THERMOFLUIDS

(22WSP830)

Semester 2 2023 In Person Examination

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.

Answer **ALL THREE** questions.

Questions carry the marks shown.

Any University-approved calculator is permitted.

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 water heating system has been designed to run on a fuel blend of 70% methane (CH_4) and 30% hydrogen (H_2) by volume. The fuel enters the combustion system at 1 atm and 25°C and is burned with air that enters the combustion chamber at the same state. The combustion is operated in a lean combustion mode, with 25% excess air producing complete combustion. Determine:

a) the stoichiometric reaction scheme, [5 marks]

b) the actual reaction scheme, [5 marks]

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

$$0.8CH_4 + 0.2H_2 + 1.8(O_2 + 3.76N_2) \rightarrow 0.8CO_2 + 1.8H_2O + 0.1O_2 + 6.77N_2$$

After heat is passed to the water, the exhaust gases exit the combustion chamber at 500K.

c) It is proposed that a condensing heat exchanger is fitted at the exit of the combustion chamber to pass more heat from the hot exhaust to the water. If the pressure of the combustion products is expected to be 110 kPa in this exchanger, what is the dew-point temperature? [°C] [5 marks]

d) If the water from the return circuit enters the boiler at 40°C, is the dew-point temperature appropriate for the condensing heat exchanger to work effectively? [2 marks]

e) At high temperatures the following dissociation reactions become important,

$$CO_2 \leftrightarrow CO + \frac{1}{2}O_2$$

$$H_2O \leftrightarrow H_2 + \frac{1}{2}O_2$$

If α moles of CO_2 and β moles of H_2O dissociate, write down the reaction equation based on the reaction given between questions b) and c). [3 marks]

f) The combustion temperature of the flame is measured to be 2200K. At this temperature, are the dissociation reactions listed in question e) worth considering? Justify your answer for each reaction. [3 marks]

g) Other than dissociation, why else might CO be formed in the exhaust gases for the reaction given? Briefly explain your answer. [2 marks]

2. Two pipes, diameter 0.4 m, carry steam to and from a heat exchanger. The supply pipe, emissivity 0.75, is at 500 °C and the return pipe, emissivity 0.35, is at 250 °C. The pipes are parallel, and axes are 0.6 m apart. The pipes are exposed to the surroundings, 20 °C, which can be considered as a black body.

a) Using the given formulae below, calculate the configuration factor F_{1-2}. You may use a two-dimensional cross section as the geometry. [2 marks]

b) Calculate the configuration factors F_{1-3} and F_{2-3}. [2 marks]

c) Develop an electrical network to calculate radiative heat transfer in this situation. [3 marks]

d) Using the electrical network developed in (c) calculate heat transfer, per meter length, at each pipe. [9 marks]

e) Calculate radiative heat transferred to the surroundings (per meter length). [2 marks]

f) Using your answers obtained in (d) and (e) demonstrate a heat balance. [2 marks]

Configuration factor between equal diameter (d) cylinders placed s

distance (axis to axis) apart may be obtained from

$$F_{1-2} = F_{2-1} = \frac{1}{\pi}\left[\sqrt{X^2 - 1} + \sin^{-1}\frac{1}{X} - X\right]$$

where

$$X = 1 + \frac{(s-d)}{d}, \quad d \text{ is the diameter.}$$

Note: In the above expression $\sin^{-1}(1/X)$ is in radians.

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

3. Cold water enters a counter-flow heat exchanger at 10ºC at a rate of 8 $kg.s^{-1}$, where it is heated by a hot-water stream that enters the heat exchanger at 70ºC at a rate of 2 $kg.s^{-1}$.

a) Assuming the specific heat of water C_p = 4180 $J.kg^{-1}K^{-1}$, and that the effectiveness of this heat exchanger is 70% determine the outlet temperatures for both cold and hot water. [5 marks]

b) If the overall heat transfer coefficient is U = 480 $W.m^{-2}K^{-1}$ what is the heat transfer surface of this heat exchanger? [5 marks]

c) What would be the heat transfer area if for the same specification a cross flow heat exchanger was used? [5 marks]

d) If the effectiveness in the counter-flow heat exchangers could be changed, what would be the lowest possible outlet temperature for the hot water and the highest possible outlet temperature for the cold water that could be achieved? [5 marks]

