UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For the following qualifications :-

B.Eng. *M.Eng.* *M.Sc.*

Chemical Eng E868: Process Heat Transfer

COURSE CODE	:	**CENGE868**
UNIT VALUE	:	**0.50**
DATE	:	**08-MAY-02**
TIME	:	**14.30**
TIME ALLOWED	:	**3 hours**

02-C0191-3-60

TURN OVER

*Answer **FOUR QUESTIONS.***
***ALL** questions carry a total of **25 MARKS** each, distributed as shown* [ ]

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

1. What is the difference in the heat flux against wall superheat curve during the pool boiling of a liquid with a heater immersed in it, when a) the temperature of the heater is increased monotonically and b) the heat flux through the heater is increased monotonically? [5]

A cylindrical heating element with diameter 2 cm and length 50 cm is immersed horizontally in a pool of saturated water at atmospheric pressure. The cylindrical surface is plated with nickel. Calculate the heat flux, q_1 and the total heat transfer rate from the cylinder to the water pool, when the surface temperature of the cylinder is 108°C. [7]

What is the critical heat flux, q_{cr}? How does it compare with q_1? [5]

If the surface temperature of the cylinder is increased to 300°C, calculate the new heat flux, q_2. How does that compare with q_1? Find the total transfer rate from the heater to the water pool. [8]

The following equations can be used for pool boiling heat transfer:

Nucleate boiling

$$q = \mu_L h_{fg} \left(\frac{g(\rho_L - \rho_G)}{\sigma} \right)^{1/2} \left(\frac{c_{pL}(T_w - T_{sat})}{C_{sf} h_{fg} \Pr_L^{1.7}} \right)^3$$

Stable film boiling

$$h = 0.62 \left(\frac{k_G^3 \rho_G (\rho_L - \rho_G) g h_{fg}}{D \mu_G (T_w - T_{sat})} \right)^{1/4}$$

Critical heat flux

$$q = 0.18 h_{fg} \rho_G \left(\frac{\sigma g (\rho_L - \rho_G)}{\rho_G^2} \right)^{1/4}$$

where:
- q is the heat flux
- μ_L, μ_G are the liquid and gas viscocities respectively
- h_{fg} is the latent heat of vaporisation
- ρ_L and ρ_G are the liquid and gas densities respectively
- σ is the surface tension of the liquid
- c_{pL} is the liquid heat capacity
- $(T_w - T_{sat})$ is the temperature difference between the wall and the saturated liquid
- $\Pr_L$ is the liquid Prandtl number,
- C_{sf} is a coefficient whose value depends on the fluid surface combination
- h is the heat transfer coefficient
- k_G is the gas thermal conductivity
- D is the heating element outer diameter

CONTINUED

You can use the graph below and the following properties:
Liquid: $\rho_L = 958$ kg/m^3, $\mu_L = 2.84\text{x}10^{-4}$ kg/m s, $c_{pL} = 4216$ kJ/kg K, $Pr_L = 1.78$
Vapour: $\rho_G = 0.6$ kg/m^3, $\mu_G = 12.95\text{x}10^{-6}$ kg/ms, $k_G = 0.0334$ W/m K
Also: $h_{fg} = 2.257\text{x}10^6$ J/kg, $\sigma = 0.059$ N/m and $C_{sf} = 0.006$.

