperature of 410 °C while the bottom plate is at a temperature of 650 °C, emissivity 0.9. Gas flow in the system is maintained such that at equilibrium the mean temperature of gases remains steady at 1227 °C and 100 kPa pressure.

a) Use **Figures Q.3(b)** and **Q.3(c)** to estimate the emissivity of the gaseous mixture. [4 marks]

b) Draw an electrical network for this configuration including gaseous radiation. [4 marks]

c) Calculate the heat transfer from the gas and heat transfer at each plate per metre length of the system. [10 marks]

d) Show a heat balance using your answers obtained in (c). [2 marks]

Path length may be taken as 0.25 m and the configuration factors F_{1-g} and F_{2-g} may be taken as 1.0. For a parallel plate situation $F_{1-2} = 1.0$, $F_{2-1} = 1.0$.

W. Malalasekera
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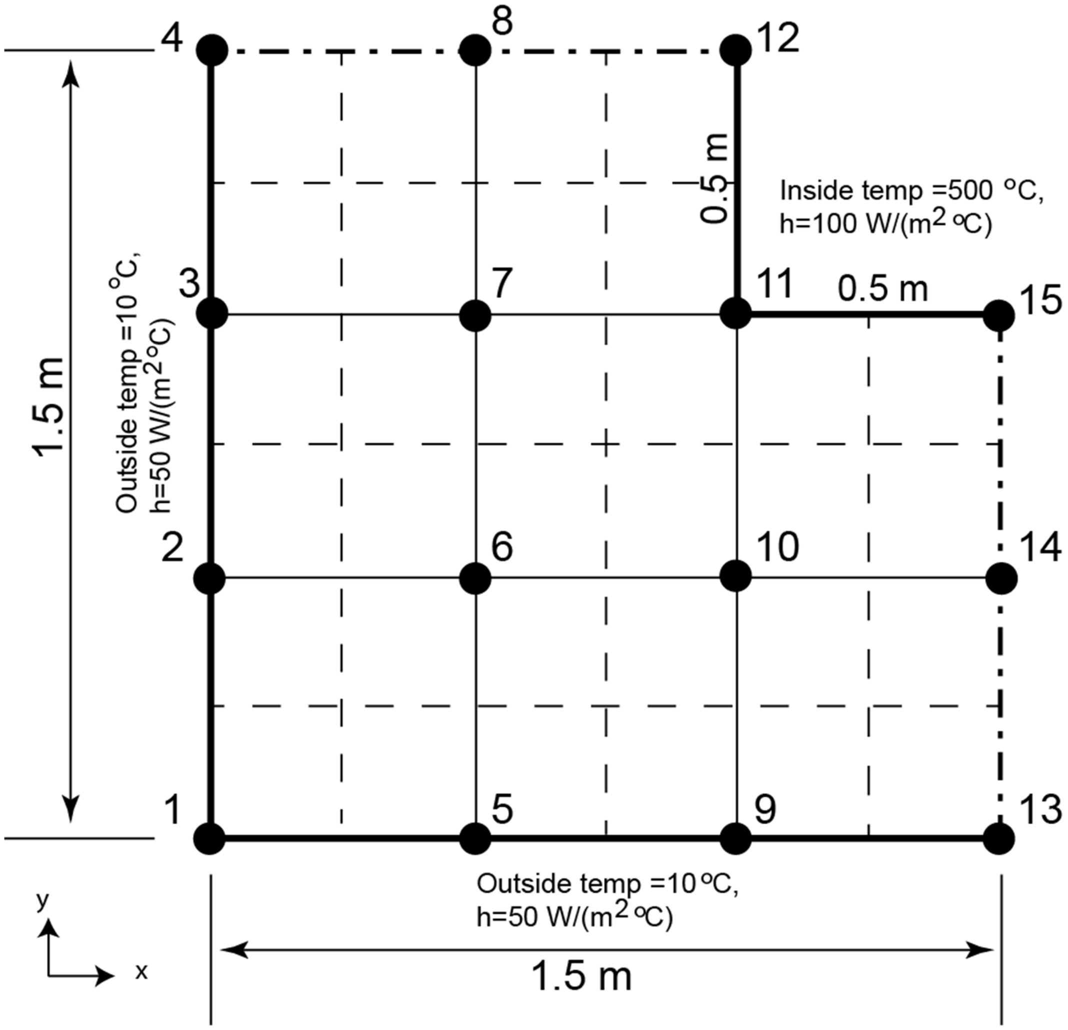
4
8
12
0.5 m
Inside temp =500 °C,
h=100 W/(m2 °C)
3
7
11
0.5 m
15
Outside temp =10 °C,
h=50 W/(m2°C)
1.5 m
2
6
10
14
1
5
9
13
Outside temp =10 °C,
h=50 W/(m2 °C)
y
x
1.5 m