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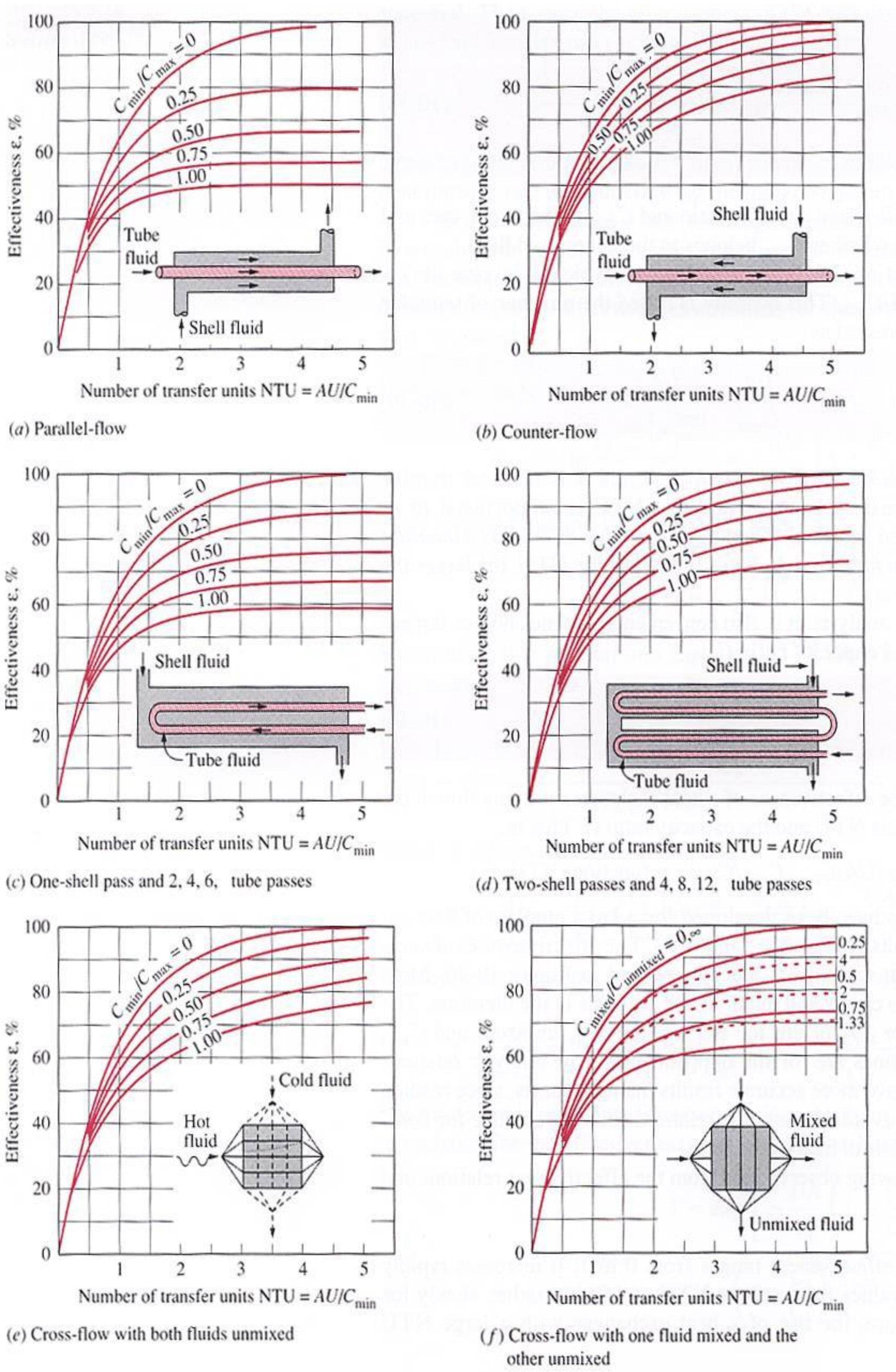
HEAT EXCHANGERS RELATIONS AND GRAPHS



(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

<table>
<tr><th colspan="4">Heat Exchangers</th></tr>
<tr><td>LMTD</td><td>$\Delta T_m = (\Delta T_1 - \Delta T_2)/\ln(\Delta T_1/\Delta T_2)$</td><td>Effectiveness
$Q^* = \left[(mC_P)_{min}(\Delta T)\right]$</td><td>$\varepsilon = Q/Q^*$</td></tr>
<tr><td>$NTU = AU_m/C_{min}$</td><td colspan="3">Stream capacity ratio $C = C_{min}/C_{max}$</td></tr>
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