National Exams May 2011

04-CHEM-A2, Mechanical and Thermal Operations

3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is an OPEN BOOK EXAM.
3. Candidates may use any **non-communicating** calculator.
4. All problems are worth 20 marks. **Two problems** from **each** of sections A and B must be attempted. A **fifth** problem from **either section** must also be attempted.
5. **Only the first five** questions as they appear in the answer book will be marked.
6. State all assumptions clearly.

Section A: Mechanical Operations

A1. **[20 marks overall]** A venturi with a throat diameter of 2□-in is used to measure the flow rate of gasoline at 70°F (SG = 0.85, viscosity = 0.6 cP) in a 3-in. sch. 40 commercial steel pipe. What would the pressure drop on a DP transmitter read (in inches of water) for a flow rate of 150 gpm?

A2. **[20 marks]** Calculate the available net positive suction head (NPSH) in a pumping system if the liquid has a density of 1200 kg/m^3, an absolute viscosity of 0.4 Pa·s, an average velocity in the suction piping of 1.0 m/s, a static head on the suction side of 3.0 m, an inside pipe diameter of 0.0526 m, and an equivalent length on the suction side of 5.0 m. You may ignore entrance and exit losses, and assume the liquid is at its normal boiling point.

A3. **[20 marks overall]** A catalyst, which consists of spherical particles of 50 mm diameter and density 1,850 kg/m^3, is to be contacted with with a liquid hydrocarbon (density 880 kg/m^3 and viscosity 2.75×10^{-3} kg/m·s) in a fluidized bed reactor. The bed height at minimum fluidization is 1.37 m and the porosity at minimum fluidization is 0.45.

- **(a)** **[5 marks]** Based on the assumption of small particles, determine the minimum fluidization velocity.
- **(b)** **[5 marks]** Calculate the pressure drop across the bed at minimum fluidization.
- **(c)** **[10 marks]** When the superficial velocity in the bed exceeds the terminal settling velocity of the particles, particles will be elutriated (begin to flow out of the bed). At what velocity will elutriation begin?

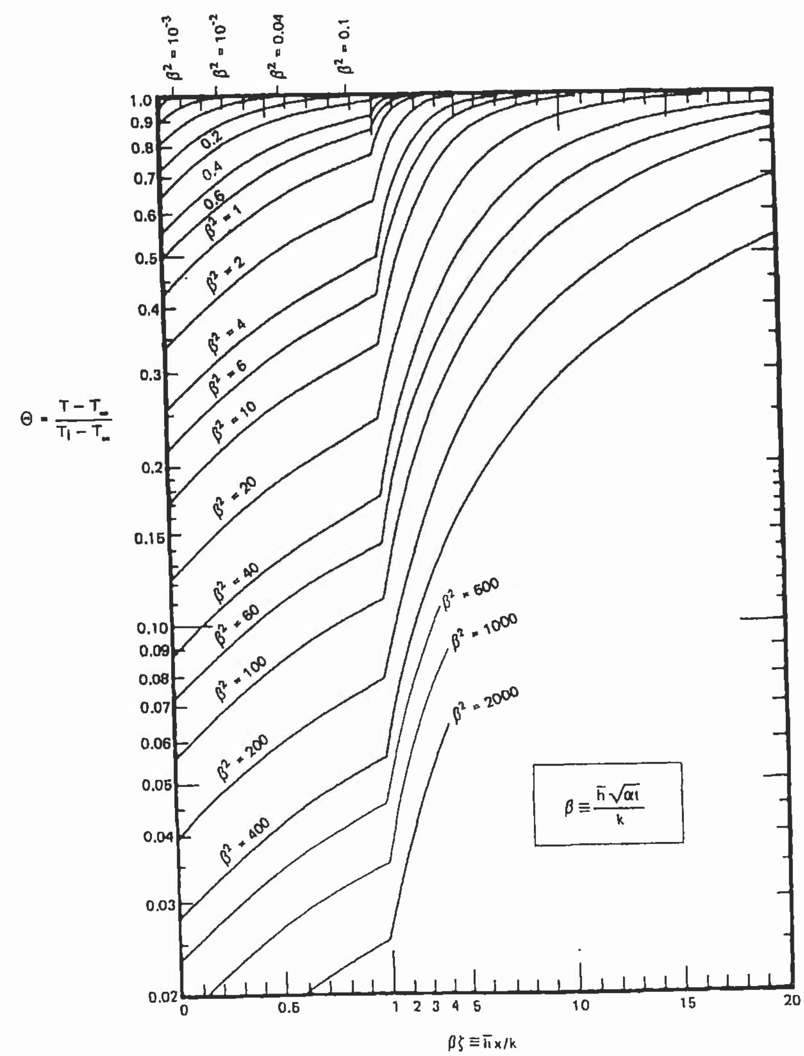
Section B: Thermal Operations

B1. **[20 marks]** Let us assume that the temperature in the earth is constant at 15.6°C to a depth of several meters. Suddenly a cold front passes through causing the temperature to drop to -17.8°C. If the average heat transfer coefficient above the soil is 11.38 W/m^2°C, and the thermal conductivity and thermal diffusivity of the soil can be taken as 0.865 W/m°C and 4.65x10^{-7} m^2/s, calculate the following:

