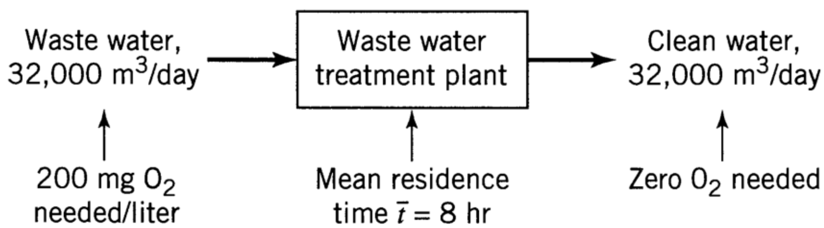
Problems Ch.1

1.1. ***Municipal waste water treatment plant***. Consider a municipal water treatment plant for a small community (Fig. P1.1). Waste water, 32 000 m^3/day, flows through the treatment plant with a mean residence time of 8 hr, air is bubbled through the tanks, and microbes in the tank attack and break down the organic material

$$\text{(organic waste)} + O_2 \xrightarrow{\text{microbes}} CO_2 + H_2O$$

A typical entering feed has a BOD (biological oxygen demand) of 200 mg O_2/liter, while the effluent has a negligible BOD. Find the rate of reaction, or decrease in BOD in the treatment tanks.



Solution:

The rate of reaction defined as rate of oxygen consumption in mole of O2 used per second per volume of the reactor.

$t := \frac{1}{3}\ day$ **mean residence time = 8 hours (1/3 day)**

$volumetric := 32000\ \frac{m^3}{day}$ **wastewater volumetric flow rate**

$$Vreactor := t \cdot volumetric = (1.067 \cdot 10^7)\ L$$

O2 used

$$dNO2perdt := 200\ \frac{mg}{L} \cdot 1\ \frac{gm}{1000\ mg} \cdot \frac{mol}{32\ gm} \cdot 1000\ \frac{L}{m^3} \cdot 32000\ \frac{m^3}{day} = 2.315\ \frac{mol}{s}$$

$$rateO2 := \frac{1}{Vreactor} \cdot dNO2perdt = (2.17 \cdot 10^{-4})\ \frac{mol}{m^3 \cdot s}$$

Another solution of P1.1

Find the rate of reaction defined as

$$r_{O_2} = \frac{\text{mol } O_2 \text{ used}}{\text{sec} \cdot \text{m}^3 \text{ of tank}}$$

Evaluate terms

$$\bar{t} = \frac{V}{v} \quad \text{or} \quad V = \bar{t}\, v$$

or

$$\begin{pmatrix}\text{Volume of} \\ \text{treatment tanks}\end{pmatrix} = \left(\frac{1}{3}\text{day}\right)\left(32000\,\frac{\text{m}^3}{\text{day}}\right) = 10667\ \text{m}^3$$

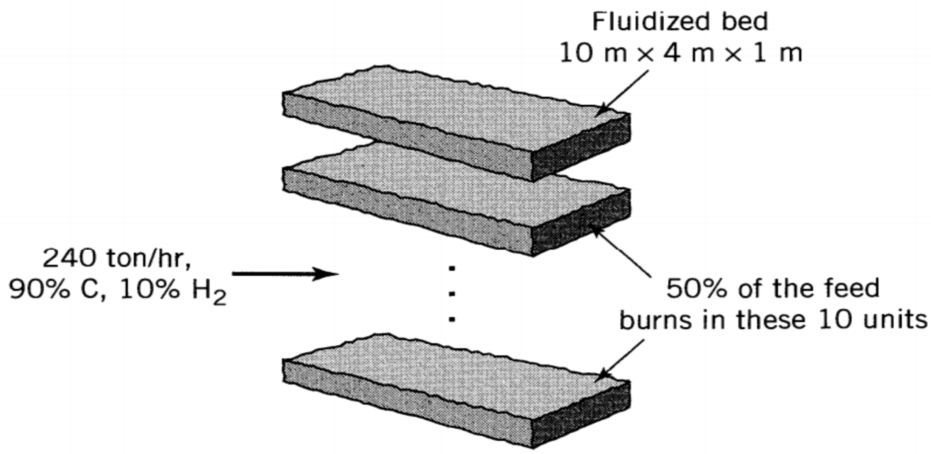
O_2 used

$$\left(200\,\frac{\text{mg}}{\text{lit}}\right)\left(\frac{1\,\text{gm}}{1000\,\text{mg}}\right)\left(\frac{\text{mol}}{32\,\text{gm}}\right)\left(\frac{1000\,\text{lit}}{\text{m}^3}\right)\left(\frac{32000\,\text{m}^3}{\text{day}}\right) = 2\times10^5\ \frac{\text{mol } O_2}{\text{day}}$$

