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	:	**29-MAY-03**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

03-C0196-3-60

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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.

Following Colburn's (1934) development show that the local heat transfer coefficient at a certain height, during film condensation over a vertical flat plate, for turbulent film flow can be found as follows:

$$h_L\left[\frac{\mu_L^{\,2}}{k_L^{\,3}\rho_L(\rho_L-\rho_G)g}\right]^{1/3}=\left(\frac{j_H}{2}\right)^{2/3}(\mathrm{Re}_L)^{1/3}(\mathrm{Pr}_L)^{1/3}$$

where j_H is the Chilton-Colburn j-factor for heat transfer:

$h_L = j_H\, c_{pL}\, (G/m)\, (\mathrm{Pr}_L)^{-2/3}$

and G is the mass flowrate of the condensate per unit width of the plate. The rest of the symbols have their usual meanings.

The Colburn analogy between fluid flow and heat transfer can also be used:

$j_H = f/8$

where f is the friction factor for the condensate flow that can be assumed to be the same as that for flow in tubes.

[15]

A flat vertical wall at temperature 80°C is in contact with stagnant saturated steam at atmospheric pressure. If the film is turbulent, calculate the local heat transfer coefficient at a height where the film thickness is 0.3 mm.
The following properties can be used:
$\rho_L = 958.4$ kgm^{-3}, $\rho_G = 0.596$ kgm^{-3}, $k_L = 0.682$ Wm^{-1}K^{-1}, $\mu_L = 2.78\times10^{-4}$ Pas, $c_{PL} = 4216$ Jkg^{-1}K^{-1} [10]

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2.

Within a forced convection boiler that operates at 9.3 bar pressure water is vaporised. Estimate the local heat transfer coefficient in the tubes of the boiler at the point where 15% of the inlet water mass has been vaporised. The tubes of the boiler are smooth with internal diameter 15mm and wall temperature of 480K. [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 use the table provided for the fluids' properties and the graphs given.

g (gravity acceleration) = 9.81 m/s^2

Please see figure at end of paper.

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 is given by:

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

where $\theta = T - T_A$ is the difference between the temperature of the rod and the external air.

ii) Derive the solution for the temperature profile in the rod, knowing that the temperature at either end is kept constant: $x = 0$, $\theta = \theta_0$ and $x = L$, $\theta = \theta_1$. [10]

If L = 0.5 m; r = 0.007 m; h = 10 W/m^{2}K; k = 20 W/mK;
T_A = 20 °C, θ_0 = 80 °C and θ_1 = –10 °C determine:

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iii) The heat exchanged at $x = 0$ [3]
iv) The heat exchanged at $x = L$ [3]
vi) The position of the inflection point in the temperature profile [4]

4.

A furnace is shaped like a long duct with an equilateral triangle cross section shown in Fig.1. The width of the base is 1 m. The surfaces may be approximated as grey bodies and have an emissivity of 0.75. The base is heated externally and maintained at 1200 K, while the two sides are maintained at 750 K.

i) Derive the electrical circuit equivalent to the radiative heat transfer process. [5]
ii) Determine the view factors for this geometry. [5]
iii) Determine the rate of heat transfer per unit length that is supplied to the base surface in order to maintain these operating conditions. [15]

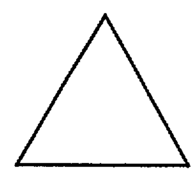

Figure 1. Cross-section of the furnace

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

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5.

Air at 500 °C enters a pipe, 10 m long, 9 cm ID and 10 cm OD, at a rate of 0.2 kg/s. The thermal conductivity of the pipe material is 15 W/mK. The pipe is insulated using one 10 cm thick sheet with k = 0.1 W/mK. The outside temperature is 20 °C.
The following equation can be used to estimate the internal heat transfer coefficient.

$$Nu = 0.021 Re^{0.8} Pr^{\frac{1}{3}}$$

The average properties of air can be taken as:
$\rho = 0.473$ kg/m^3; $c_P = 1087$ J/kg K; k = 0.0541 W/m K; $\mu = 3.5 \cdot 10^{-5}$ kg/ms
Pr = 0.703

Knowing that the outlet temperature is 488 °C, determine:

i) The internal heat transfer coefficient [5]
ii) The overall heat transfer coefficient based on the external surface area of the insulation [5]
iii) The overall heat transfer resistance [5]
iv) The average external heat transfer coefficient [5]
v) The average temperature on the outside of the insulation [5]

6

A double pipe heat exchanger has been connected in a co-current configuration. 0.4 kg/s of glycerine, $C_P = 2510$ J/kgK, are heated from 24 °C to 54 °C, using 0.3 kg/s of water, $C_P = 4180$ J/kgK, at 85 °C.

