Re-examination Physical Transport Phenomena 2

Year 2017-2018

Thursday April 12, 2018

13:00-16:00, 5419.0013 (Kapteynborg)

Provide the following information on the first page of the answer sheet:

- Name
- Study program
- Student number

And your name on every subsequent answer sheet!

Points per question:

1. 20
2. 15
3. 25
4. 10
5. 30

How is the final grade determined?

Exam questions are worth 100 full points. Your score will be thus divided by 10 to give your final grade (rounded off to a half point).

Success!

Jun Yue

N.B. During the exam, a formula sheet is provided and the book <Transport Phenomena Data Companion> can be used. No other study materials are allowed.

Question 1. (20 points)

A fluid is flowing down a flat vertical wall at 18 °C. The flow is laminar and stationary.

a. If the fluid is water, calculate the film thickness and the mass flow rate in kg per second per m wall width. It is known that *Re* = 10. Assume a water density of 1000 kg/m^3 and dynamic viscosity of 0.001 Pa.s. (8 points)

b. If the fluid is a power law fluid, derive an expression for the velocity profile in the film and find the ratio of the maximum velocity to the average velocity in the film. (12 points)

Question 2. (15 points)

The rheological properties of a particular suspension may be approximated reasonably well by either a power law model or a Bingham plastic model over the shear strain rate range of 10 to 50 s^{-1}. It is known that in the power law model, the consistency coefficient (K) is 10 N.s^n/m^2 and the power law index (n) is 0.2.

a. What will be the approximate values of the yield stress and the plastic viscosity in the Bingham plastic model? (Hint: the shear strain rate can be considered equal to the absolute value of the velocity gradient.) (5 points)
b. Estimate the pressure drop according to the power law model, when the suspension is flowing under steady laminar flow conditions in a horizontal pipe (2 m in length and 30 mm in diameter) and the velocity in the pipe center line is 1 m/s. (5 points)
c. Calculate the velocity in the pipe center line according to the Bingham plastic model at the pressure drop needed in part (b). (5 points)

Question 3. (25 points)

Heat is generated uniformly in a long and flat stainless steel plate. One side of the plate has a very thick heat insulation. The other side of the plate is directly exposed to an environment and loses heat to the environment through a combination of free convection and radiation.

a. If the surface temperature at the other side of the plate without insulation is measured to be at 80 ^oC, calculate the maximum temperature in the plate. (10 points)
b. In part (a), estimate the heat transfer coefficient that describes the free convection between the plate and the environment. (15 points)

Given:

Thickness of the plate:	8 cm
Thermal conductivity of stainless steel:	20 W/(m.K)
Temperature of the environment:	20 ^oC
Heat generation rate in the plate:	30 kW/m^3

Emission coefficient of stainless steel:	0.6
Absorption coefficient of the environment:	1.0
Radiation constant:	$\sigma = 5.67\times10^{-8}$ W/(m^2.K^4)

Question 4. (10 points)

A long, cylindrical lamb meat chunk has a temperature of 2 ^{o}C initially. It is dropped into boiling water at 95 ^{o}C. Calculate the total amount of heat transferred per unit length into the meat chunk during the first 2 hours of cooking.

Given:
Diameter of the cylindrical lamb meat chunk: D = 7.6 cm.
Density of the lamb: ρ = 1030 kg/m^3.
Thermal conductivity of the lamb: λ = 0.456 W/(m.K).
Specific heat capacity of the lamb: c_p = 3.49 kJ/(kg.K).

Question 5. (30 points)

In one bachelor research assignment, the following mass transfer cases are considered:

Case I: A wall is coated on one side with a 0.5 mm thick layer of paint consisting of a very volatile component and a heavier, non-volatile component. The paint is allowed to dry in air, i.e., the volatile component is caused to evaporate. The diffusion coefficient of the volatile component in the paint is known as 2×10^{-11} m^2/s.

Case II: A bottle filled with liquid carbon tetrachloride (CCl_4) is connected with the surrounding oxygen gas by a long vertical tube. The total pressure on the system is 755 mmHg and the temperature is 0 ^{o}C. The tube is 16.6 cm long and 1 cm in diameter. The experiment reveals that 0.033 g CCl_4 evaporate in a 10-hour period after steady state has been attained. It is known that the molecular weight of CCl_4 is 153.8 g/mol and the vapor pressure of CCl_4 at this temperature is 33 mmHg (1 mmHg = 133.32 Pa).

Case III: During long-time operation, the bottom of a cylindrical reactor vessel (inner diameter D = 2 m, Height H = 1.5 m) has been contaminated by an 8 mm thick layer of solid substance. To remove this layer, the vessel is filled with a liquid in which the solid dissolves and further decomposes according to a first-order chemical reaction. It is known that the physical mass transfer coefficient (without chemical reaction) is 10^{-5} m/s and the density of the solid substance is 2100 kg/m^3. The solubility and diffusion coefficient of the solid substance in the liquid are 70 kg/m^3 and 1.2×10^{-9} m^2/s, respectively. The reaction rate constant is 4×10^{-3} s^{-1}.

a. In Case I, estimate roughly how long it takes before the drying front has reached the interface between the paint and wall, and how long it takes before 90% of the volatile component in the paint has evaporated? (10 points)
b. In Case II, estimate the diffusion coefficient of CCl_4 in oxygen. (10 points)

c. In Case III, estimate the remaining average thickness of the solid substance on the vessel bottom after an operation time of 4 hours from the beginning. (10 points).