

**TestExam FTV1-RUG****June 8<sup>th</sup>, 2015****Exercise 1**

Consider a completely fluid-filled cylindrical chemical reactor of length 3 m and diameter 1 m. Due to the chemicals present, exothermal reactions produce a heat per unit volume ( $q$ ) of 2 kW/m<sup>3</sup>. The stirring device of the reactor is switched off. The tank is cooled down by flowing air of 20 °C. The overall heat transfer coefficient between the reactor wall and the outside air equals 100 W/m<sup>2</sup>K. Assume steady-state conditions.

- A) What is the total heat production by the chemical reaction?
- B) What is the total heat exchange with the environment?
- C) Calculate the temperature at the reactor wall ( $T_w$ ).
- D) Give the expression for the temperature distribution in the reactor.
- E) Given a thermal conductivity of the medium of  $\lambda=50$  W/mK, calculate the temperature in the center of the reactor ( $T_c$ ).

At a certain moment, the stirring device of the tank is switched on. The fluid is well stirred, implying the bulk of the fluid has a uniform temperature ( $T_B$ ). The overall heat transfer coefficient between the bulk of the fluid and the reactor wall is 200 W/m<sup>2</sup>K. Assume steady-state conditions.

- F) Calculate  $T_B$ .

## Exercise 2

The Reynolds number plays an important role in the hydrodynamic behavior of a medium (gas or fluid) flowing around an obstacle. The velocity of the medium is a function of the density and viscosity of the particular medium and a characteristic length, e.g. the obstacle diameter.  $1 \text{ N} = 1 \text{ kg.m/s}^2$

- A) Establish by dimensional analysis the expression for the Reynolds number. **10**

Suppose an oil company is interested in the behavior of oil that encounters an obstacle in the pipe it is flowing through. Because of cost reduction and environmental issues they decide to start out with a pilot experiment in a wind tunnel using a scale model air : oil=1 : 5.

- B) Given an oil pipe diameter of 1 m and a volumetric oil flow of  $1.57 \text{ m}^3/\text{s}$ , what air velocity should be used in the wind tunnel experiments? **10**

oil:  $\eta=10^{-2} \text{ Ns/m}^2$

oil  $\rho=0,8.10^3 \text{ kg/m}^3$

air:  $\eta=1,8.10^{-5} \text{ Ns/m}^2$

air:  $\rho=1,2 \text{ kg/m}^3$

- C) During the wind tunnel experiment, the volumetric air flow is  $0.2 \text{ m}^3/\text{s}$  while the power loss of the air flowing around the obstacle is 500 Watt. Calculate the pressure drop over the obstacle given the air is blown in horizontal direction? **10**

### **Exercise 3**

Consider an (open) cylindrical tank of 500 liter that is continuously supplied with water containing a waste concentration ( $c_{in}$ ) of 30 gram per liter. Part of the waste is digested by micro-organisms and disappears in the form of CO<sub>2</sub> and methane. These micro-organisms consume at a constant rate of 5 gram waste per hour per liter water in the tank.

Additionally, waste particles slowly sink to the bottom. At the bottom, concentrated waste water is discharged. The rest of the water, which is relatively clean, is discharged with a flow rate of 250 liter per hour from the top of the waste water tank. The concentration in the outgoing streams depends on the residence time in the tank. The ratio between the concentration in the concentrated stream ( $c_{conc}$ ) and the concentration in the relatively clean outgoing stream ( $c_{out}$ ) is given by:

$$\frac{c_{conc}}{c_{out}} = 1 + k \cdot t$$

In which the deposition rate  $k$  is 20 hour<sup>-1</sup>, and  $t$  is the residence time of the water in the tank (in hours). Assume stationary conditions and a constant density of 1 kg/m<sup>3</sup>.

- A)** Give the mass balance for the waste concentration in the tank.
- B)** What are the outgoing concentrations (of the concentrated and diluted stream) if the flow of the concentrated stream is 10 liter per hour?