Determine:

i) The effectiveness of the heat exchanger and the outlet water temperature [5]
ii) The number of transfer units, NTU [5]
iii) The effectiveness of the heat exchanger when connected in a counter-current configuration [5]
iv) The outlet temperatures in the counter-current configuration [5]
v) For the counter-current case, verify your result using the LMTD method [5]

The effectiveness can be calculated from the following equations

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

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

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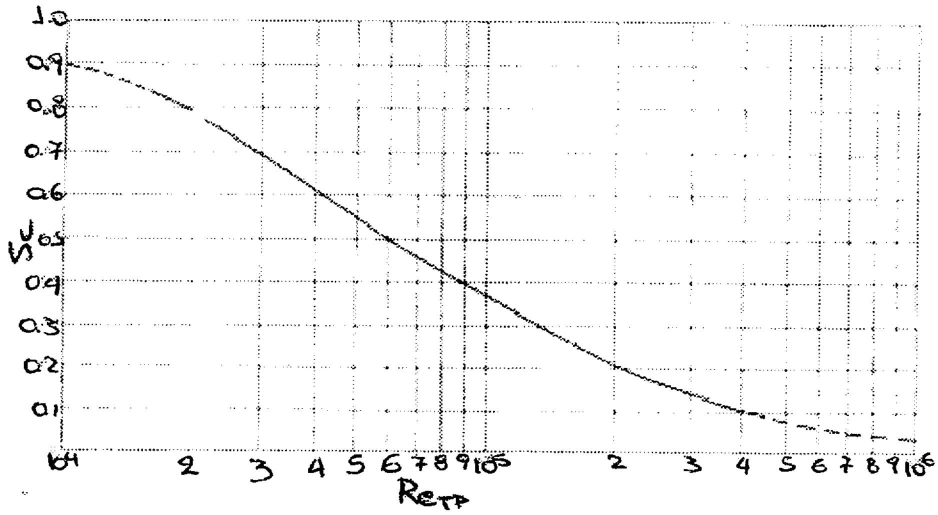

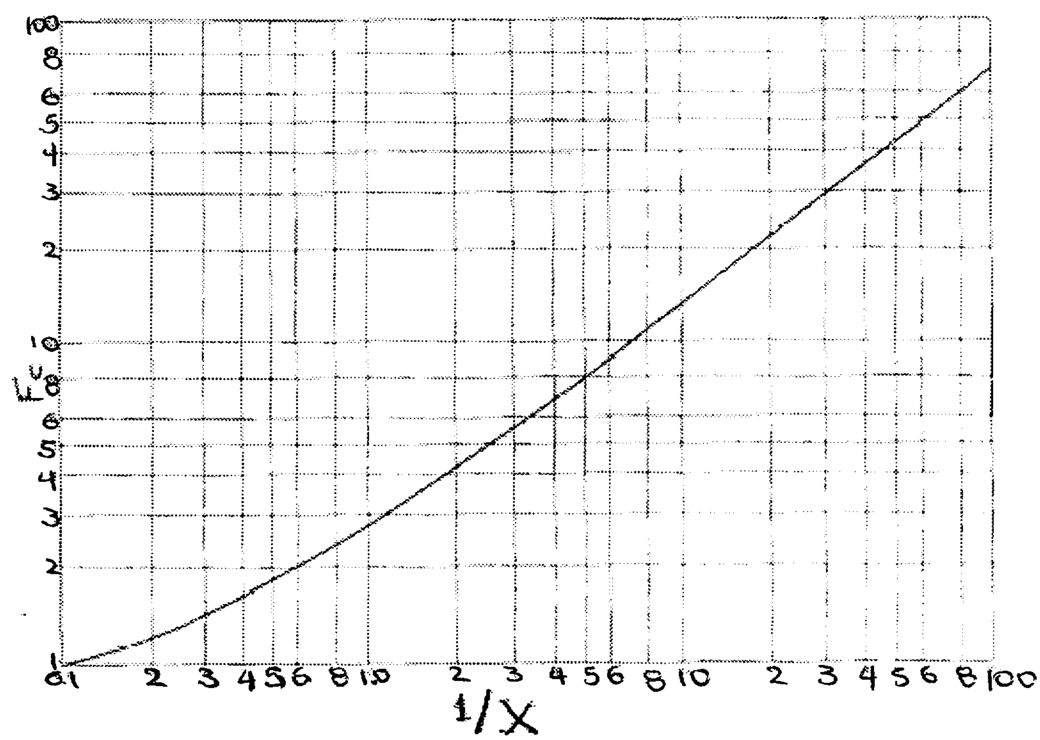

Graphs for Question 2.

Temp (K)	Pressure (bar)	Density Liquid (kg/m^3)	Specific heat Liquid (J/kg.k)	Thermal conductivity Liquid (10^{-2} K/m.K)	Viscosity Liquid (10^4 J/kg)	Density gas (kg/m^3)	Latent heat (10^3 J/kg)	Surface tension (10^{-3} N/m) (dyne/cm)
450	9.32	890	4390	67.9	1.51	4.80	20.2	42.9
480	17.9	856	4532	66.1	1.30	8.92	19.1	36.3

Table for Question 2.

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