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 : **19-MAY-05**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

05-C0192-3-60

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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** [ ]*

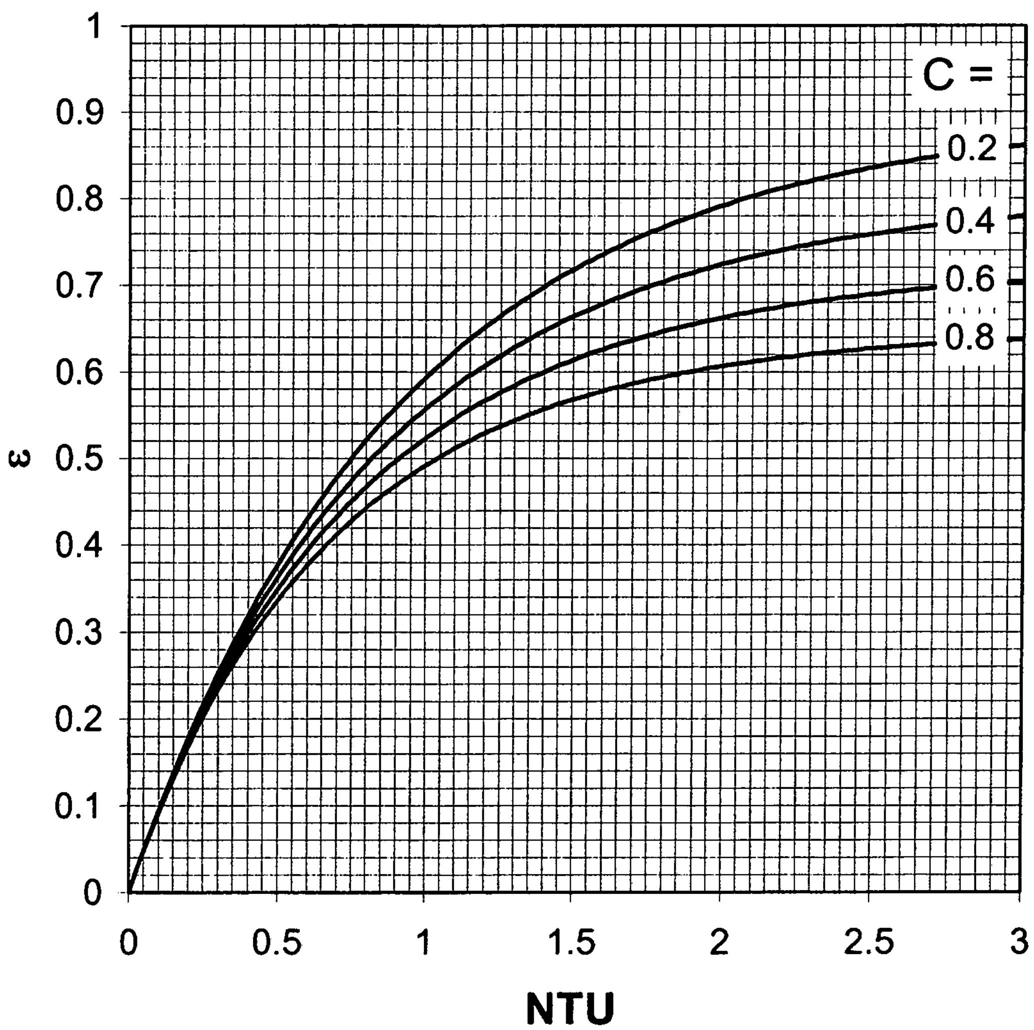
1.

A flow of 3.9 kg/s of a 35°API light oil (c_P = 2430 J/kg K) is cooled from 170 to 115 °C using 10.1 kg/s of 48°API naphtha (c_P = 2345 J/kg K). This is achieved in a 1-2 shell and tube heat exchanger with an efficiency, $\varepsilon = 0.7$.

