Gassification material and heat balance

Basis

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.

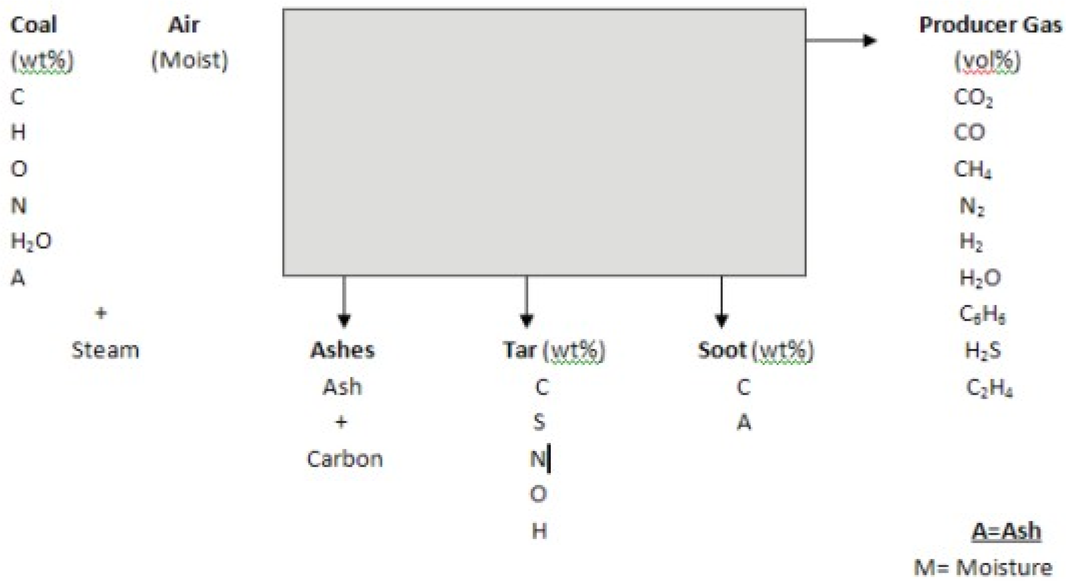

Figure 37.1: Material balance in gasification

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 H_2.
Moisture of coal directly enters into PG without being decomposed.
Moisture of air and steam decompose to H_2 and is included in CH_4, H_2 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. So that both potential energy of gas (CV) and sensible heat can be utilized. A more prevalent practisc is to cool the gas and purify it to remove deleterious constituents, for example H_2S and then distribute to plants.

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

Hot gas efficiency

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

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

Normally following efficiency values are reported in the literature:
Cold gas efficiency ≈ 60-80%
Hot gas efficiency ≈ 90%
Losses ≈ 9%

Illustration

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.

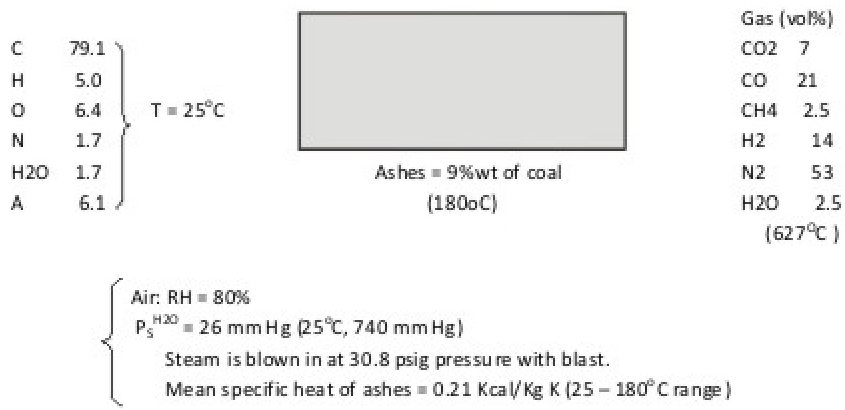

Figure 37.2: **Material balance diagram**

Basis 1 Kg coal.

