Lecture 8
Gasification: Material and Heat Balance

The following diagram shows the input of materials like coal, air and steam in a gasifier and the outputs are producer gas, ashes, tar and soot.

Coal (wt%) Air (Moist)
C
H
O
N
H₂O
A

+ Steam

Ashes Tar (wt%) Soot (wt%)
Ash
+ Carbon

Producer Gas (vol%)
CO₂
CO
CH₄
N₂
H₂
H₂O
H₂S
C₆H₆
C₂H₄

A=Ash

Basis: 1000 Kg coal

a) Amount of producer gas

Carbon balance
C from coal = C in ashes + C in tar + C in soot + C in producer gas

b) To calculate amount of steam decomposed
- Decomposition of steam produces H₂.
- Moisture of coal directly enters into PG without being decomposed.
- Moisture of air and steam decompose to H₂ and is included in CH₄, H₂ and other hydrocarbons.

H balance
H from coal + H from Moisture of coal + H from steam + H from moist air = H in tar + H in PG (producer gas)

c) Water in producer gas = Moisture from coal + undecomposed steam

d) Nitrogen balance for amount of air

Oxygen balance if required to check the results of calculation.

e) Ash balance to know amount of ashes, if not given.
The raw hot gas from producer can be delivered through insulated mains as such to the furnaces and plants nearby.

Advantages: Both potential energy of gas (CV) and sensible heat, can be utilized. Also PE + sensible heat of tar and soot will also be available.

A more prevalent practise is to cool the gas and purify it to remove deleterious constituents. E.g. H$_2$S and then distribute to plants.

Cold gas efficiency = \( \frac{\text{Potential Energy (CV) of gas made} \times 100}{\text{Total heat input} = \text{CV of coal} + \text{sensible heat of coal, air, steam}} \)

Hot gas efficiency = \( \frac{(\text{PE of gas} + \text{sensible heat of gas} + \text{sensible heat of water vapour} + \text{PE of tar} + \text{PE of soot} + \text{sensible heat of tar} + \text{sensible heat of soot}) \times 100}{\text{Total heat input}} \)

Thermal efficiency = \( \frac{(\text{Potential energy of gas} + \text{enthalpy of steam produced}) \times 100}{\text{Total heat input}} \)

Cold gas efficiency = 60-80%
Hot gas efficiency = 90%
Losses = 9%
Determine Material and heat balance of a gasifier and calculate efficiencies. The analysis of various inputs and outputs are given. Temperatures of input and outputs are also given.

\[
\begin{align*}
\text{C} & = 79.1 \\
\text{H} & = 5.0 \\
\text{O} & = 6.4 \\
\text{N} & = 1.7 \\
\text{H}_2\text{O} & = 1.7 \\
\text{A} & = 6.1
\end{align*}
\]
\[\text{T} = 25^\circ\text{C}\]

\[
\text{Ashes} = 9\%\text{wt of coal}
\]

\[\text{Gas (vol\%)}\]
\[
\begin{align*}
\text{CO}_2 & = 7 \\
\text{CO} & = 21 \\
\text{CH}_4 & = 2.5 \\
\text{H}_2 & = 14 \\
\text{N}_2 & = 53 \\
\text{H}_2\text{O} & = 2.5
\end{align*}
\]

\[
\text{Air: RH} = 80\%
\]
\[
P_s\text{H}_2\text{O} = 26 \text{ mm Hg (25°C, 740 mm Hg)}
\]

Steam is blown in at 30.8 psig pressure with blast.

Mean specific heat of ashes \(= 0.21 \text{ Kcal/Kg K (25 – 180°C range)}\)

**Basis 1 Kg coal.**

**Volume of producer gas (fuel gas)**

Let \(Y\) Kg mole producer gas

\[
\text{C in coal} = \text{C in producer gas} + \text{C in ashes}
\]

\[
0.791/12 = (0.07 + 0.21 + 0.025) Y + (0.09 – 0.061)
\]

\[
Y = 0.208 \text{ Kg mole or } = 4.66 \text{ m}^3/\text{Kg coal (1 atm, 273K)}
\]

**Volume of air (moist)**

Let \(X\) Kg mole moist air

Since the air is moist, we have to calculate composition of air.

\[
P_{\text{N}_2} + P_{\text{O}_2} + P_{\text{H}_2\text{O}} = 740 \text{ mm Hg}
\]

\[
P_{\text{N}_2} + P_{\text{O}_2} = 740 – 0.8 \times 26
\]

\[
P_{\text{N}_2} + P_{\text{O}_2} = 719.2 \text{ mm Hg}
\]

\[
P_{\text{N}_2} = 568.168 \text{ mm}
\]

\[
P_{\text{O}_2} = 151.032 \text{ mm}
\]

\[
P_{\text{H}_2\text{O}} = 20.800 \text{ mm}
\]

**Composition of 1 Kg mole of moist air**

\[
\text{N}_2 = 0.7677
\]

\[
\text{O}_2 = 0.2041
\]

\[
\text{H}_2\text{O} = 0.0281
\]
N₂ balance

N in coal + N₂ from moist air = N₂ in Producer gas
0.017/28 + 0.7677X = 0.53 × 0.208
X = 0.14279 Kg mole or = 3.601 m³ (26°C and 740 mm Hg)