Determine

a)	the heat duty of the heat exchanger	[5]
b)	the number of transfer units	[5]
c)	the inlet and outlet temperatures of the naphtha	[10]
d)	the temperature correction factor, F_T, of the heat exchanger	[5]

Definitions: $NTU = \frac{UA}{C_{Min}}$ $C = \frac{C_{Min}}{C_{Max}}$



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2.

Steam at 500 K enters a 5 cm ID, 5.5 cm OD stainless steel pipe (k_{Steel} = 15 W/m K) at a rate of 0.1 kg/s. The pipe is insulated using a 3 cm thick layer of glass wool (k_{Ins} = 0.04 W/m K). Heat is lost to the surrounding environment at 280 K and the external heat transfer coefficient is 10 W/m^2 K.

The Fanning friction coefficient in turbulent flow can be calculated from

$$f_F = 0.046\,\mathrm{Re}^{-0.2}$$

and you can use the Chilton-Colburn analogy

$$Nu = \frac{f_F}{2}\mathrm{Re}\,\mathrm{Pr}^{\frac{1}{3}}$$

Determine

a) the internal heat transfer coefficient [7]

b) solve Fourier's law for the cylindrical geometry and derive the heat transfer resistance for conduction [7]

c) the heat loss per unit length of pipe [6]

d) the surface temperature of the insulation [5]

The average properties of the steam can be taken as:

ρ = 10 kg/m^3; c_P = 2895 J/kg K; k = 0.043 W/m K; $\mu = 1.68 \cdot 10^{-5}$ kg/ms
Pr = 1.13.

3.

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

a) $$\frac{d^2\theta}{dx^2} = \frac{2h}{kr}\theta$$ [5]

where $\theta = T - T_A$ is the difference between the temperature of the rod and the external air, h is the heat transfer coefficient, k is the thermal conductivity of the rod and x is the axial position.

Show that the solution for the temperature profile in the rod, if the temperature at one end is kept constant (x = 0, $\theta = \theta_0$) and at x = L the tip is adiabatic, is given by

b) $$\theta = \frac{\theta_0 \cosh(m(L-x))}{\cosh(mL)}$$ [5]

If L = 0.25 m; r = 0.005 m; h = 15 W/m^{2}K; k = 45 W/mK; θ_0 = 80 °C determine:

c) The heat exchange rate of the rod [9]

d) The rod's efficiency, η, defined relative to the case in which the entire rod is at the base temperature. [3]

e) The rod's effectiveness, e. [3]

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4.

A furnace is shaped like a long duct with a cross section shaped as a rectangle with 2 m by 0.5 m sides. The surfaces may be approximated as grey bodies and have an emissivity of 0.8. The 2 m wide base is heated externally and maintained at 1200 K, while the remaining three sides are maintained at 750 K.

a) Derive the electrical circuit equivalent to the radiative heat transfer process. [7]

b) Determine the view factors for this geometry. [8]

c) Determine the rate of heat transfer per unit length that is supplied to the base surface in order to maintain these operating conditions. [10]

The surface and space resistances are given by $R_i = \frac{(1-\varepsilon_i)}{A_i \varepsilon_i}$ and $R_{ij} = \frac{1}{A_i F_{ij}}$.

The Stefan-Boltzmann constant is $\sigma = 5.67\ 10^{-8}$ W/m^{2}K^4. Neglect end-effects and assume radiation to be the only relevant heat transfer mechanism.

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5.

Water is vaporised in a forced convection boiler that operates at 9.3 bar absolute pressure and 450 K temperature. The water enters the tubes with a velocity of 1.5 m/s. At what length inside the tubes has 2% of the inlet water mass vaporised? The tubes of the boiler are smooth with internal diameter 20mm and wall temperature 480K (absolute saturation pressure = 17.9 bar). You can assume that the heat transfer coefficient is constant and equal to that at 2% quality. [25]

You can use the following equation for the heat transfer coefficient by convection, h_C, in the gas-liquid mixture:

$$h_C = 0.023 \frac{k_L}{D} Re_{TP}^{0.8} Pr_L^{0.4}$$

and the following equation for the heat transfer coefficient by pool boiling, h_{PB}:

$$h_{PB} = 0.00122 \left(\frac{k_L^{0.79} c_{pL}^{0.45} \rho_L^{0.49}}{\sigma^{0.5} \mu_L^{0.29} h_{fg}^{0.24} \rho_G^{0.24}} \right) (T_W - T_{SAT})^{0.24} (P_W - P_{SAT})^{0.75}$$

where

Re_{TP} is the two phase Reynolds number,

T_W and T_{SAT} are the wall and the liquid saturation temperatures respectively, and P_W and P_{SAT} are the saturation pressures corresponding to the wall and the liquid temperatures

The rest of the symbols have their usual meanings.

