13.

FUEL

DULONG'S FORMULA for HCV calculation

If C, H, O, & S are the % of C, H, O & S in a fuel, the HCV of fuel can be calculated as

$$HCV = \frac{1}{100}\left[8080\,C + 34500\left(H - \frac{O}{8}\right) + 2240\,S\right]$$

e.g. Calculate the GCV & NCV of coal having the following composition: C = 85%, H = 8%, S = 1%, N = 2% and ash = 4%. Latent heat of steam = 587 cal/g.

Soln. % O = 100 − % [C + H + S + N + ash] = 100 − 100 = 0 (zero)

$$HCV = \frac{1}{100}\left[8080 \times 85 + 34500\left(8 - \frac{0}{8}\right) + 2240 \times 1\right] \text{ cal/g}$$

$$= 6,86,800 + 2,76,000 + 2,240$$

$$= 9,650.4 \text{ cal/g}$$

$$LCV = HCV - 0.09\,H \times 587$$

$$LCV = 9650.4 - 0.09 \times 8 \times 587 \text{ cal/g}$$

$$= 9,650.4 - 422.64 \text{ cal/g}$$

$$LCV = 9227.76 \text{ cal/g}.$$

Bomb calorimeter

Q. 0.85 g of a fuel is burnt completely in excess supply of O_2. The increase in temp. of water in calorimeter containing 1800 g of water was found to be 3°C. Calculate the HCV of the fuel. Given that the water eq. of calorimeter etc. = 180g.

Sol^n. $HCV = \frac{(W+w)(t_2-t_1)}{m} = \frac{(1800+180)\times 3}{0.85} = 6988.23$ cal/g.

Q. The following data is obtained in a Bomb calorimeter expt :-

Wt of crucible = 3.649 g
Wt of crucible+fuel = 4.687 g
Water eq. of calorimeter = 570 g
Water taken in calorimeter = 2200 gm.
Observed rise in temp. = 2.3°C
Cooling correction = 0.047°C
Acid correction = 62.6 calories
Fuse wire correction = 3.8 calories
Cotton thread correction = 1.6 calories

Calculate the GCV of fuel sample. If the fuel contains 6.5% Hydrogen, determine NCV.

$$HCV = \frac{(2200+570)(2.3+0.047)-(62.6+3.8+1.6)}{4.687-3.649}$$

$$= \frac{(2200+570)\cdot(2770\times 2.347)-68}{1.029} = 6197.6 \text{ cal/g.}$$

Since the fuel contains 6.5% H

$$LCV = HCV - (0.09\times H\times 587) = 6197.6 - 0.09\times 6.5\times 587$$

$$= 5854.27 \text{ cal/g.}$$

Q. A sample of coal containing 80% C, 15% H, 5% ash is tested in a bomb calorimeter. The following results were obtained:

Wt of coal burnt = 0.98 g
Wt of water taken = 1000 g
water eq. of bomb & calorimeter = 2500 g
Rise in temp. = 2.5°C
Cooling correction = 0.02°C
Fuse wire " = 8.0 calories
Acid " = 50.0 "

Assuming the latent heat of condensation of steam as 580 cal/g, calculate (i) HCV, (ii) LCV of the fuel.

$$HCV = \frac{(1000+2500)(2.5+0.02)-(50+8)}{0.98} = 8940.82 \text{ cal/g}$$

$$LCV = HCV - 0.09 \times H \times 580$$
$$= 8940.82 - 0.09 \times 15 \times 580 = 8940.82 - 783$$
$$LCV = 8157.82 \text{ cal/g}$$

Ultimate Analysis

Q. 0.257 g of an organic substance was heated with conc H_2SO_4 and then distilled with excess of strong alkali. The NH_3 gas evolved was absorbed in 50 mL of N/10 HCl which required 23.2 mL of N/10 NaOH for neutralization at the end of the operation. Determine the % of N in the substance.

Soln. Vol. of N/10 HCl neutralized by NH_3 = 50 − 23.2 = 26.8 mL
(with NaOH) (used HCl with NH_3)

$$\% \text{ of } N = \frac{N \times V \times 1.4}{m} = \frac{0.1 \times 26.8 \times 1.4}{0.257} = 14.6\%$$

Q. 3.25 g of coal was Kjeldahlised and NH_3 gas that evolved was absorbed in 45 mL of 0.1 N H_2SO_4. To neutralise excess acid, 11.5 mL of 0.1 N NaOH was required. Determine the % of N in coal sample.

Soln. Vol. of 0.1 N H_2SO_4 neutralised by NH_3 = 45 − 11.5 = 33.5 mL

$$\% \text{ of } N = \frac{N \times V \times 1.4}{m} = \frac{0.1 \times 33.5 \times 1.4}{3.25} = 1.44\%$$

Proximate Analysis:

Q. A sample of coal was analysed as follows: Exactly 1.40 g was weighed into a silica crucible. After heating for 1 hr at 105–110°C, the residue weighed 1.10 g. The crucible next was covered with a vented lid and strongly heated for exactly 7 min. at 950 ± 20°C. The residue was weighed 1.00 g. The crucible was then heated without cover, until a constant weight was obtained. The last residue was found to weight 0.21 g. Calculate the ash content, moisture content, volatile matter and % of fixed carbon.