(a) **[10 marks]** the surface temperature after 5 hours; and

(b) **[10 marks]** the depth in the soil to which the freezing temperature of 0°C penetrate in 5 hours.

The following chart is helpful



The cooling of a semi-infinite region by an environment at T_∞ through a heat transfer coefficient $\bar{h}$ [1]

[1] From: Lienhard, J.H. (1987) *ibid.* p181.

B2. **[20 marks overall]** A heat exchanger is to cool 1500 kg/h of kerosene (specific heat capacity = 2.092 kJ/kg·K) from 100°C to 65°C. A cold-water stream is available at 20°C, and its outlet temperature must be 35°C. The specific heat capacity of water is 4.184 kJ/kg·K and may be considered independent of temperature. The overall heat transfer coefficient, U_0 (based on the outside tube area) may be assumed constant at 280 W/m^2·K. Calculate the following:

(c) **[10 marks]** the area A_0 (in m^2) required for a parallel flow double-pipe heat exchanger; and

(d) **[10 marks]** the area A_0 (in m^2) required for a counter flow double-pipe heat exchanger.

B3. **[20 marks overall]** The idealized variation of spectral emissivity with wavelength for Tungsten at 1600K is: $0 < \lambda < 1.0$ μm, $\varepsilon_\lambda = 0.5$; 1.0 μm $< \lambda < 5.0$ μm, $\varepsilon_\lambda = 0.3$; and $\lambda > 5.0$ μm, $\varepsilon_\lambda = 0$. Calculate the following:

(a) **[10 marks]** the total hemispherical emissivity at 1600K using Blackbody radiation functions;

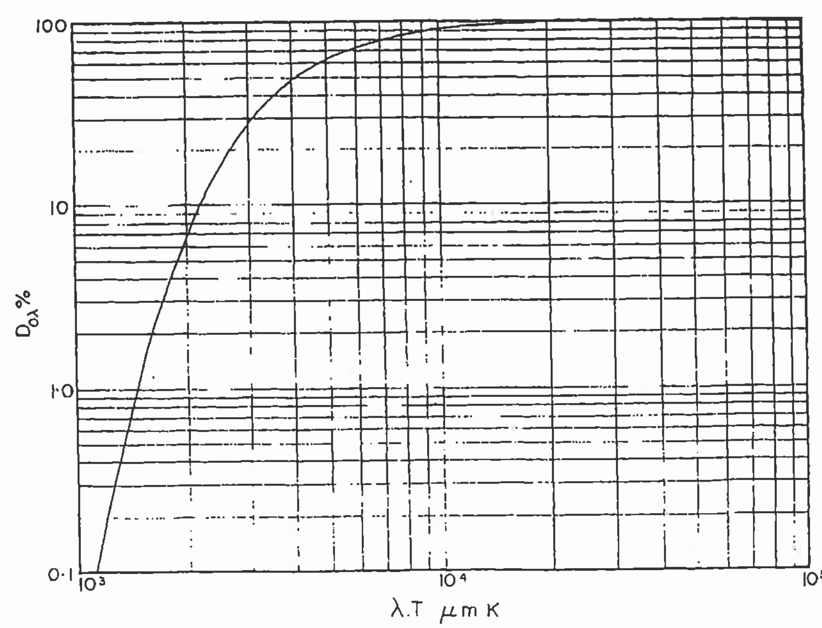
(b) **[2 marks]** the rate at which energy is radiated from a rod of tungsten, 1.0 m long and 20 mm in diameter, at 1600 K;

(c) **[2 marks]** the normal intensity of radiation;

(d) **[2 marks]** the brightness temperature of the rod; and

(e) **[4 marks]** the change in wavelength at which the maximum emissive power occurs between the tungsten rod at 1600 K and at its blackbody temperature.

The following chart is helpful



Fraction of blackbody radiation emitted between wavelengths 0 and λ[2]

[2] From: Gray, W.A and Müller, R. (1974) *"Engineering Calculations in Radiative Heat Transfer"* Pergamon Press, Oxford.