At a certain moment the tank starts to leak due to a small hole in the bottom. Inflow and outflow are stopped immediately. It takes 500 seconds before the tank is completely empty.

C) Calculate the cross sectional area of the leaking hole given a tank height of 50 cm and assuming that the tank is completely filled at  $t=0$ .

# Test exam RUG 2015

① A) total heat production is  $q \cdot V$   
 $= 2 \cdot 10^3 \times \frac{\pi}{4} \cdot 1^2 \cdot 3 = 4.7 \text{ kW}$

B) Steady-state: 4.7 kW

C) Newton:  $q \cdot V = h \cdot A \cdot \Delta T$

$$q \cdot \pi R^2 L = h \cdot 2\pi R L \Delta T$$

$$q \cdot R = 2h \Delta T$$

$$\Delta T = T_{\text{wall}} - T_A = \frac{2 \cdot 10^3 \times 0.5}{200} = 5$$

$$T_{\text{wall}} = T_A + 5 = 25^\circ \text{C}$$

D) No stirring  $\rightarrow$  conduction

$$q \cdot V = -\lambda \frac{dT}{dr} \cdot A$$

$$q \cdot \pi r^2 L = -\lambda \frac{dT}{dr} \cdot 2\pi r L$$

$$\frac{dT}{dr} = -\frac{q}{2\lambda} \cdot r$$

$$\int_{T_c}^T dT = - \frac{q}{2\lambda} \int_0^R 2 r dr$$

$$T - T_c = - \frac{q}{\lambda} r^2$$

$$T(r) = T_c - \frac{q}{\lambda} r^2$$

$$E) T_w = T_c - \frac{q}{\lambda} R^2$$

$$T_c = 25 + \frac{2 \cdot 10^3}{50} (0.5)^2$$
$$= 35^\circ \text{C}$$

$$F) \frac{1}{h_{tot}} = \frac{1}{h_1} + \frac{1}{h_2}$$

$$= \frac{1}{200} + \frac{1}{100}$$

$$h_{tot} = \frac{200}{3} \text{ W/m}^2\text{K}$$

$$q \cdot V = h_{tot} A \Delta T$$

$$q \cdot R = 2 h_{tot} \Delta T$$

$$\Delta T = \frac{T_B - T_A}{1} = \frac{2 \cdot 10^3 \times 0.5 \times 3}{2 \times 200} = 7.5$$

$$T_B = 27.5^\circ \text{C}$$

$$(2) A) v = f(\rho, \eta, D)$$

$$\frac{m}{s} = K \cdot \left(\frac{kg}{m^3}\right)^a \left(\frac{kg}{m \cdot s}\right)^b \cdot m^c$$

$$m: \quad 1 = -3a - b + c \quad c = -1$$

$$s: \quad -1 = -b \quad b = 1$$

$$kg: \quad 0 = a + b \quad a = -1$$

$$v = K \cdot \rho^{-1} \cdot \eta^1 \cdot D^{-1}$$

$$K = \frac{v \cdot \rho \cdot D}{\eta} = Re$$

$$B) v_{oil} = \frac{\Phi}{v/A} = \frac{1.57}{\frac{\pi \cdot 1^2}{4}} = 2 \text{ m/s}$$

$$\left(\frac{v \cdot \rho \cdot D}{\eta}\right)_{oil} = \left(\frac{v \cdot \rho \cdot D}{\eta}\right)_{AIR}$$

$$\left(\frac{v \cdot \rho \cdot D}{\eta}\right)_{oil} = \left(\frac{v \cdot \rho \cdot D/5}{\eta}\right)_{AIR}$$

$$\frac{2 \times 0,8 \cdot 10^3 \times D}{10^{-2}} = \frac{v_{\text{AIR}} \times 1,2 \times \frac{D}{5}}{1,8 \cdot 10^{-5}}$$