Weight of steam: Hydrogen balance

Consider Z Kg mole steam.
0.025 + 0.00094 + Z + 0.00401 = 0.004472
Z = 0.015 Kg mole
= 0.266 Kg steam/Kg coal

% H₂O blown in, that was decomposed

Water vapour in PG = Water from evaporation of M of coal + Water of undecomposed steam
0.025 × 0.208 = 0.017/18 + W
W = 0.004255 Kg mole undecomposed steam
Steam decomposed = [0.266 – (0.004255 × 18)]
= 0.1895 Kg

% steam blown, that is decomposed in producer gas = 0.1895 × 100/ 0.266 = 71.2%

NCV of producer gas

<table>
<thead>
<tr>
<th></th>
<th>Kg moles</th>
<th>Kcal/Kg mole</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.04368</td>
<td>− 67.6 × 103</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.0052</td>
<td>− 194.91 × 103</td>
</tr>
<tr>
<td>H₂</td>
<td>0.02912</td>
<td>57.8 × 103</td>
</tr>
</tbody>
</table>

NCV of coal

= 81 %C + 341 [%H − %O/8] − 5.84 (9 %H + M)
= 81 × 79.1 + 341 [5 − 6.4/8] − 5.84 (9 × 5 + 1.7)
= 7566.32 Kcal

Enthalpy of water vapour in moist air

H₂O(l) = H₂O(g)

Heat absorbed = 584 Kcal/Kg H₂O
= 584 × 1.7 /100
= 9.93 Kcal
Enthalpy of saturated steam:

Gauge pressure = 30.8 psi
Pressure 740 mm = 14.3 psi
Absolute pressure = 45.1 psi

Enthalpy of saturated steam at 45 psi referred to water at 0°C = 651 Kcal/Kg
Enthalpy difference between water at 25°C and water at 0°C = 24.94 Kcal/Kg
Enthalpy of steam referred to water at 25°C = 626 Kcal/Kg
Enthalpy of steam used = 626 × 0.266
= 166 Kcal

Enthalpy of water vapour in hot gas at 900K

\[
\begin{align*}
\text{H}_2\text{O} \ (l) = \text{H}_2\text{O} \ (g) & \quad \Delta H_{298}^o = 10.5 \text{ Kcal/g mole} \ \text{H}_2\text{O} \\
\text{H}_2\text{O} \ (g), \ 298K = \text{H}_2\text{O} \ (g), \ 900K & \quad \Delta H^o = 5.2 \text{ Kcal/g mole} \ \text{H}_2\text{O}
\end{align*}
\]

Enthalpy of water vapour referred to \(\text{H}_2\text{O} \ (l)\) = 15.7 Kcal/g mole \(\text{H}_2\text{O}\)

Enthalpy of water vapour in hot gas = \(15.7 \times 0.208 \times 1000 \times 2.5/100\)
= 81.64 Kcal

Sensible heat of dry producer gas at 900K

\[
\begin{align*}
\text{H}_{900} – \text{H}_{298} & \mid \text{CO}_2 = 6708 \text{ Kcal/Kg mole} \\
\text{H}_{900} – \text{H}_{298} & \mid \text{CO} = 4400 \text{ Kcal/Kg mole} \\
\text{H}_{900} – \text{H}_{298} & \mid \text{CH}_4 = 7522 \text{ Kcal/Kg mole} \\
\text{H}_{900} – \text{H}_{298} & \mid \text{H}_2 = 4224 \text{ Kcal/Kg mole} \\
\text{H}_{900} – \text{H}_{298} & \mid \text{N}_2 = 4358 \text{ Kcal/Kg mole}
\end{align*}
\]

Heat Balance

Heat Input:

<table>
<thead>
<tr>
<th>Input</th>
<th>Kcal</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV of coal</td>
<td>7566.32</td>
</tr>
<tr>
<td>Sensible heat in coal, air</td>
<td>0</td>
</tr>
<tr>
<td>Enthalpy of water vapour in air</td>
<td>9.93</td>
</tr>
<tr>
<td>Enthalpy of steam</td>
<td>166</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7742.25</strong></td>
</tr>
</tbody>
</table>
Heat Output:

<table>
<thead>
<tr>
<th>Output</th>
<th>Kcal</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV of dry PG</td>
<td>5640</td>
</tr>
<tr>
<td>Sensible heat of dry PG</td>
<td>932.8</td>
</tr>
<tr>
<td>Enthalpy of water vapour in hot gas</td>
<td>81.6</td>
</tr>
<tr>
<td>Heat losses</td>
<td>1087.85</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7742.25</strong></td>
</tr>
</tbody>
</table>

Cold gas efficiency = $\frac{5640 \times 100}{7742.25}$

= 72.85%

Hot Gas efficiency = $\frac{6653.6 \times 100}{7742.25}$

= 85.9 %

Thermal efficiency = $\frac{5721.6 \times 100}{7742.25}$

= 73.9%

Source for thermodynamic values:

H.Alan Fine and G.H.Geiger: Handbook of material and energy balance calculations in metallurgical processes

A. Butts Metallurgical problems (for more problems)

**Key words:** Materials and heat balance, Gas producer, Efficiency