Thus the rate of reaction

$$\frac{2.0\times10^5\ \text{mol } O_2/\text{day}}{10667\,\text{m}^3} = 18.75\ \text{mol}/\text{m}^3\cdot\text{day} = 2.17\times10^{-4}\ \text{mol}/\text{m}^3\cdot\text{s}$$

1.2. *Coal burning electrical power station*. Large central power stations (about 1000 MW electrical) using fluidized bed combustors may be built some day (see Fig. P1.2). These giants would be fed 240 tons of coal/hr (90% C, 10%



H_2), 50% of which would burn within the battery of primary fluidized beds, the other 50% elsewhere in the system. One suggested design would use a battery of 10 fluidized beds, each 20 m long, 4 m wide, and containing solids to a depth of 1 m. Find the rate of reaction within the beds, based on the oxygen used.

Solution:

$$Vbatteries := 10 \cdot 20\ m \cdot 4\ m \cdot 1\ m = (8 \cdot 10^5)\ L$$

$$Cmoles := 0.9 \cdot 240\ \frac{ton}{h} \cdot 1000\ \frac{kg}{ton} \cdot 1000\ \frac{gm}{kg} \cdot \frac{1}{12\ \frac{gm}{mol}} \cdot \frac{h}{3600\ s} = (5 \cdot 10^3)\ \frac{mol}{s}$$

$$H2moles := 0.1 \cdot 240\ \frac{ton}{h} \cdot 1000\ \frac{kg}{ton} \cdot 1000\ \frac{gm}{kg} \cdot \frac{1}{2\ \frac{gm}{mol}} \cdot \frac{h}{3600\ s} = (3.333 \cdot 10^3)\ \frac{mol}{s}$$

C+O2 ----> CO2
H2+1/2O2 ----> H2O

So, the total moles of oxygen consumed are equal to carbon moles plus half amount of the hydrogen moles.

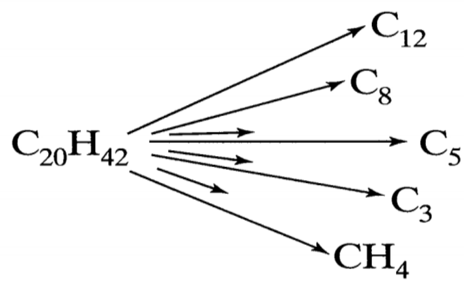
$$O2totalmoles := Cmoles + \frac{H2moles}{2} = (6.667 \cdot 10^3)\ \frac{mol}{s}$$

Only 50% of coal feed are burned in the beds

$$ratebatteries := \frac{0.5 \cdot O2totalmoles}{Vbatteries} = 4.167\ \frac{mol}{m^3 \cdot s}$$

1.3. ***Fluid cracking crackers (FCC).*** FCC reactors are among the largest processing units used in the petroleum industry. Figure P1.3 shows an example of such units. A typical unit is 4-10 m ID and 10-20 m high and contains about 50 tons of $\rho = 800$ kg/m^3 porous catalyst. It is fed about 38 000 barrels of crude oil per day (6000 m^3/day at a density $\rho \cong 900$ kg/m^3), and it cracks these long chain hydrocarbons into shorter molecules.

To get an idea of the rate of reaction in these giant units, let us simplify and suppose that the feed consists of just C_{20} hydrocarbon, or



If 60% of the vaporized feed is cracked in the unit, what is the rate of reaction, expressed as $-r'$ (mols reacted/kg cat · s) and as r''' (mols reacted/m^3 cat · s)?

Solution:

$$Wcat := 50000\ kg \qquad \rho cat := 800\ \frac{kg}{m^3} \qquad Vcat := \frac{Wcat}{\rho cat} = (6.25 \cdot 10^4)\ L$$

$$Feedrate := 6000\ \frac{m^3}{day} \qquad \rho feed := 900\ \frac{kg}{m^3} \qquad Feed := Feedrate \cdot \rho feed = 62.5\ \frac{kg}{s}$$

$$M.Wt.C20H42 := (20) \cdot 12\ \frac{gm}{mol}\ \frac{kg}{1000\ gm} + (42) \cdot 1\ \frac{gm}{mol}\ \frac{kg}{1000\ gm} = 0.282\ \frac{kg}{mol}$$

$$dNperdt := \frac{Feed}{M.Wt.C20H42} \cdot 0.6 = 132.979\ \frac{mol}{s}$$

The 0.6 is the 60% of the vaporized feed cracked (given)

$$r' := \frac{1}{Wcat}\ dNperdt = 0.003\ \frac{mol}{kg \cdot s}$$

$$r''' := \frac{1}{Vcat}\ dNperdt = 2.128\ \frac{mol}{m^3 \cdot s}$$