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 : **30-APR-04**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

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

1.

Describe the four different modes of condensation. [8]

Atmospheric pressure saturated steam condenses on the outside of a horizontal tube with wall temperature $T_w = 60$ °C and outer diameter $D = 2$ cm. Assume that the condensate forms a laminar film and calculate the mass flowrate per unit length of tube dripping from the bottom of the tube. [12]

You can use the following equation for the overall heat transfer coefficient h_L

$$h_L = 0.725\left[\frac{k_L{}^3 \rho_L(\rho_L - \rho_G) g h_{fg}}{\mu_L(T_s - T_w)D}\right]^{1/4}$$

Where: μ_L is the liquid viscosity, h_{fg} is the latent heat of condensation, ρ_L and ρ_G are the liquid and gas densities respectively, k_L is the liquid thermal conductivity, T_s is the saturation temperature and g is the acceleration of gravity.

Calculate also the film Reynolds number and check if the film laminar flow assumption is correct. [5]

You can use the following properties for the steam and the condensate:
Liquid: $\rho_L = 958.4$ kg m^{-3}, $\mu_L = 2.84\text{x}10^{-4}$ kg m^{-1} s^{-1}, $k_L = 0.682$ W m^{-1} K^{-1}
Vapour: $\rho_G = 0.596$ kg m^{-3}.
$h_{fg} = 2.257\text{x}10^6$ J kg^{-1}.

2.

A saturated mixture of steam and water at 390 K is flowing through a horizontal smooth pipe with internal diameter 4 cm. The superficial velocities of the gas and the liquid are 1.5 m s^{-1} and 30 m s^{-1} respectively. Calculate the frictional pressure drop in the pipe using

a) the homogeneous model [8]
b) the following correlation suggested by Turner and Wallis (1965) for separated flow [14]

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

where $\Phi_G{}^2$ and X^2 are the Lockhart-Martinelli parameters and n is the power (absolute value) of the Reynolds number in the friction factor correlation.

The homogeneous viscosity can be calculated as follows:

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

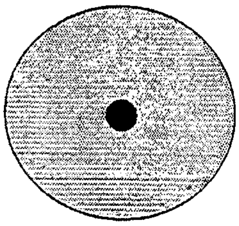
where: x is the quality
μ_g and μ_l are the gas and liquid viscosities respectively

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

The following properties can be used:
Water density = 946 kg m^{-3}, water viscosity = 2.39×10^{-4} Pa s
Steam density = 1.02 kg m^{-3}, steam viscosity = 12.7×10^{-6} Pa s

3.

Steam at 473 K flows in a 5 cm OD pipe, which is inside a 30 cm ID galvanised duct of 0.5 cm thickness. The space between the pipes is filled by a gas with thermal conductivity k = 0.03 W m^{-1} K^{-1}. Assuming that the emissivity of the steel pipe is $\varepsilon_1 = 0.75$ and that of the galvanised duct is $\varepsilon_2 = 0.3$, given a Nusselt number for the enclosure of 15, and a temperature of the duct of 330 K, determine:



Schematic cross-section of pipe inside a duct.

i) the view factors for this geometry. [5]
ii) the heat balance equation neglecting heat resistances inside the pipe and in the pipe and duct walls [5]
iii) the heat lost for a pipe 10 m long [10]
iv) the effective heat transfer coefficient from the galvanised duct to the external air [5]

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 $\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}. Neglect end-effects. The external air is at 300 K.

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4.

A double pipe heat exchanger is connected in a counter-current configuration. 0.4 kg s^{-1} of glycerine, C_P = 2510 J kg^{-1} K^{-1}, are heated from 20 °C using 0.3 kg s^{-1} of water, C_P = 4180 J kg^{-1} K^{-1}, at 90 °C. When the heat exchanger is new the glycerine outlet temperature is 70 °C, while before the exchanger is cleaned the glycerine stream will only reach 64 °C.

For the two operating conditions, determine:

i) The effectiveness of the heat exchanger [5]
ii) The outlet water temperature [5]
iii) The number of transfer units, NTU (UA/C_{Min}) [10]
iv) Verify your result using the following effectiveness equation [5]

$$\varepsilon_{Counter-Cur} = \frac{1-\exp[-NTU(1-C_{Ratio})]}{1-C_{Ratio}\exp[-NTU(1-C_{Ratio})]}$$

5.

A Duralumin rod is kept at T_0 = 15.9 °C at one end using water and at T_1 = 115.5 °C at the other end using steam. The rod is 470 mm long and has an OD of 12.7 mm. The Duralumin thermal conductivity, k = 164 W m^{-1} K^{-1}. The air temperature, T_A = 21.8 °C.

i) Assuming a constant external heat transfer coefficient, h, show that the following equation is the solution for the temperature profile in the rod,

$$\theta = \frac{\theta_0 \sinh[m(L-x)] + \theta_1 \sinh(mx)}{\sinh(mL)}$$

where $m^2 = \frac{2h}{kr}$, $\theta = T - T_A$ and x is the distance from the cold end. [15]

ii) At a distance of 429 mm from the cold end, the experimental rod temperature is 75 °C. Determine the average heat transfer coefficient. [10]

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6.

A pipe 22 mm ID, 25.4 mm OD, is made of steel of thermal conductivity $k_P = 45$ W m^{-1} K^{-1}. The external heat transfer coefficient is $h_{Ex} = 30$ W m^{-2} K^{-1} and the ambient temperature is 20 °C. An oil, $k_{oil} = 0.13$ W m^{-1} K^{-1}, flows through the pipe at 120 °C, with $Re = 25000$ and $Pr = 3$. The fluid viscosity is 5.4×10^{-4} and 4.2×10^{-4} kg m^{-1} s^{-1} at 100 and 120 °C respectively. Given the following correlation

$$Nu = 0.027 Re^{0.8} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

determine:

i) The internal wall temperature. [10]
ii) The overall heat transfer coefficient. [10]
iii) The heat loss for 1 m of pipe. [5]

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