You can also use the following fluid properties.

Liquid at 450 K: $\rho_L = 890$ kg/m^3, $\mu_L = 1.51 \times 10^{-4}$ kg/m s, $k_L = 0.679$ W/m K, $c_{PL} = 4390$ J/kg K

Vapour at 450 K: $\rho_G = 4.8$ kg/m^3, $\mu_G = 14.9 \times 10^{-6}$ kg/m s

$h_{fg} = 20.2 \times 10^5$ J/kg, $\sigma = 42.9 \times 10^{-3}$ N/m

The following graphs can be used (from "Coulson and Richardson's Chemical Engineering Vol. 6". R.S. Sinnott, 2nd Ed, Butterworth Heinemann, 1993).

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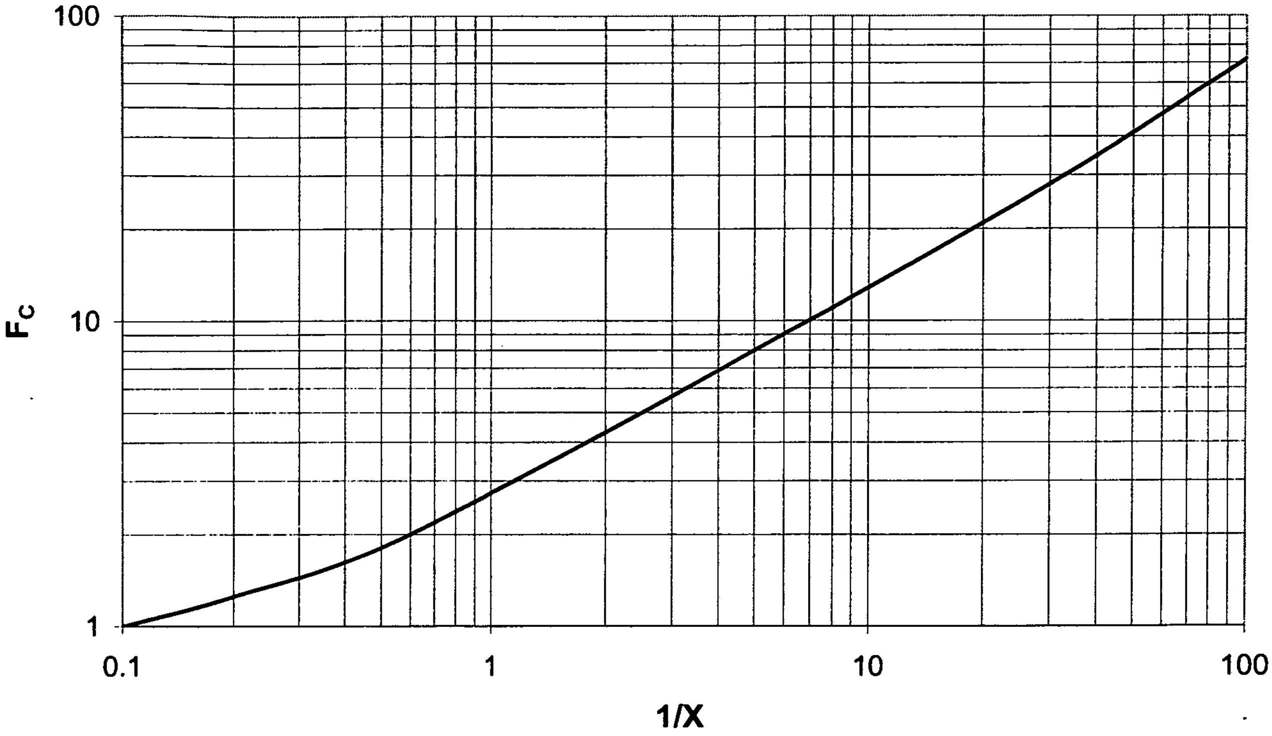

