Loughborough University

THERMOFLUIDS

23WSP830

Semester 2 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.

Questions carry the marks shown.

Use a **SEPARATE** answer book for **EACH** question.

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).

A range of formulae and diagrams likely to be of benefit in the solution of these questions is provided at the rear of the paper.

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1. An experimental lean-burn research engine is being developed to run on renewable bio-methanol (CH_3OH) for a marine application. An analysis of the emissions while running under steady-state conditions has given the following results on a dry volumetric basis:

12.2% CO_2 0.19% CO 3.72% O_2 0.06% NO

Determine:

a) The stoichiometric reaction scheme for the combustion of bio-methanol (CH_3OH); [2 marks]

b) The actual reaction scheme from the emission analysis provided; [4 marks]

c) The volumetric percentage of excess air in the actual reaction; [2 marks]

d) The air-fuel ratio of the actual reaction on a mass basis; [2 marks]

The fuel and air ratios of the system are changed so that the following reaction scheme is produced:

$$CH_3OH + 1.65(O_2 + 3.76N_2)$$

$$\rightarrow 0.98CO_2 + 0.02CO + 2H_2O + 0.16O_2 + 6.2N_2$$

e) If combustion occurs within the cylinder at 70 bar, and assuming all CO in the products is produced via dissociation of CO_2, determine the equilibrium constant (K_p); [4 marks]

f) Given this level of dissociation, what is the inferred combustion temperature produced in the reaction [K]? [2 marks]

g) It is proposed that heat from the exhaust gas is used to provide heating for the vessel via a recirculating water system, and that a condensing heat exchanger is fitted. The pressure of the combustion products is expected to be 100 kPa in this exchanger. Considering the dew-point temperature of the exhaust gases, what should be the maximum temperature of the water returning to the heat exchanger? [°C] [4 marks]

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2. Shown in **Figure Q.2(a)** is a configuration of a large room. Surface 1 is a large heated area with temperature 55 °C, emissivity 0.8 and Surface 2 is a large window at temperature 15 °C, emissivity 0.8. All other surfaces may be treated as one single re-radiating surface (3).

a) Using the configuration factor relationship given below in **Figure Q.2(b)** calculate the configuration factor F_{1-2}. [4 marks]

b) Use the enclosure property and calculate configuration factors F_{1-3} and F_{2-3} . [2 marks]

c) Draw an equivalent electrical circuit for this configuration and calculate necessary resistance values. [2 marks]

d) Using the electrical circuit calculate the heat transfer from surface 1 to 2. [4 marks]

e) Use the calculated heat transfer value to obtain radiosities (J) of surfaces 1 and 2. [2 marks]

f) Calculate temperature of the re-radiating surface. [2 marks]

g) Making appropriate reference to emission absorption characteristics of gases like CO_2, H_2O and methane briefly describe how they contribute to the 'Greenhouse' effect. [4 marks]

Data:

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

For two surfaces i and j: if the i surface is sub-divided into areas A_1 and A_2, and the j surface is subdivided into areas A_3 and A_4

$$A_{12}F_{12-34} = A_1F_{1-3} + A_1F_{1-4} + A_2F_{2-3} + A_2F_{2-4}$$

3.

a) Determine the heat transfer surface area required for a heat exchanger constructed using a tube with a cooling water taken at the inlet temperature of 10ºC and at flow rate 6.3 $kg.s^{-1}$ (Cp=4200 $J.kg^{-1}.K^{-1}$). The heat exchanger is used to cool ethanol (Cp=3810 $J.kg^{-1}.K^{-1}$; flow rate of 7 $kg.s^{-1}$) from 65ºC to 40ºC.

You may assume that the overall heat transfer coefficient is 570 $W.m^{-2}K^{-1}$. Use the NTU method.

Consider the following heat exchanger geometries.

- Parallel flow
- Counter flow
- 2 shells and 8 tube passes [15 marks]

b) Determine the outlet temperature of water. [5 marks]

