1 QJ

The University of Calgary
Department of Chemical & Petroleum Engineering

ENCH 501: Transport Phenomena Quiz #4 **October 11, 2011**

Time Allowed: 45 mins. **Name:**

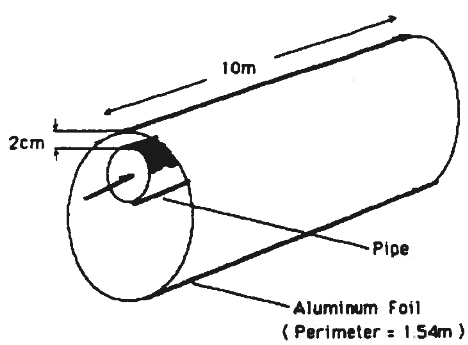
Q. #1 (5 points)
A large hydrocarbon molecule (A) is cracked in a batch reactor to form two molecules (B and C). The molar mass of A is 5 times the molar mass of C. The rate of depletion of A is proportional to the mass of A present in the reactor. The stoichiometric equation for the reaction is:

$$A \rightarrow 2B + C$$

When 45 kg of A was charged into the reactor at time t = 0, no products were present. After 8 minutes, the mass of A had decreased by 5 kg.
a) Derive an expression for the mass of A (kg) present in the reactor as a function of time (mins).
b) Estimate the time for 98% of A to be converted.
Show all your steps.

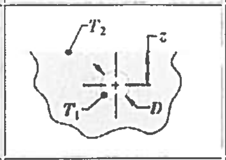
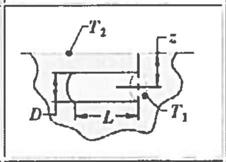
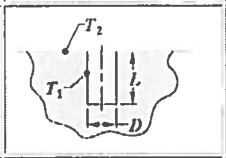
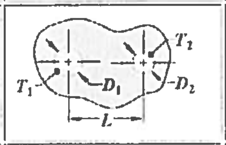
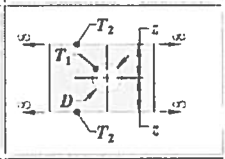
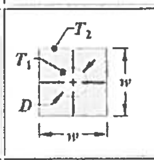
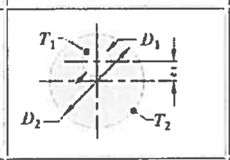
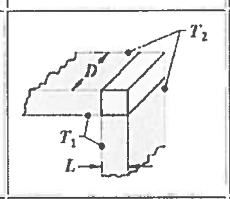
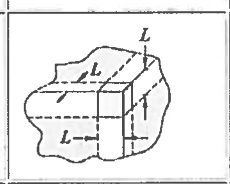
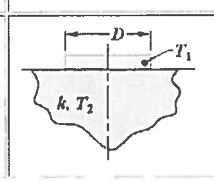
Q. #2 (5 points)
The following is problem 4.2 in the lecture notes.

Crude oil, heated to +350°C in a furnace, is passed through a 20 cm diameter (OD), 10 m long, straight pipe into an atmospheric distillation column. The pipe is uninsulated and, on cold windy days, the separation of the components of the oil is poor. You attribute this to the cooling of the oil in the short transit. You do not have insulation material on hand but you had a big roll of thin aluminum foil that was 1.54 m wide. As the chief engineer on site, you instructed the crew to cut a 10 m long piece of the foil and loop it, as per the sketch, around the pipe to trap air. You instructed that a 2 cm spacer be used to separate the foil and the pipe.
a) If the aluminum foil quickly attained a temperature of -35°C, and the average temperature of the oil and the pipe wall is 340°C, estimate the rate at which heat will be lost from the pipe. The thermal conductivity of the air is 0.035 W/mK.
b) Compare your answer for part (a) to the heat loss from the bare pipe when the convective coefficient of heat transfer is 225 W/m^2K. Assume the ambient is at -35°C and the pipe wall is at 340°C.



