Øving 2

Problem 1

The composition of a gas derived by the gasification of coal is, volume percentage: carbon dioxide 4, carbon monoxide 16, hydrogen 50, methane 15, ethane 3, benzene 2, balance nitrogen. If the gas is burnt in a furnace with 20% excess air, calculate:

a) the amount of air required per 100 kmol of gas,

b) the amount of flue gas produced per 100 kmol of gas,

c) the composition of the flue gases, on a dry basis.

Assume complete combustion.

a) Antar ideell gasslov => Vol% = mol%

$CO_2 + O_2 \not\rightarrow$ (inert)

$CO + \frac{1}{2}O_2 \rightarrow CO_2$

$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

$C_2H_6 + 3{,}5O_2 \rightarrow 2CO_2 + 3H_2O$

$C_6H_6 + 7{,}5O_2 \rightarrow 6CO_2 + 3H_2O$

$N_2 + O_2 \not\rightarrow$ (inert)

b) ut: CO_2 H_2O N_2 O_2

c) Dry basis, stryk H_2O

=> Beregn composisjon av $CO_2 + N_2 + O_2$

Basis: 100 kmol

	Inn	Brukt O_2	CO_2 ut	H_2O ut
CO_2	4	–	4	–
CO	16	8	16	–
H_2	50	25	–	50
CH_4	15	30	15	30
C_2H_6	3	10,5	6	9
C_6H_6	2	15	12	6
N_2	10	–	–	–
Sum	100	88,5	53	95

Trenger 88,5 kmol O_2/100 kmol gass

20% excess => $1{,}2 \cdot 88{,}5$ kmol O_2 = 106,2 kmol

N_2 (luft) = $106{,}2 \cdot \frac{79}{21}$ = 399,5 kmol

=> $\dot{n}$ (luft) = (106,2 + 399,5) kmol/h = **505,7 kmol luft/h**

b) Ut = Inerte gasser + luft inn − O_2 brukt + Produkter

$$= \underset{N_2}{10} + \underset{N_2}{399{,}5} + \underset{O_2}{(106{,}2 - 88{,}5)} + \underset{CO_2}{53} + \underset{H_2O}{95}$$

$$= 575{,}2 \text{ kmol/h}$$

c) Tørr basis: Neglisjer H_2O, ny mengde ut: $(575{,}2 - 95)$ kmol/h $= 480{,}2$

Utgasser	Mengde kmol/h	Fraksjon
N_2	409,5	0,853
O_2	17,7	0,037
CO_2	53	0,110

Problem 2

The off-gases from a gasoline stabilizer are fed to a steam reforming plant to produce hydrogen. The composition of the off-gas, molar%, is: CH_4 77.5, C_2H_6 9.5, C_3H_8 8.5, C_4H_{10} 4.5. The gases entering the reformer are at a pressure of 2 bara and 35 °C and the feed rate is 2000 m^3/h. The reactions in the reformer are:

$$C_nH_{2n+2} + nH_2O \longrightarrow nCO + (2n+1)H_2 \quad (1)$$
$$CO + H_2O \longrightarrow CO_2 + H_2 \quad (2)$$

The molar conversion of C_nH_{2n+2} in reaction (1) is 96% and of CO in reaction (2) 92%. Calculate:

a) the average molecular mass of the off-gas,

b) the mass of gas fed to the reformer, kg/h,

c) the mass of hydrogen produced, kg/h.

$M(CH_4) = 16{,}042$

$M(C_2H_6) = 30{,}068$

$M(C_3H_8) = 44{,}094$

$M(C_4H_{10}) = 58{,}12$

a) $\overline{M_m} = \sum X_i M_{m_i} = 0{,}775 \cdot 16{,}042 + 0{,}095 \cdot 30{,}068 + 0{,}085 \cdot 44{,}094 + 0{,}045 \cdot 58{,}12$

$\overline{M_m} = 21{,}65$ g/mol

b) $P = 2$ bara $= 2$ bar $= 2 \cdot 10^5$ Pa

$T = 30°C = 303K$

$$P\dot{V} = \dot{n}RT \Rightarrow \dot{n} = \frac{P\dot{V}}{RT}, \quad \dot{n} = \frac{\dot{m}}{\overline{M_m}}$$

$$\dot{m} = \frac{P\dot{V}}{RT} \cdot \overline{M_m} = \frac{2 \cdot 10^5 \text{ Pa} \cdot 2000 \text{ m}^3/\text{h}}{8{,}314 \text{ J/mol} \cdot \text{K} \cdot 303 \text{ K}} \cdot 21{,}65 \text{ g/mol}$$

$$\dot{m} = 3438 \text{ kg/h}$$

c) Reakjonene blir: $n=1$: $CH_4 + H_2O \rightarrow CO + 3H_2$

$n=2$: $C_2H_6 + 2H_2O \rightarrow 2CO + 5H_2$

$n=3$: $C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2$

$n=4$: $C_4H_{10} + 4H_2O \rightarrow 4CO + 9H_2$

Bruker en 100 kmol/h basis: (Antar)

	Inn	Dannet CO	Dannet H_2
CH_4	77,5	77,5	232,5
C_2H_6	9,5	19	47,5
C_3H_8	8,5	25,5	59,5
C_4H_{10}	4,5	18	40,5
Sum	100	140	350 ← Fullstendig forbrenning
		134,4	**336** ← Fullstendig · 0,96