Figure Q.1

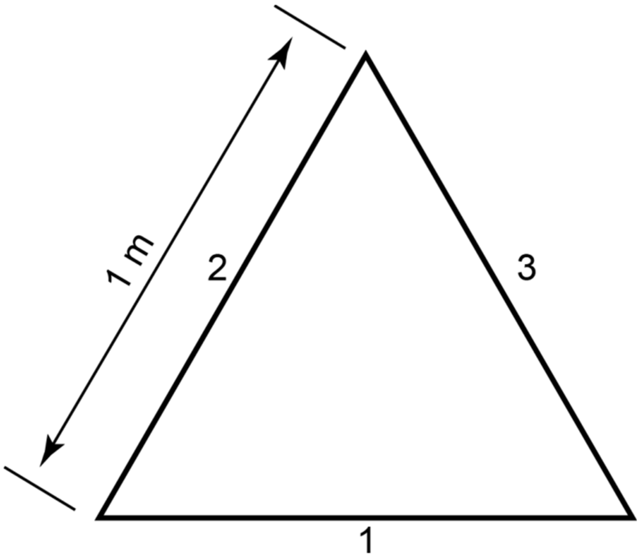

Figure Q.2

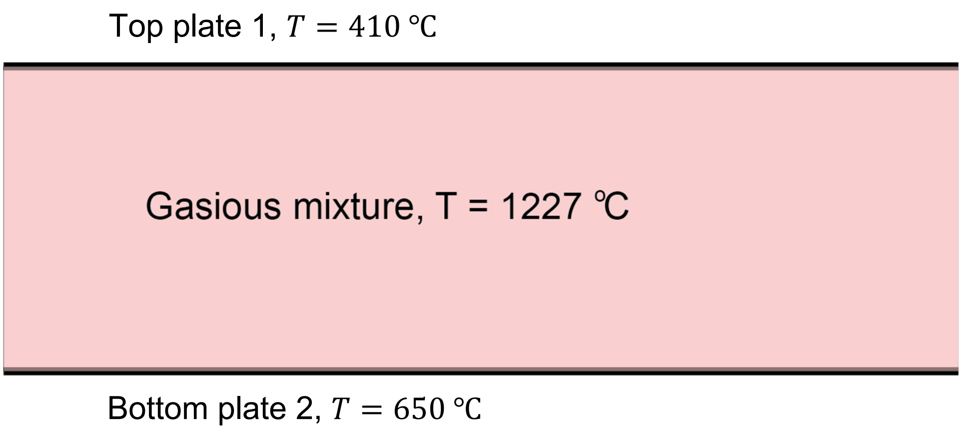

Figure Q.3(a)

