UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Eng. *M.Eng.*

Chemical Eng E868: Process Heat Transfer

COURSE CODE	:	**CENGE868**
UNIT VALUE	:	**0.50**
DATE	:	**17-MAY-06**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

06-C0228-3-70

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*Answer **FOUR QUESTIONS**. Only the first **FOUR** answers will be marked.*
***ALL** questions carry a total of **25 MARKS** each, distributed as shown* [ ]

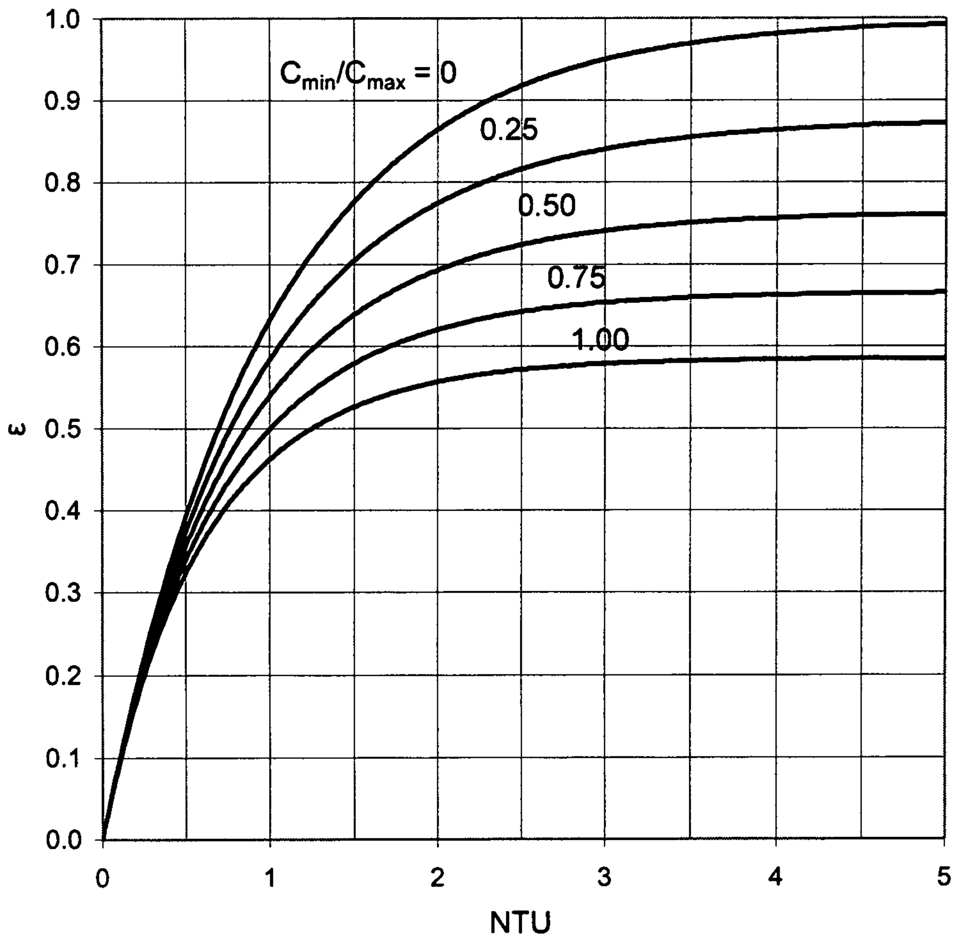
1.

A flow of 15 kg/s of hot fluid (c_{PH} = 1333 J/(kg K)) is cooled from 500 to 300°C using 10 kg/s of coolant (c_{PC} = 4000 J/(kg K)) entering at 100°C and leaving at 200°C. This is achieved in a 1-2 shell and tube heat exchanger with a surface area of 43.14 m^2. The overall heat transfer coefficient is 400W/(m^2 K) (design conditions).
At start-up, when the unit is clean, the overall heat transfer coefficient is expected to be 480 W/(m^2 K).

a) What is the effectiveness, ε, of the heat exchanger under design conditions? [5]

b) What are the effectiveness and the heat duty at start-up? [10]

c) What outlet temperatures will be achieved at start-up? [10]



Effectiveness, ε, of a shell-and-tube heat exchanger with one shell and any multiple of two tube passes.

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2.

