Energy & Environment II
HW #10
Recommended Answers

#1 Landfill Energy

Nominal composition of organic waste digested: $C_6H_9O_3$

Our general chemical equation for anaerobic digestion is

$$C_xH_yO_z + aH_2O \rightarrow bCH_4 + dCO_2$$

where:

$$a = x - \frac{y}{4} - \frac{z}{2} = 6 - \frac{9}{4} - \frac{3}{2} = 2.25$$

$$b = \frac{x}{2} + \frac{y}{8} - \frac{z}{4} = \frac{6}{2} + \frac{9}{8} - \frac{3}{4} = 3.375$$

$$d = \frac{x}{2} - \frac{y}{8} + \frac{z}{4} = \frac{6}{2} - \frac{9}{8} + \frac{3}{4} = 2.625$$

The % of CH_4 in the product gas is $\frac{3.375}{6} \times 100 = 56.25\%$
The % of CO_2 in the product gas is $\frac{2.625}{6} \times 100 = 43.75\%$

Electrical power (on average) = 2 MW
Since the engine/generators are 38% efficiency, this means $2/.38 = 5.263$ MW of chemical energy per sec must be provided to the engines.
Since the heating value of CH_4 is 50,000 KJ/Kg (LHV basis) or 50 MJ/Kg, this means the flow rate of CH_4 must be

$$\dot{m}_{CH_4} = \frac{5.263 \frac{MJ}{s}}{50 \ MJ/Kg} = \underline{\underline{0.105}} \ \frac{Kg}{s}$$

By our anaerobic digestor chemical equation, 1 kmol of $C_6H_9O_3$ yields 3.375 kmol of CH_4. Since the molecular weight of $C_6H_9O_3 = 6 \times 12 + 9 \times 1 + 3 \times 16 = 129 \frac{kg}{kmol}$ and since the molecular weight of Methane is 16, we have that:

$1 \text{ kmol} \times 129 \frac{kg}{kmol} = 129$ kg of organic waste

yields $3.375 \text{ kmol} \times 16 \frac{kg}{kmol} = 54$ kg of CH_4

Thus the rate of conversion of the organic waste must be

$$0.105 \frac{kg}{s} CH_4 \times \frac{129 \text{ kg organic waste}}{54 \text{ kg methane}}$$

$$= \underline{0.251 \frac{kg}{s}} \text{ of organic waste}$$

Multiplication of this by the number of seconds in a year and division by the number of kg in a metric ton (tonne) gives the answer

$$0.251 \frac{kg}{s} \times 3600 \frac{s}{hr} \times \frac{24 \text{ hr}}{day} \times \frac{365 \text{ day}}{yr} \times \frac{1 \text{ tonne}}{1000 \text{ kg}}$$

$$= \underline{7916} \text{ tonnes of organic waste/yr}$$

The kwh of electricity generated per yr is:

$$2 \text{ MW} \times \frac{1000 \text{ KW}}{\text{MW}} \times 8760 \frac{hr}{yr} = \underline{17{,}520{,}000} \frac{kwh}{yr}$$

#2 Wood-fired Steam Electric Power Plant

Electrical power of 50 MW for 8000 hr per year. The HHV efficiency of the plant is 25%. Thus, the amount of wood energy that must be provided to the plant each year is:

$$\frac{50\ \text{MW} \times 8000\ \text{hr} \times 1000\ \frac{\text{Kwh}}{\text{Mwh}} \times \frac{3600\ \text{KJ}}{\text{Kwh}}}{0.25}$$

$= 5.76 \times 10^{12}$ KJ of wood energy (HHV)/yr

Assuming a HHV of 15,000 KJ/kg for dry wood, the amount of dry wood required per year is:

$$\frac{5.76 \times 10^{12}\ \text{KJ/yr}}{15{,}000\ \text{KJ/kg}} \times \frac{1\ \text{tonne}}{1000\ \text{kg}} = 384{,}000\ \frac{\text{tonnes}}{\text{yr}}$$

of dry wood

(Of course, a lot of moisture will come along, into the power plant with the wood).

If we assume a 1% efficiency for the conversion of sunlight energy to wood energy, our forest must receive

$$\frac{5.76 \times 10^{12}\ \text{KJ}}{0.01} = 5.76 \times 10^{14}\ \text{KJ of } \frac{\text{sunlight}}{\text{yr}}$$

If we assume our forest is in Western Washington, and we use the average daily solar energy value of 3300 watt-hours/m²/day,

or $\frac{3.30 \cancel{\text{kwh}}}{\text{m}^2\text{-}\cancel{\text{day}}} \times 365 \frac{\cancel{\text{day}}}{\text{yr}} \times \frac{3600 \text{ kJ}}{\cancel{\text{kwh}}}$

we arrive at a yearly solar energy per m^2 of:

$4{,}336{,}200 \frac{\text{kJ}}{\text{m}^2\text{-yr}}$

Dividing 4,336,200 into 5.76×10^{14} gives the forest area:

132,835,200 m^2

or $\underline{\underline{11.525 \text{ km} \times 11.525 \text{ km}}}$