Energy & Environment II
HW #16
Recommended Answers

#1 Landfill Energy

Nominal composition of organic waste digested: \( C_6 H_9 O_3 \)

Our general chemical equation for anaerobic digestion is

\( C_x H_y O_2 + a H_2 O \rightarrow b C H_4 + d CO_2 \)

where:

\[
\begin{align*}
a &= x - \frac{y}{4} - \frac{3}{2} = 6 - \frac{9}{4} - \frac{3}{2} = 2.25 \\
b &= \frac{x}{2} + \frac{y}{8} - \frac{3}{4} = \frac{6}{2} + \frac{9}{8} - \frac{3}{4} = 3.375 \\
d &= \frac{x}{2} - \frac{y}{8} + \frac{3}{4} = \frac{6}{2} - \frac{9}{8} + \frac{3}{4} = 2.625
\end{align*}
\]

The \( \% \) of \( C H_4 \) in the product gas is \( \frac{3.375}{6} \times 100 = 56.25\% \)

The \( \% \) of \( C O_2 \) 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 \( 0.38 \times 5.263 \) MW of chemical energy per sec must be provided to the engines.

Since the heating value of \( C H_4 \) is 50,000 KJ/kg (LHV basis) or 50 MJ/kg, this means the flow rate of \( C H_4 \) must be

\[
m_{C H_4} = \frac{5.263 \text{ MJ}}{50 \text{ MJ/kg}} = 0.105 \frac{\text{ Kg}}{\text{s}}
\]
By our anaerobic digester chemical equation 1 kmol of C₆H₉O₃ yields 3.375 kmol of CH₄. Since the molecular weight of C₆H₉O₃ = 6×12 + 9×1 + 3×16 = 129 kg/kmol and since the molecular weight of Methane is 16, we have that:

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

yields \[ 3.375 \text{ kmol} \times 16 \frac{\text{kg}}{\text{kmol}} = 54 \text{ kg of CH}_4 \]

Thus the rate of conversion of the organic waste must be

\[ 0.105 \frac{\text{kg}}{s} \text{ CH}_4 \times \frac{129 \text{ kg of organic waste}}{54 \text{ kg of methane}} = 0.251 \frac{\text{kg}}{s} \text{ of organic waste} \]

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

\[ 0.251 \frac{\text{kg}}{s} \times 3600 \frac{s}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{365 \text{ day}}{\text{yr}} \times \frac{1 \text{ tonne}}{1000 \text{ kg}} = 7916 \text{ tonnes of organic waste/yr} \]

The kwh of electricity generated per year is:

\[ 2 \text{ MWh} \times \frac{1000 \text{ kWh}}{\text{MWh}} \times \frac{8760 \text{ hr}}{\text{yr}} = 17,520,000 \text{ kWh/yr} \]
The #2 Wood-fired Steam Electric Power Plant has an electrical power output of 50 MW. The HHV efficiency of the plant is 25%. Thus, the amount of wood energy that must be provided to the plant each year is:

\[
50 \text{ MW} \times 8000 \text{ h/yr} \times 1000 \text{ kwh/Mwh} \times \frac{3600 \text{ KJ}}{1 \text{ kwh}} \\
\]

\[
= 0.25 \\
= 5.76 \times 10^{12} \text{ KJ/yr}
\]

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

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

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

\[
\frac{5.76 \times 10^{12} \text{ KJ}}{0.01} = 5.76 \times 10^{14} \text{ KJ of sunlight/yr}
\]
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 \( \frac{3.30 \text{ kWh}}{\text{m}^2 \cdot \text{day}} \times \frac{365 \text{ day}}{\text{yr}} \times \frac{3600 \text{ kJ}}{\text{kWh}} \)

we arrive at a yearly solar energy per m² of:

\( 4,336,200 \frac{\text{kJ}}{\text{m}^2 \cdot \text{yr}} \)

Dividing 4,336,200 into \( 5.76 \times 10^{14} \) gives the forest area:

\( 132,835,200 \text{ m}^2 \)

or \( 11.525 \text{ km} \times 11.525 \text{ km} \)