Lecture 27: Material balance in Coke making

Illustration-I
Do yourself

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In coke-making, it is often required to calculate the amount of coke, coke oven gas and tar produced per ton of coal. This can be done by performing elemental balance. For this purpose ash, C, N, H and O balance can be done to obtain the require information. This is illustrated by the following problem

1. By product coke ovens are surrounded by air. There may occur leakage of air in the oven. Consider a coke- oven surrounded by moist air, (The air is at 750 mm Hg pressure and 26°C temperature) . The relative humidity of air is 40%. It carbonizes coal of the composition (Wt%) C76.1, H 4.6, N2.3, S 1.9,O 2.5, H_2O 6.3 and ash 6.3. The following product and by products are produced:

 Product: Coke (Wt %) C 85.2, H 1.9, O 2.2, N 0.8, S 1.2 and Ash 8.7

By –product: (a) Coke oven gas (vol % dry basis)

and C_6H_6 1.1,C_2H_4 2.7,CH_4 4.4, CO 1.7, CO_2 1.3, H_2 36.5, N_2 6.9, O_2 2, H_2S2.1 and $NH_3$1.3

(b) Tar (40 kg/ton of coal) analysis (Wt %)

C=89.4, H 4.5, N 1.1. and incombustibles Rest.

Required per ton of Coal

    i.   Amount of coke /ton of coal
    ii.   Amount of coke-oven gas
    iii.   fraction of S in coke and coke oven gas
    iv.   Amount of air leakage: The vapor pressure of moisture in air at saturation is 25.21 mmHg.
    v.   Calorific value in coke and coke oven gas in terms of fraction of calorific value of Coal.

Solution: Basis of calculation: 1000 kg coal

     i. Amount of coke /ton of coal

     Ash balance is used to determine the amount of coke. Let x kg is amount of coke.

$$\frac{6.3 \times 1000}{100} = \frac{x \times 8.7}{100}$$

$$\therefore x = 724.1 \text{ kg coke Answer.}$$

ii. Amount of coke oven gas can be calculated by performing C balance

C from coal= C in tar+ C in coke + C in Cokes oven gas

Let y kg is the amount of Cokes oven gas

$$\frac{761}{12} = \frac{0.894 \times 40}{12} + \frac{0.852 \times 724.1}{12} + y\,[6 \times 0.01 + 2 \times 0.027 + 0.344 + 0.117 + 0.013]$$

By solving we get y= 15.357 kg mole

iii. Sulphur distribution

a) f_s =fraction of S in coke $= \frac{S\ in\ coke}{S\ in\ coal} = 0.457$ Ans.

b) fraction of S in coke oven gas$= \frac{0.021 \times 15.357 \times 32}{0.019 \times 1000} = 0.543$ Ans.

iV. To calculate amount of air leaked in to coke oven. N_2 balance is to be done. N_2 is inert.

Let Z kg mole is amount of air leaked.

In this problem air is moist. We have to find composition of moist air. It follows drom Dalton's law;

$p_{N2} + p_{O2} + pH_2O = 750$ mm

Where p is partial pressure.

$(RH)\text{Relative humanitiy} = \frac{pH_2O}{p_{H_2O}^S} = \frac{\text{Vapour pressure of } H_2O \text{ in air}}{\text{Vapour pressure of H2O in air at saturation}}$

$P_{N2} + p_{O2} + RH \times p^S_{H2O} = 750$

Substituting the value of RH and p^S_{H2O}, we get after simplification

$\therefore pN_2 = 584.533, pO2 = 155.382$ and p H2O $= 10.084$

$\therefore \text{moles of } N_2 \text{ from moist air} = \frac{548.533}{750} = 0.7794$

N_2 from coal+ N_2 from air = N in coke + N in tar+ N_2 in coke oven gas

$$\frac{0.023 \times 1000}{28} + 0.7794\,Z = \frac{0.8}{100} \times \frac{724.1}{28} + \frac{0.011 \times 40}{28} + (0.069 + 0.0065) \times 15.357.$$

Solving: Z=20.84 kg air leaked Ans.

V.   Calorific value calculation

I Coal. First we have to convert ultimate analysis of moist coal to dry coal. (This is illustrated in Lecture 3).

Using Dulong's formula:

$$\text{GCV of coal} = 81 \times 81.22 + 341 \left(4.91 - \frac{2.67}{8}\right) + 22 \times 2.03$$

=8183.98 k cal/kg.

Similarly CV of coke and tar could be calculated.

GCV of coke = 7481.72 k cal/kg.

GCV of tar =8775.9k cal/kg.

Calorific Value of Coke oven gas: It can be determined by adding calorific values of all combustible components of Coke oven gas.

Combustible components Of coke oven gas	Heat of Combustion (k cal/kg mole)	Combustible components (kg mole).	Calorific value kcal.
C_6H_6	736×10^3	0.1689	124.3×10^3
C_2H_4	297.5×10^3	0.4146	123.4×10^3
CH_4	194.91×10^3	5.2830	1029.67×10^3
CO	67.6×10^3	1.796	121.4×10^3
H_2	57.8×10^3	5.605	323.97×10^3
H_2s	123.96×10^3	0.3225	39.98×10^3
NH_3	75.8×10^3	0.199	15.13×10^3.

Total 1778.85×10^3

$$\text{fraction of calorific value of coal in Coke (f1)} = \frac{7481 \times 724.1}{8183.98 \times 1000} = 0.6618$$

$$\text{fraction of calorific value of coal in tar (f2)} = \frac{8775.9 \times 40}{8183.98 \times 1000} = 0.0429$$

$$\text{fraction of calorific value of coal in coke oven gas (f3)} = \frac{1778.85 \times 10^3 \times}{8183.98 \times 10^3} = 0.2172$$

unaccounted calorific value of coal =1-(0.6618+0.0429+0.2172)=0.0781.

This shows that 7.81%of calorific value of coal is being utilized in raising temperatures of coke oven gas and tar to the discharge temperature.

Do Yourself

A by- product coke-oven carbonizes coal of the composition (Wt %) C 75.2, H 3.4, 0 5.8, N 3.5, H_2O 4.6 and ash 7.5. The Coke produced contains C 88.2%, H 0.2% and ash 11.6%. Tar contains 52kg carbon . The Coke-oven gas produced analysed
(vol % dry)CH_4 28.2, H_2, 56.4, C_2H_4 2.2, $C_6H_6$0.8, CO_2 1.7, CO 6.0, O_2 0.7 and N_2 4

Calculate ∴ per ton of coal.

    i.   Amount of coke
    ii.   Amount of coke oven gas.
    iii.   Fraction of calorific value of coal (a) in coke and (b) Coke- oven gas.

Answer:

    i.   647kg
    ii.   536 m^3 (1 atm, 273 K)
    iii.   (a) 0.63 (b) 0.34

Those interested to solve more problems, see the following book.

1. A. Butts Metallurgical problems.