Dr EJ Long

Prof W Malalasekera

Prof J Szmelter

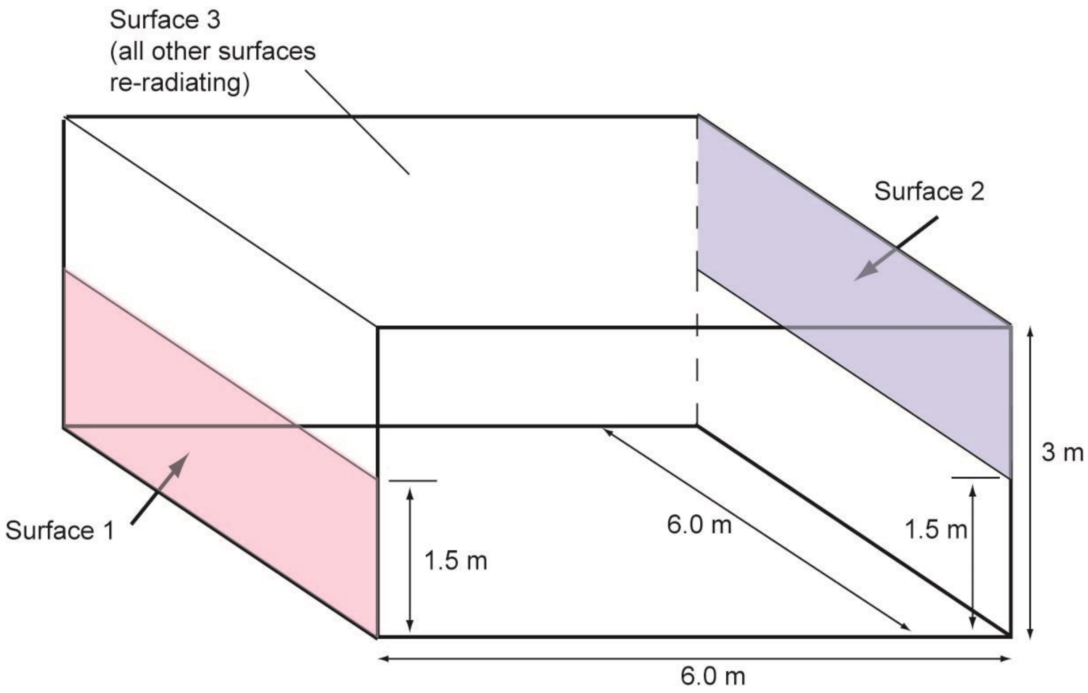

Figure Q.2a

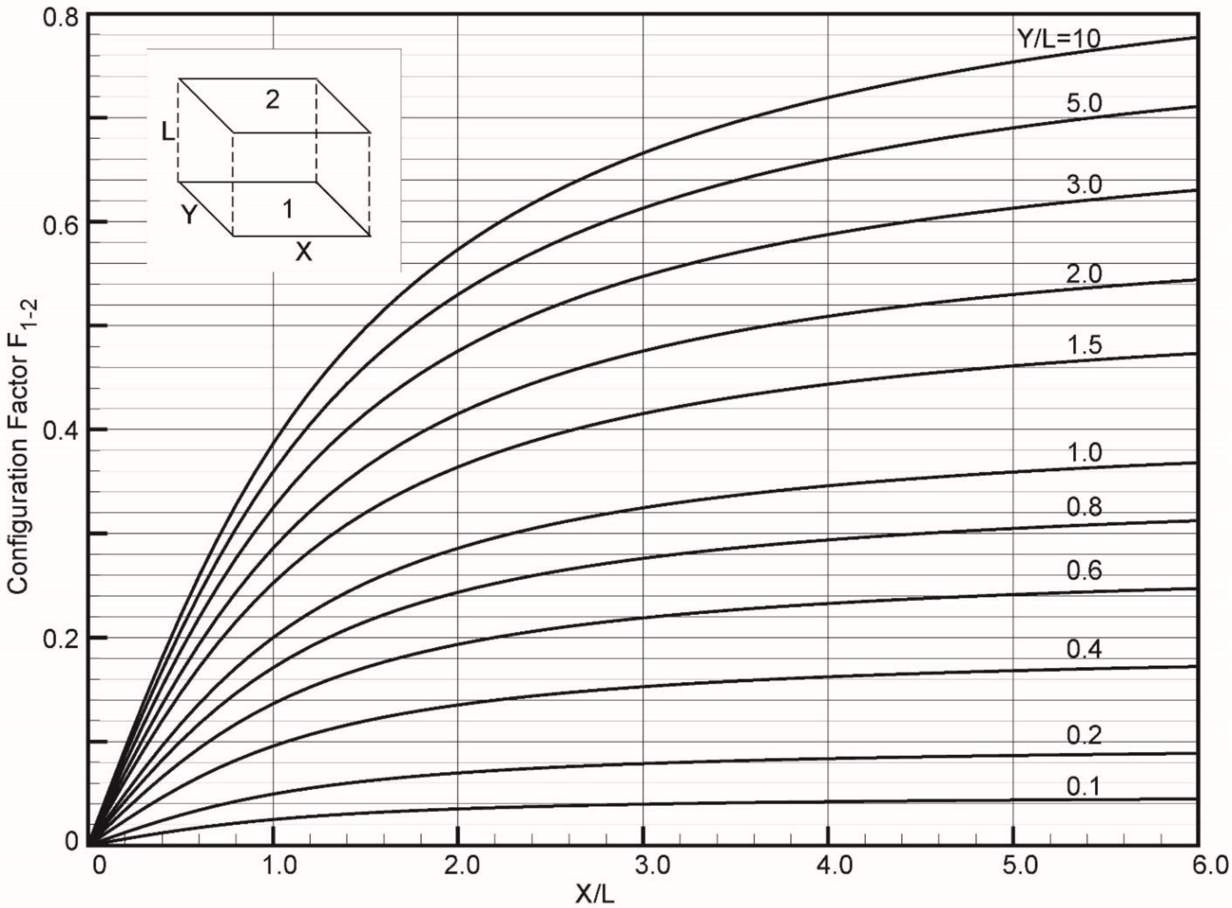

Figure Q.2b Configuration factor for parallel rectangular surfaces

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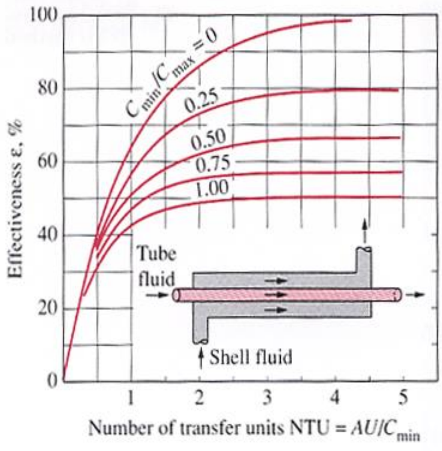
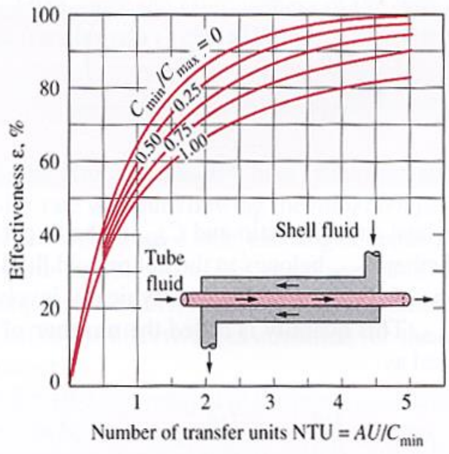
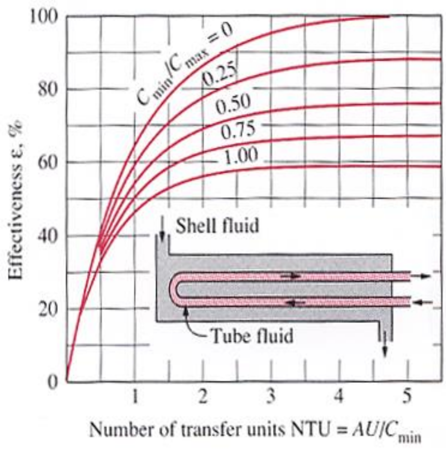
HEAT EXCHANGERS RELATIONS AND GRAPS



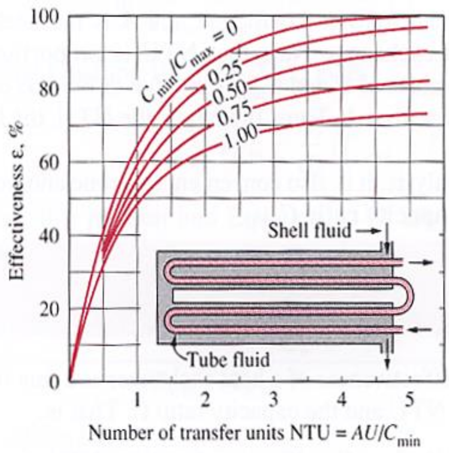
(*a*) Parallel-flow



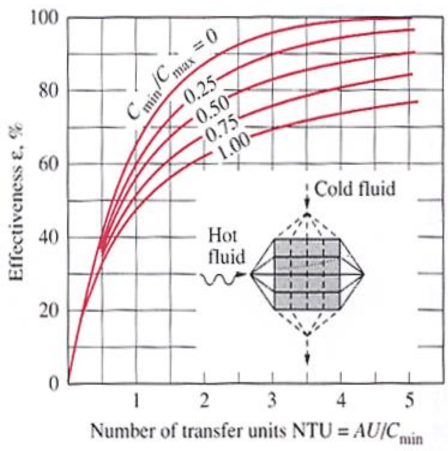