$$v_{\text{AIR}} = 12 \text{ m/s}$$

c) Extended Bernoulli



$$h_1 = h_2$$

$$v_1 = v_2$$

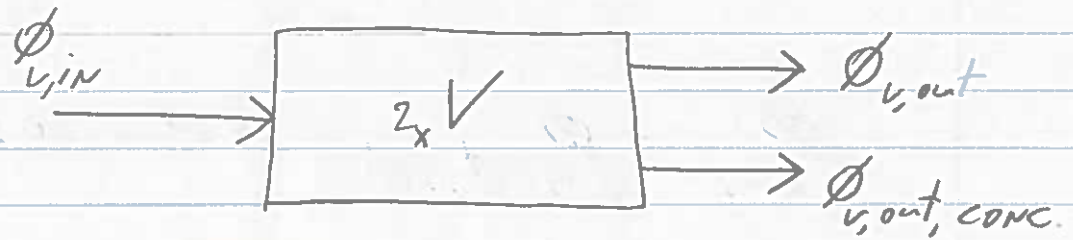
$$0 = - \left( \frac{p_2 - p_1}{\rho} \right) \dot{\Phi}_m - \sum_{SR} \dot{\Phi}_m = 500 \text{ W}$$

$$\dot{\Phi}_m = \rho \cdot \dot{\Phi}_v = 1,2 \times 0,2 = 0,24 \text{ kg/s}$$

$$p_2 - p_1 = - \frac{500 \times 1,2}{0,24} = -2500 \text{ Pa}$$



3



$$A) V \frac{dc}{dt} = \phi_{v,in} c_{in} - \phi_{v,out} c - \phi_{v,out,conc} c_{conc} - 2_x V$$

$$B) \frac{dc}{dt} = 0 \quad c_{conc} = (1 + h\alpha) \cdot c$$

$$\alpha = \frac{V}{\phi_{v,in}} = \frac{V}{\phi_{v,out, to}}$$

$$0 = \phi_{v,in} c_{in} - \phi_{v,out} c - \phi_{v,out,conc} \left(1 + \frac{V}{\phi_{v,in}} \cdot h\right) c - 2_x V$$

$$0 = \phi_{v,in} \cdot c_{in} - c \left[ \phi_{v,out} + \phi_{v,out,conc} \left(1 + \frac{V}{\phi_{v,in}} h\right) \right] - 2_x V$$

$$c = \frac{\phi_{v,in} \cdot c_{in} - 2_x V}{\phi_{v,out} + \phi_{v,out,conc} \left(1 + \frac{V}{\phi_{v,in}} h\right)}$$

$$\phi_{v,IN} = \phi_{v,out,tot} = 250 + 10 = 260 \text{ l/s}$$

$$C = \frac{260 \times 30 - 5 \times 500}{250 + 10 \left(1 + \frac{500}{260} \times 20\right)} \approx 8 \text{ g/l}$$

$$\alpha = \frac{500}{260} \approx 2.5$$

$$C_{conc} = (1 + h\alpha) C = (1 + 20 \times 2) 8 = 49 \text{ g/l}$$

(c) velocity . Bernoulli



$$h = 0.5 \text{ m}$$

$$P_1 = P_2$$

$$v_1 \approx 0 \text{ m/s}$$

$$h_2 = 0 \text{ m}$$

$$\frac{1}{2} v_1^2 + gh_1 = \frac{1}{2} v_2^2 + gh_2$$

$$v_2 = \sqrt{2gh_1}$$

$$\frac{dM}{dt} = -\dot{\phi}_m = -\rho \dot{\phi}_v = -\rho \cdot v \cdot A$$

$$M = \rho \cdot W \cdot h$$

$W =$  CROSS SECTIONAL AREA TANK

~~$$\rho \cdot W \frac{dh}{dt} = -\rho \cdot (2gh)^{1/2} \cdot A$$~~

$$\int_{h_0}^0 \frac{dh}{h^{1/2}} = -\frac{A}{W} (2g)^{1/2} \int_0^t dt$$

$$-2h_0^{1/2} = -\frac{A}{W} (2g)^{1/2} \cdot t$$

$$A = \frac{2h_0^{1/2} \cdot W}{(2g)^{1/2} \cdot t}$$