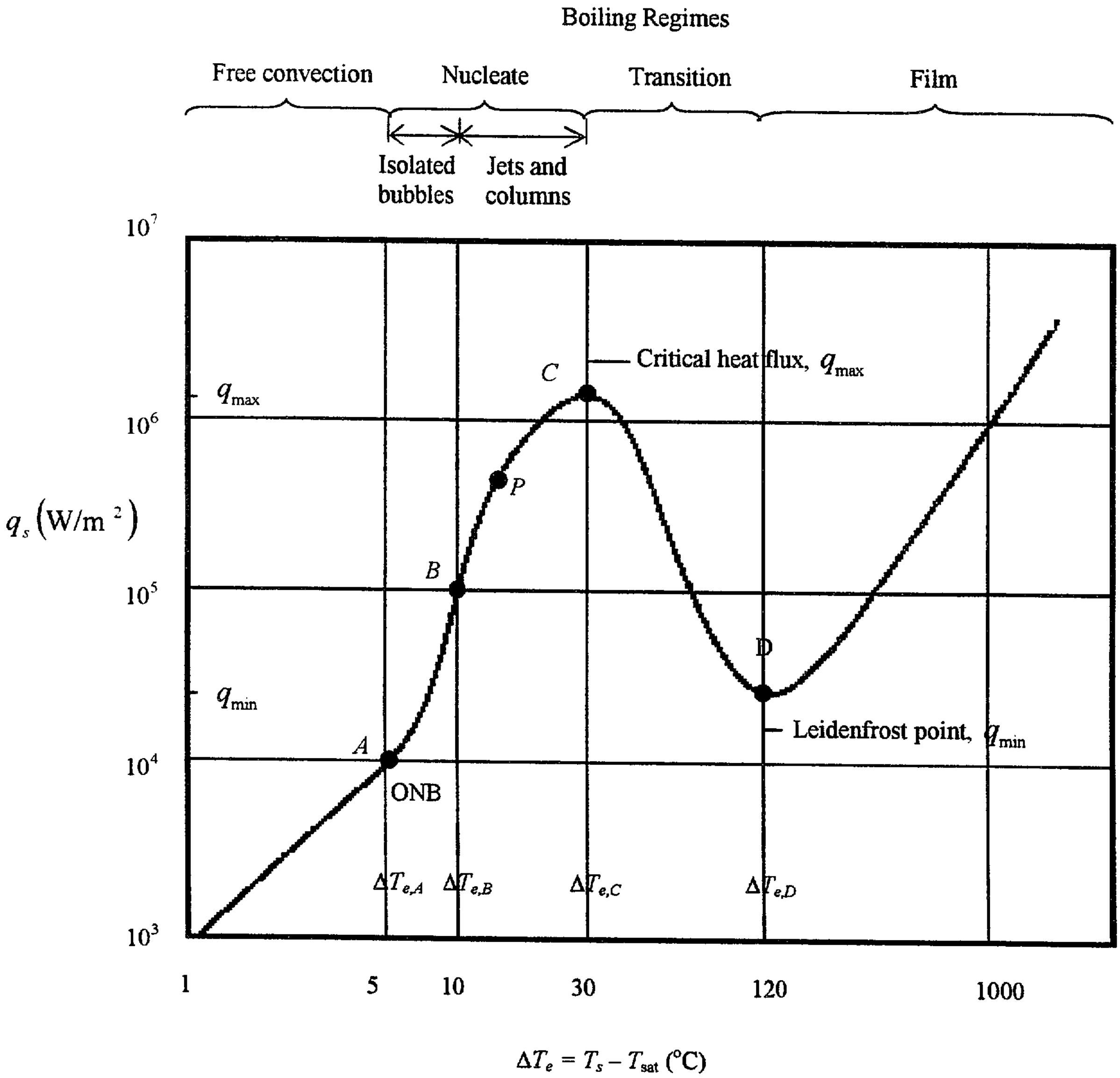


Figure 1 Typical boiling curve for water at 1 atm: surface heat flux q_s as a function of excess temperature, $\Delta T_e \equiv T_s - T_{sat}$

TURN OVER

2. A saturated mixture of steam and water at 510 K is flowing through a horizontal pipe with internal diameter 3cm. The mixture has a quality of 0.4 and mass flux of 1500 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]

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

where: C=20 for turbulent-turbulent flow
C=12 for laminar (liquid) - turbulent flow
C=10 for turbulent (liquid) - laminar flow
C=5 for laminar-laminar flow
and $\Phi_L{}^2$ 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_g and μ_l are the gas and liquid 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 1000.