Hot air at 103 °C enters an uninsulated sheet metal duct (k = 65 W/(m K)) of diameter (ID = 0.05 m, OD = 0.053 m) at a rate of 0.15 kg/s, which is in the crawlspace of a house. After a distance L = 10 m, the air cools to 77 °C (Tout). Heat is lost to the surrounding environment at T = 0 °C and the external heat transfer coefficient is 8 W/(m^2 K)

You can use the *Colburn equation* valid for convection in a circular pipe under fully developed turbulent flow conditions

$Nu = 0.023 \times Re^{4/5} Pr^{1/3}$

a) Calculate the total heat loss from the duct over the length L. [5]

b) Verify that the flow is turbulent and fully developed at x = L. [5]

c) Explain why the resistance in the pipe wall may be neglected. [2.5]

Determine:

d) The heat flux at x = L and compare it to the value that would be obtained if the internal convective heat transfer resistance is neglected [7.5]

e) The duct surface temperature at x = L [5]

Properties: at Taverage = 363K air: Cp = 1011 J/(kg K); k = 0.031W/(m K); $\mu = 214 \times 10^{-7}$ N s/m^2.

at Tout = 350K air: k = 0.030W/(m K), $\mu = 208 \times 10^{-7}$ N s/m^2, Pr = 0.70.

3.

a) Show that the one dimensional heat balance for a cylindrical rod of length L and diameter D with convective heat transfer at the surface h is given by:

$$\frac{d^2\theta}{dx^2} - \frac{hP}{kA_c}\theta = 0 \qquad \lambda^2 = \frac{hP}{kA_c}$$

where $\theta = T - T_\infty$ is the difference between the temperature of the rod and the external air, P is the perimeter of the cross sectional area A_c, k is the thermal conductivity of the rod and x is the axial position.

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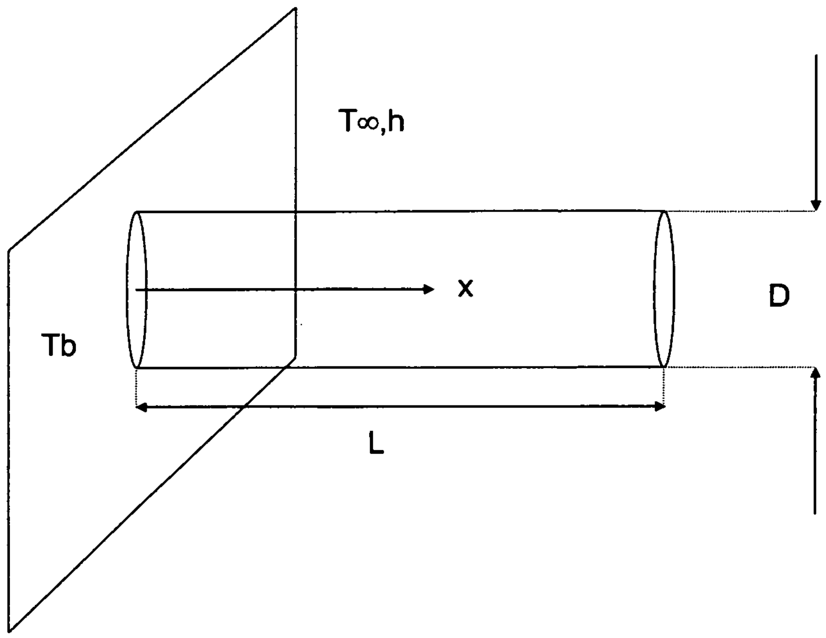

[5]

b) If the base temperature is maintained at T_b (x = 0) and at the other end the temperature is held at T_L (x = L):

Show that the solution for the temperature profile is given by

$$\frac{\theta}{\theta_b} = \frac{\left(\frac{\theta_L}{\theta_b}\right) \sinh(\lambda x) + \sinh[\lambda(L-x)]}{\sinh(\lambda L)}$$

and when λL is very large it simplifies to $\frac{\theta}{\theta_b} = e^{-\lambda x}$ [10]

c) A very long copper rod (k = 398 W/(m K), 5 mm in diameter) has one end maintained at 100 °C. The surface of the rod is exposed to ambient air at 25 °C with a convective heat transfer coefficient of 100 W/(m^2 K).
What are the corresponding heat losses from the rod? [10]

4.

A furnace is shaped like a cylinder of 45 mm diameter and 100 mm length and all the surfaces may be approximated as blackbodies. The furnace upper surface is at 300 K. The side and bottom surfaces are heated electrically, are well insulated externally and are maintained at temperatures of 1700 K and 2000 K, respectively.