CO reagerer videre etter:

$$CO + H_2O \rightarrow CO_2 + H_2$$

Reaksjonen går 92% => H_2: $0{,}92 \cdot 134{,}4 =$ **123,648 kmol**

Totalt produseres det 459,648 kmol H_2 / 100 kmol gass inn

$$\dot{m} = \dot{n} \cdot M_{H_2} = 459{,}648 \text{ kmol} \cdot 2{,}016 \text{ g/mol}$$

$$\dot{m} = 926{,}65 \text{ kg } H_2/100 \text{ kmol gass inn}$$

$$\dot{n}_{inn} = \frac{PV}{RT} = \frac{2 \cdot 10^5 \text{ Pa} \quad 2000 \text{ m}^3/\text{h}}{8{,}314 \text{ J/mol·K} \cdot 303 \text{ K}} = 158{,}78 \text{ kmol gass inn/h}$$

$$\dot{m}_{H_2} = \dot{n}_{inn} \cdot \dot{m} = 158{,}78 \text{ ~~kmol gass inn~~/h} \cdot 926{,}65 \text{ kg } H_2 / 100 \text{ ~~kmol gass inn~~}$$

$$\underline{\underline{\dot{m}_{H_2} = 1471{,}4 \text{ kg/h}}}$$

Problem 3

In a continuous bio-reactor (or fermenter), the volumetric flow rate of feed to the fermenter is q (L/h). The liquid volume is constant V (L). The cell concentration of the feed and out of the fermenter are X_0 and X (g/L), respectively. While the substrate concentration in and out of the fermenter are S_0 and S (g/L), respectively. The growth rate of cells is μX (g/Lh) and the consumption rate of substrate is $k\mu X$. Here, the constant $k = 1.2$ is the inverse yield of substrate to cell mass. The cell death rate is neglected. The specific growth rate μ is a function of the substrate concentration.

a) Set up a dynamic model of the continuous stirred reactor describing the cell and substrate concentrations.

b) Simulate concentration of cells and substrate as function of time when the specific growth rate is $\mu = \frac{2S}{S+3}$ (1/h) and $q/V = 0.5$ (1/h) with $S_0 = 4.0$ g/L and $X_0 = 0.01$ g/L and starting with no cells and substrate in the reactor.

c) Reduce the model by assuming steady-state conditions and negligible feed of cell mass to the reactor. Calculate the steady-state concentrations.

a) Setter opp masse balanser for celler X og substrat S

$$\frac{d(V\cdot X)}{dt} = qX_0 - q\cdot X + \mu X\cdot V \qquad /\cdot\frac{1}{V}$$

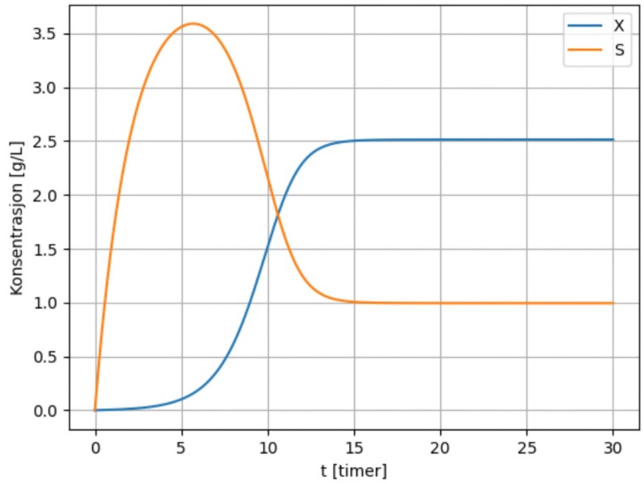
$$\frac{dX}{dt} = \frac{qX_0}{V} - \frac{qX}{V} + \mu X$$

$$\frac{d(V\cdot S)}{dt} = qS_0 - qS - k\mu X\cdot V \qquad /\cdot\frac{1}{V}$$

$$\frac{dS}{dt} = \frac{qS_0}{V} - \frac{qS}{V} - k\mu X$$

Initial Conditions: $S = X = 0$

b) Legger inn i python, får grafen:



c) Gitt antakelsene, $\frac{dX}{dt} = \frac{dS}{dt} = 0$, og $X_0 = 0$

$$\Rightarrow (1)\quad -\frac{qX}{V} + \mu X = 0$$

$$(2)\quad \frac{q}{V}(S_0 - S) - k\mu X = 0$$

$$(1) \cdot \frac{1}{X} \qquad -\frac{q}{V} + \mu = 0 \Rightarrow \mu = \frac{q}{V} = 0{,}5$$

$$\frac{2S}{3+S} = 0{,}5$$

$$2S = 1{,}5 + 0{,}5$$

$$1{,}5S = 1{,}5$$

$$\underline{S = 1}$$

$$(2)\quad \frac{q}{V}(S_0 - S) - k\mu X = 0$$

$$k\mu X = \frac{q}{V}(S_0 - S)$$

$$X = \frac{\frac{q}{V}(S_0 - S)}{k\mu} = \frac{0{,}5(4-1)}{1{,}2 \cdot 0{,}5} = 2{,}5$$

$$\Rightarrow \underline{\underline{X = 2{,}5,\ S = 1}}$$