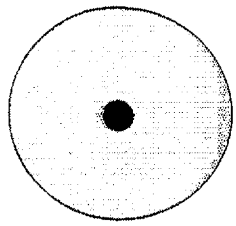
What are the main assumptions in the above models for homogeneous and separated flow? [3]

The following properties can be used:
Water density = 818 kg m^{-3}, water viscosity = 1.15x10^{-4} Pa s
Steam density = 15.8 kg m^{-3}, steam viscosity = 16.9x10^{-6} Pa s

$f = \frac{64}{Re}$ LAMINAR $\quad$ $f = 0.316\ Re^{-0.25}$ TURBULENT

TURN OVER

3. A 5 cm OD pipe carrying steam is at 400 K and is inside a 30 cm ID duct of 0.5 cm thickness. Assuming that the emissivity of the steel pipe is $\varepsilon_1 = 0.79$ and that of the galvanized duct is $\varepsilon_2 = 0.276$, given a Nusselt number for the enclosure of 9.5, and a temperature of the duct of 317 K, determine:



Schematic cross-section of pipe inside a duct.

The view factors for this geometry [5]

The heat balance equation neglecting heat resistances inside the pipe and in the pipe and duct walls [5]

The heat lost for a pipe 10 m long [10]

The heat transfer coefficient from the duct to the external air [5]

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

The Stefan-Boltzmann constant is $\sigma = 5.67\ 10^{-8}$ W/m^{2}K^4. Neglect end-effects and assume a gas between pipe and duct with thermal conductivity $k = 0.03$ W/mK. The external air is at 300 K.

4. Given the general equation for a fin

$$A_x \frac{d^2\theta}{dx^2} + \frac{dA_x}{dx}\frac{d\theta}{dx} = \frac{2hL}{k}\theta$$

derive the equation for the profile of the fin which minimises the amount of material used, knowing that this corresponds to a constant heat flux along the fin, i.e. all the material is used uniformly and

$$\frac{d\theta}{dx} = \text{const}$$

at the base of the fin $x = 0$, $\theta = \theta_0$ and $A_x = A_0 = L\delta_0$ (where L is the length of the fin and δ is the width). Also at the tip of the fin of height b, $x = b$ and $A_x = 0$. [25]

TURN OVER

5. 130000 kg/h of a bottom product from a distillation column (c_P = 2200 J/kg K) at 146°C is used to preheat 150000 kg/h of crude oil (c_P = 1990 J/kg K) initially at 20 °C. This is achieved using a 1-2 shell and tube heat exchanger. When the exchanger is installed the design heat transfer coefficients are U_{Clean} = 410 W/m^{2}K and U_{Dirty} = 290 W/m^{2}K the surface area is A = 120 m^2. Using the ε-NTU method determine:

the heat exchanged when the heat exchanger is new ($U = U_{Clean}$) [7.5]
the outlet temperatures when the exchanger is new [5]
the heat exchanged under design conditions ($U = U_{Dirty}$) [7.5]
the outlet temperatures under design conditions [5]

$$\varepsilon = \frac{Q}{Q_{Max}} = \frac{2}{1 + C + \sqrt{1+C^2}\left(\dfrac{1+\exp\left(-NTU\sqrt{1+C^2}\right)}{1-\exp\left(-NTU\sqrt{1+C^2}\right)}\right)}$$

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

6. A gas heater delivers uniformly 13.5 kW of heating power to 2 pipes 5 m long, 1.27 cm OD, 0.94 cm ID. This is used to heat water, which enters the pipe a rate of 0.1 kg/s and at 15 °C. Use the following correlation to determine the heat transfer coefficient

$$Nu = 0.023\, Re^{0.8}\, Pr^{\frac{1}{3}}$$

The average properties of water can be taken as:
ρ = 994 kg/m^3; c_P = 4180 J/kg K; k = 0.623 W/m K; $\mu = 7.2 \cdot 10^{-4}$ kg/ms
Pr = 4.83

Calculate the exit water temperature [5]
The internal heat transfer coefficient [15]
The temperature profile of the pipe [5]

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