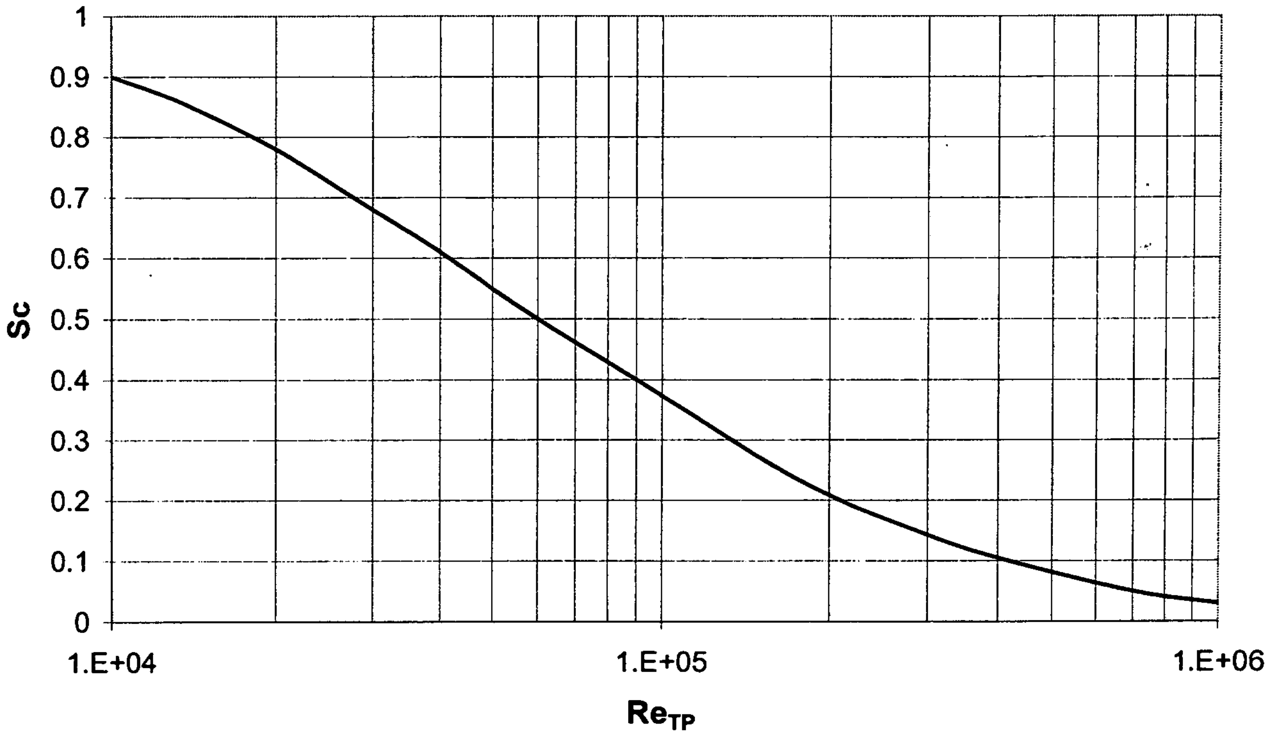

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6.

Define the Lockhart-Martinelli parameters Φ_G and X. [4]

What are the main assumptions in the correlation suggested by Lockhart and Martinelli for two-phase pressure drop? [6]

Using the above assumptions prove that:

$$\Phi_G{}^2 = \left[1 + (X)^{4/(5-n)}\right]^{(5-n)/2} \qquad [15]$$

where n is the power of the Reynolds number (Re) in the correlation used to calculate the friction factor (f)

$f = C / Re^n$
and C is a constant.

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