Sketch-1 Cross-section of pipe and foil

Conduction Shape Factors

System	Schematic	Restrictions	Shape Factor
Case 1 Isothermal sphere buried in a semi-infinite medium		$z > D/2$	$\dfrac{2\pi D}{1 - D/4z}$
Case 2 Horizontal isothermal cylinder of length L buried in a semi-infinite medium		$L >> D$ $L >> D$, $z > 3D/2$	$\dfrac{2\pi L}{\cosh^{-1}(2z/D)}$ $\dfrac{2\pi L}{\ln(4z/D)}$
Case 3 Vertical cylinder in a semi-infinite medium		$L >> D$	$\dfrac{2\pi L}{\ln(4L/D)}$
Case 4 Conduction between two cylinders of length L in infinite medium		$L >> D_1, D_2$ $L >> w$	$\dfrac{2\pi L}{\cosh^{-1}\left(\dfrac{4w^2 - D_1^2 - D_2^2}{2D_1D_2}\right)}$
Case 5 Horizontal circular cylinder of length L midway between parallel planes of equal length and infinite width		$z >> D/2$ $L >> z$	$\dfrac{2\pi L}{\ln(8z/\pi D)}$
Case 6 Circular cylinder of length L centered in a square solid of equal length		$w > D$ $L >> w$	$\dfrac{2\pi L}{\ln(1.08w/D)}$
Case 7 Eccentric circular cylinder of length L in a cylinder of equal length		$D_2 > D_1$ $L >> D_2$	$\dfrac{2\pi L}{\cosh^{-1}\left(\dfrac{D_2^2 + D_1^2 - 4z^2}{2D_1D_2}\right)}$
Case 8 Conduction through the edge of adjoining walls		$D > 5L$	$0.54D$
Case 9 Conduction through corner of three walls with a temperature difference ΔT_{1-2} across the walls		$L <<$ length and width of wall	$0.15L$
Case 10 Disk of diameter D and temperature T_1 on a semi-infinite medium of thermal conductivity k and temperature T_2		None	$2D$

ENCH 501 Quiz #4 Solution Oct. 11, 2011

#1 The reaction is

Let x kg of C formed in t min's

$$A \longrightarrow 2B + C$$

	A	2B	C
molar masses	$5M_c$	$2M_c$	M_c
moles used or formed	$\frac{x}{M_c}$	$\frac{2x}{M_c}$	$\frac{x}{M_c}$
mass used or formed	$5x$	$4x$	x
mass present (kg)	$45-5x$	$4x$	x

Equation for change in A:

$$\frac{dA}{dt} = \frac{d(45-5x)}{dt} = -k(45-5x)$$

$$\therefore \frac{dx}{dt} = k(9-x) \quad ; \; k \text{ unknown}$$

Subject to 2 conditions

$t = 0 \quad x = 0$

$t = 8 \text{ min} \quad x = 1 \text{ kg}$ (from above relations)

$$\therefore \int_0^1 \frac{dx}{9-x} = k\int_0^8 dt \quad \text{or} \quad k(8) = \ln(9-x)\Big|_1^0$$

$$k = 0.01472 \text{ min}^{-1}$$

At any time.

$$\int_0^x \frac{dx}{9-x} = -\int_0^x d\ln(9-x) = \int_0^t k\,dt$$

$$\therefore \ln \frac{9-x}{9} = -kt$$

$$\therefore x = 9\left(1 - e^{-kt}\right)$$

(a) mass of A in reactor

$$A = 45 - 45\left(1 - e^{-kt}\right)$$
$$= 45 e^{-kt}$$

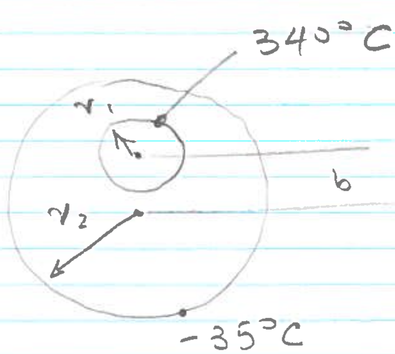
(b) For 98% conversion of A

$$(0.02)(45) = 45 e^{-kt}$$

$$\Rightarrow kt = -\ln(0.02)$$

$$t = 265.71 \text{ mins}$$

#2



Shape factor

$$S = \frac{2\pi l}{\cosh^{-1}\left[\dfrac{r_1^2 + r_2^2 - b^2}{2 r_1 r_2}\right]}$$

(case 7 of table provided)

$$r_1 = 10 \text{ cm}$$

$$r_2 = \frac{1.54 \text{ m}}{2\pi} = 24.51 \text{ cm}$$

$$b = r_2 - r_1 - 2 = 12.51 \text{ cm}$$