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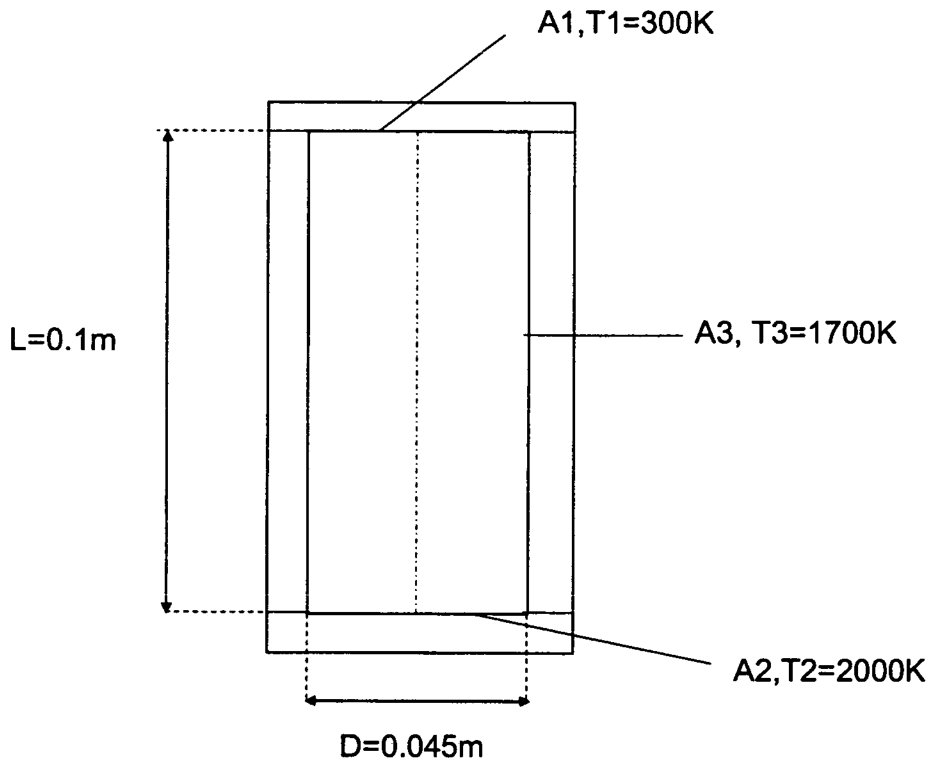


a) Determine the view factors for this geometry. [10]

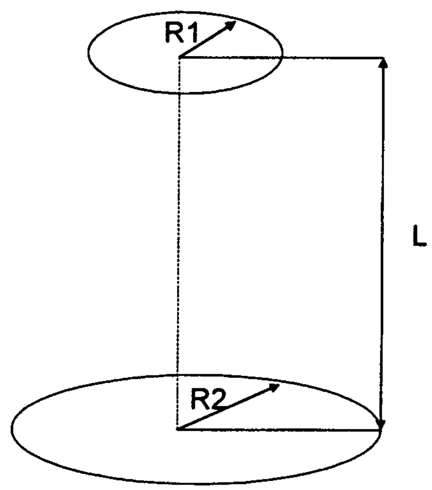
b) How much power is required to maintain the temperatures set for the side and bottom surfaces? [15]

The view factor between two coaxial discs is given by:

$$\rho_1 = \frac{R_1}{L} \quad \rho_2 = \frac{R_2}{L}$$

$$S = 1 + \frac{1+(\rho_1)^2}{(\rho_2)^2}$$

$$F_{21} = \frac{1}{2}\left\{ S - \left[S^2 - 4\left(\frac{\rho_1}{\rho_2}\right)^2 \right]^{1/2} \right\}$$



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5.

a) Steam is condensing at atmospheric pressure within a horizontal tube with 30 mm diameter and wall temperature 57°C. At the inlet of the condenser there is only vapour with a velocity of 25 m/s. At a certain location in the pipe the quality of the mixture is 0.3. If the flow at this point is stratified (see Fig.1) and the tube is smooth, what is the overall heat transfer coefficient? [22]

The heat transfer coefficient for heat transfer through the condensate film is:

$$h_A = \beta\left[\frac{k_L^3\rho_L(\rho_L-\rho_G)gh_{fg}}{\mu_L D(T_{sat}-T_w)}\right]^{1/4}$$

where: μ_L is the condensate viscosity
h_{fg} is the latent heat of vaporisation
ρ_L and ρ_G are the liquid and gas densities respectively
(T_w-T_{sat}) is the temperature difference between the wall and the saturated liquid
h_A is the heat transfer coefficient
k_L is the condensate thermal conductivity
D is the tube diameter
g is the acceleration of gravity

The coefficient β can be estimated from Fig. 1 below. In Fig. 2 below, X is the Lockhart-Martinelli parameter.

b) What are the main assumptions that you have to make to approach this problem? [3]