<u>Volume of producer gas(fuel gas)</u>

Let Y Kg mole producer gas

C in coal = C in producer gas + C in ashes

$0.791/12 = (0.07 + 0.21 + 0.025)\ Y + (0.09 - 0.061)$

$Y = 0.208$ Kg mole or $= 4.66\ m^3$/Kg coal (1 atm, 273K)

<u>Volume of air (moist)</u>

Let X Kg mole moist air

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

$P_{N2} + P_{O2} + P_{H2O} = 740$ mm Hg

$P_{N2} + P_{O2} = 740 - 0.8 \times 26$

$P_{N2} + P_{O2} = 719.2$ mm Hg

$P_{N2} = 568.168$ mm

$P_{O2} = 151.032$ mm

$P_{H2O} = 20.800$ mm

Composition of 1 Kg mole of moist air

$N_2 = 0.7677$

O_2 = 0.2041
H_2O = 0.0281

N_2 balance

N in coal + N_2 from moist air = N_2 in Producer gas
0.017/28 + 0.7677X = 0.53 × 0.208
X = 0.14279 Kg mole or = 3.601 m^3 (26^oC 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

% H_2O 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

NVC pf producer gas

	Kg moles	Kg moles	
CO	0.04368	-67.6 X 103	NVC =5.64 X 103 Kcal
CH_4	0.0052	-194.91 X 103	
H_2	0.02912	57.8 X 103	

	Kg moles	Kcal/Kg mole	
CO	**0.04368**	**− 67.6 × 103**	**NCV = 5.64 × 103 Kcal**
CH_4	**0.0052**	**− 194.91 × 103**	
H_2	**0.02912**	**57.8 × 103**	

NCV of coal

= 81 %C + 341 [%H − %O/8] – 5.84 (9 %H + M)

$= 81 \times 79.1 + 341 [5 – 6.4/8] – 5.84 (9 \times 5 + 1.7)$
$= 7566.32$ Kcal

Enthalpy of water vapour in moist air

$H_2O_{(l)} = H_2O_{(g)}$

Heat absorbed = 584 Kcal/Kg H_2O
$= 584 \times 1.7 /100 = 9.93$ 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^oC = 651 Kcal/Kg
Enthalpy difference between water at 25^oC and water at 0^oC = 24.94 Kcal/Kg
Enthalpy of steam referred to water at 25^oC = 626 Kcal/Kg
Enthalpy of steam used = 626×0.266
= 166 Kcal

Enthalpy of water vapour in hot gas at 900K

$H_2O_{(l)} = H_2O_{(g)}$ $\Delta H^o_{298} = 10.5$ Kcal/g mole H_2O

$H_2O_{(g)}$, 298K = $H_2O_{(g)}$, 900K ΔH^o– 5.2 Kcal/g mole H_2O

Enthalpy of water vapour referred to $H_2O_{(l)}$ = 15.7 Kcal/g mole H_2O

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

$H_{900} – H_{298} | CO_2$ = 6708 Kcal/Kg mole

$H_{900} – H_{298} | CO$ = 4400 Kcal/Kg mole

$H_{900} – H_{298} | CH_4$ = 7522 Kcal/Kg mole

$H_{900} – H_{298} | H_2$ = 4224 Kcal/Kg mole

$H_{900} - H_{298} | N_2$ = 4358 Kcal/Kg mole

Heat Balance

Heat Input:

Input	Kcal
CV of coal	7566.32
Sensible heat in coal, air	0
Enthalpy of water vapour in air	9.93
Enthalpy of steam	166
Total	7742.25

Heat Output:

Output	Kcal
CV of dry PG	5640
Sensible heat of dry PG	932.8
Enthalpy of water vapour in hot gas	81.6
Heat losses	1087.85
Total	7742.25

Cold gas efficiency = 5640 ×100/7742.25
= 72.85%
Hot Gas efficiency = 6653.6 × 100/7742.25
= 85.9 %
Thermal efficiency = 5721.6 × 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)