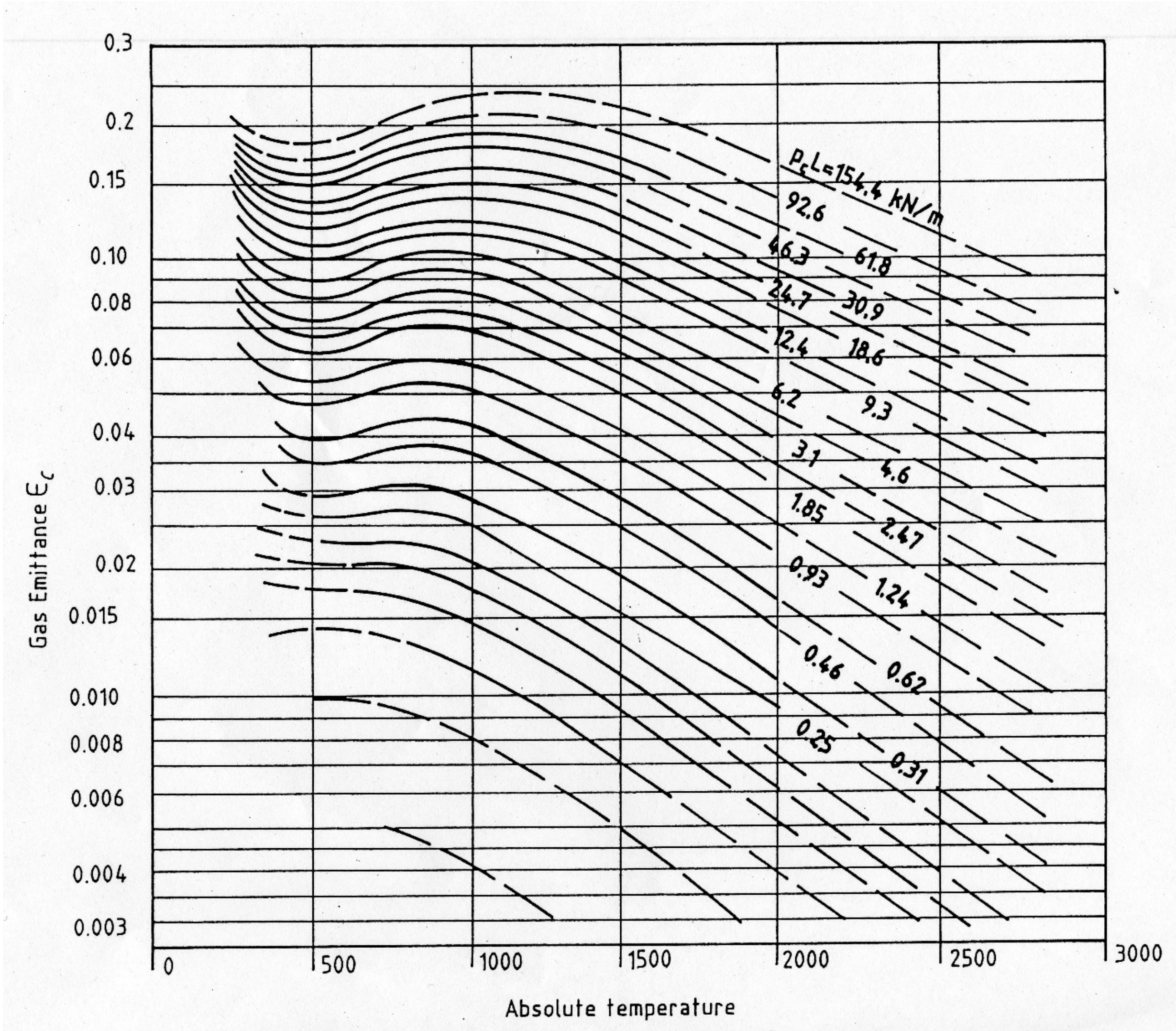

Figure Q.3(b) – Emissivity of CO_2 at a total pressure of 100 kPa

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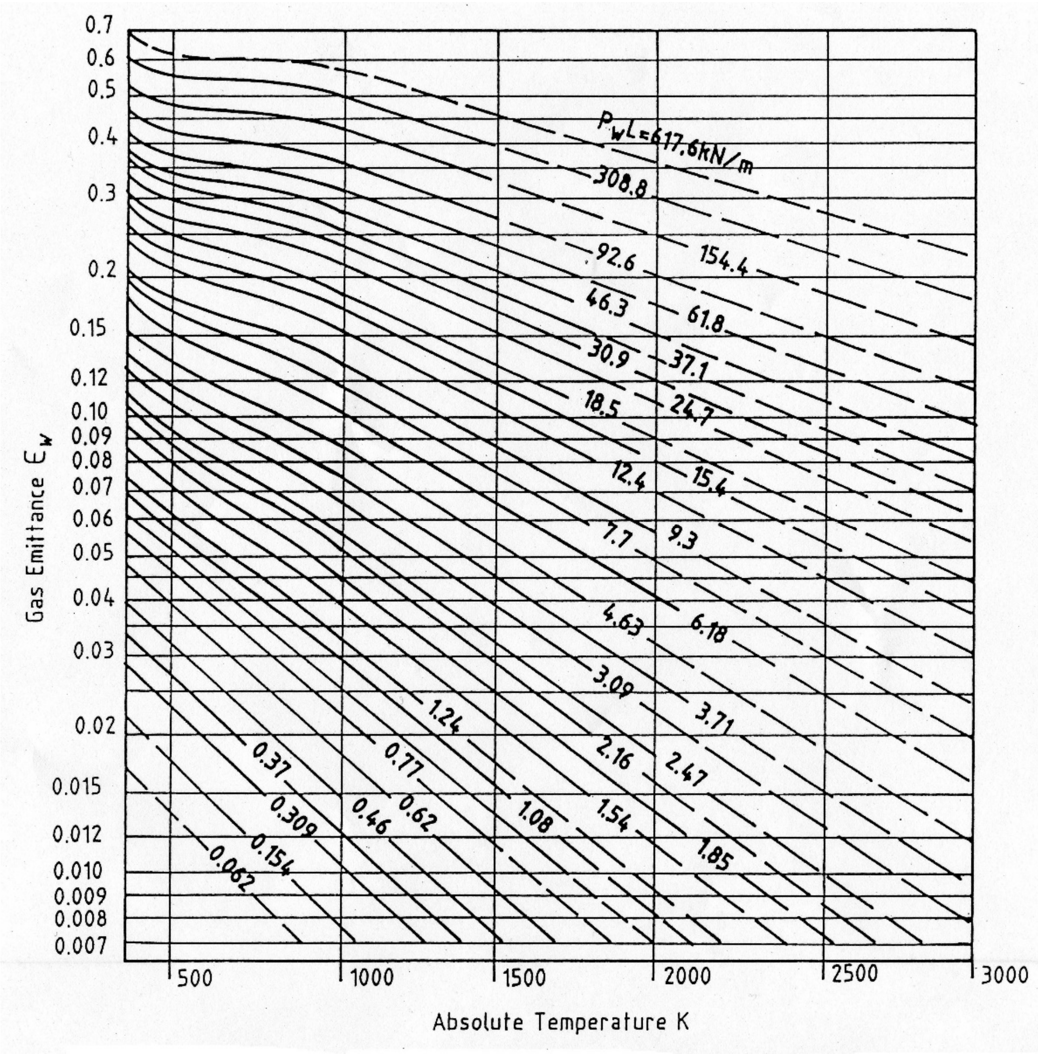

Figure Q.3(c) – Emissivity of H_2O at a total pressure of 100 kPa