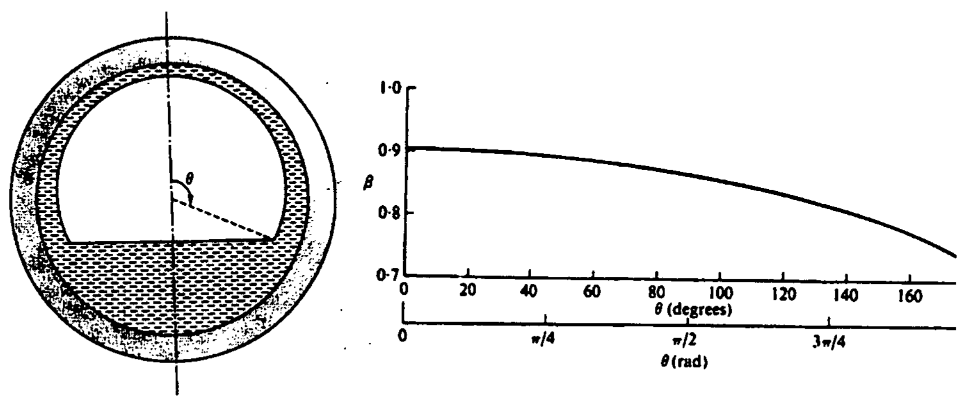

Figure 1

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Given at the above conditions are the following physical properties:
Condensate: $\rho_L = 958.4$ kg/m^3, $\mu_L = 2.84\times10^{-4}$ kg/(m s), $k_L = 0.682$ W/(m K)

Vapour: $\rho_G = 0.596$ kg/m^3, $\mu_G = 12.95\times10^{-6}$ kg/(m s), $h_{fg} = 2.257\times10^6$ J/kg.
Note that the total heat transfer h_T coefficient is given by:

$$h_T = \frac{\theta}{\pi} h_A + \frac{\pi - \theta}{\pi} h_B$$

where θ is defined in Figure 1 and h_B is the heat transfer coefficient through the condensate film at the bottom of the pipe.

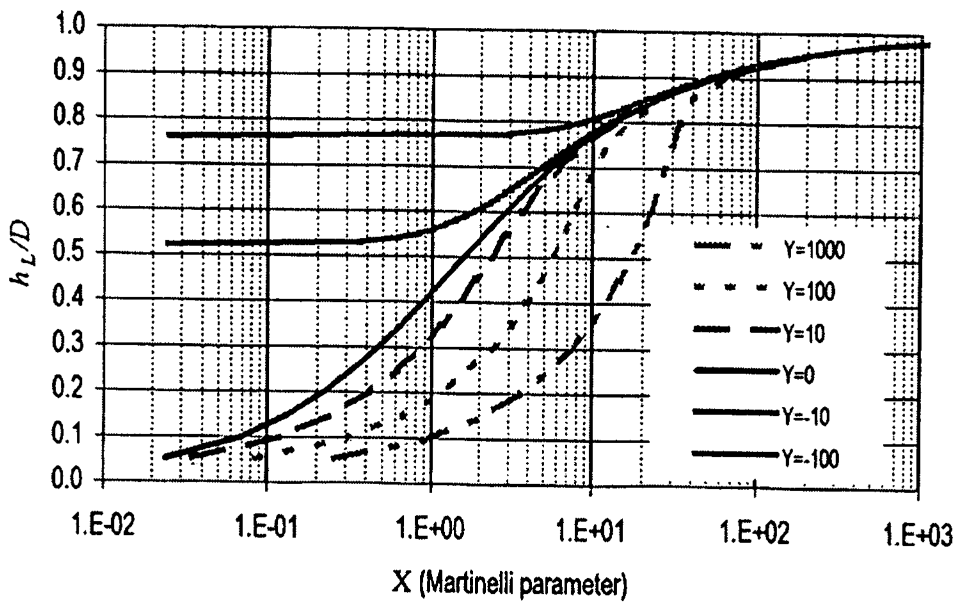

Figure 2

6.

A saturated mixture of steam and water at 510 K is flowing through a horizontal pipe with internal diameter 4 cm. The mixture has a quality of 0.3 and mass flux of 3000 kg/(m^2 s).

Calculate the frictional pressure drop in the pipe using

a) the homogeneous model [8]

b) the following correlation suggested by Chisholm for separated flow [14]

$$\Phi_L^2 = 1 + \frac{C_1}{X} + \frac{1}{X^2}$$

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where: C_l=20 for turbulent-turbulent flow
C_l=12 for laminar (liquid) – turbulent (gas) flow
C_l=10 for turbulent (liquid) – laminar (gas) flow
C_l=5 for laminar-laminar flow
and Φ_L and X are the Lockhart-Martinelli parameters.

The homogeneous viscosity can be calculated as follows:

$$\frac{1}{\mu} = \frac{x}{\mu_g} + \frac{1-x}{\mu_l}$$

where:
x is the quality
μ_l and μ_g are the liquid and gas viscosities respectively

You can assume that transition from laminar to turbulent flow for each phase occurs when its Reynolds number based on superficial velocity is greater than 2000.

c) What are the main assumptions in the above models for homogeneous and separated flow? [3]

The following properties can be used:
Water density = 818 kg m^{-3}, water viscosity = 1.15×10^{-4} Pa s
Steam density = 15.8 kg m^{-3}, steam viscosity = 16.9×10^{-6} Pa s

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