(*b*) Counter-flow



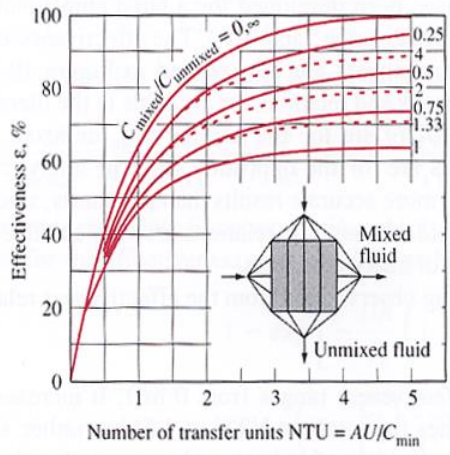
(*c*) One-shell pass and 2, 4, 6, tube passes



(*d*) Two-shell passes and 4, 8, 12, tube passes



(*e*) Cross-flow with both fluids unmixed



(*f*) Cross-flow with one fluid mixed and the other unmixed

Heat Exchangers			
LMTD	$\Delta T_m = (\Delta T_1 - \Delta T_2)/\ln(\Delta T_1/\Delta T_2)$	Effectiveness $Q^* = [(mC_P)_{\min}(\Delta T)]$	$\varepsilon = Q/Q^*$
$NTU = AU_m/C_{\min}$	Stream capacity ratio $C = C_{\min}/C_{\max}$		