Soln. wt of moisture in coal = 1.40 − 1.10 = 0.30 gm.

wt of volatile matter = 1.10 − 1.00 = 0.10 gm.

wt of ash = 0.21 gm.

$$\% \text{ of moisture} = \frac{0.30}{1.4} \times 100 = 21.4\%$$

$$\% \text{ of volatile matter} = \frac{0.10}{1.4} \times 100 = 7.14\%$$

$$\% \text{ of Ash} = \frac{0.21 \times 100}{1.4} = 15\%$$

$$\% \text{ of fixed carbon} = 100 - (21.4 + 7.14 + 15) = 56.46\%$$

Dulong's method.

Q. A coal has the following composition by wt: C = 92%, O = 2%, S = 0.5%, N = 0.5% and ash = 1.5%. NCV of the coal was found to be 9430 Kcal/kg. Calculate the % of H & HCV.

1st Method.

$$HCV = \frac{1}{100}\left[8080 \times 92 + 34500\left[H - \frac{2}{8}\right] + 2240 \times 0.5\right]$$

$$= [7433.60 + 345 \times H - 86.25 + 11.2]$$

$$= [7358.55 + 345 \times H] \quad \text{---(I)}$$

Also $HCV = NCV + 0.09 \times H \times 587$

$HCV = 9430 + 0.09 \times H \times 587 = 9430 + 52.83 \times H$ ---(II)

from (I) & (II)

$$7358.55 + 345 \times H = 9430 + 52.83 \times H$$

$$292.17 \times H = 2071.45$$

$$\% \text{ of } H = \frac{2071.45}{292.17} = 7.089\%$$

$$HCV = (7358.55 + 345 \times H)$$

$$= 7358.55 + (345 \times 7.089)$$

$$= 9804.6 \text{ Kcal/kg}$$

IInd method.

$$\% \text{ of } O = 100 - \% [C + H + N + S + ash]$$

$$\% H = 100 - \% [C + O + N + S + ash]$$

$$= 100 - [92 + 2 + 0.5 + 0.5 + 1.5]$$

$$\% H = 3.5$$

$$LCV = HCV - (0.09 \times H \times 587)$$

$$HCV = LCV + (0.09 \times H \times 587)$$

$$= 9430 + (0.09 \times 3.5 \times 587)$$

$$= 9614 \text{ Kcal/kg}$$

Dulong's method

Q. Calculate the GCV & NCV of the coal having the following compositions :-

C = 85%, H = 7%, S = 1%, N = 2% ash = 4% & heat capacity of steam = 2458 J/g.

$\% O = 100 - \%(C + N + S + H + ash)$

$= 100 - (85 + 2 + 1 + 7 + 4) = 1\%$

$GCV = \frac{1}{100}\left[8080 \times C + 34400\left(H - \frac{O}{8}\right) + 2240 S\right)$

$= \frac{1}{100}\left[8080 \times 85 + 34500\left(7 - \frac{1}{8}\right) + 2240 \times 1\right]$

$= \frac{1}{100}\left[686800 + 237187.5 + 2240\right]$

$= 9262.27$ cal/g.

Heat capacity of steam = 2458 J/g $= \frac{2458}{4.184} = \underline{\underline{588}}$ cal/g.

$\left[1 J = \frac{1}{4.184} cal\right]$

NCV = HCV − 0.09 × H × 588

= 9262.27 − 0.09 × 7 × 588

= $\underline{\underline{8891.81}}$ cal/g.

Q. A coal sample has the following composition's by wt :
C = 90%, O = 3%, S = 0.5%, N = 0.5% and ash = 2.5%.
LCV of fuel was found to be 8,490.5 Kcal/kg.
Calculate % of H & HCV.

NOTE: Water eq. of a calorimeter is defined as the no. of calories required to heat the calorimeter by 1°C. If M is the mass of the calorimeter and S be. its specific heat, then water eq. $w = M \times S$

If the calorimeter is made of different parts having different sp. heats S_1, S_2, S_3 etc. and different masses M_1, M_2, M_3 etc. then, water equivalent $= M_1 S_1 + M_2 S_2 +$ ...

Bomb calorimeter (water equivalent calculation)

Q. The following data were obtained in a bomb calorimeter experiment. Wt of coal burnt = 0.994 g
Wt of water in calorimeter = 2592 g
Wt of Bomb, calorimeter etc. = 3940 g
Rise in temp. = 2.732°C
Mean sp. heat of the apparatus = 0.098
Find the GCV of the fuel. If the fuel contains 8% H, calculate its lower cal. value (Latent heat of condensation of steam = 587 cal/g).

Soln: Wt of fuel, $x = 0.994$ g
Wt of water, $W = 2592$ g
Wt of apparatus = 3940 g
Mean specific heat of apparatus = 0.098

∴ Water eq. of apparatus, $w = 3940 \times 0.098 = 386.12$
Rise in temp. of water = 2.732°C

$$GCV = \frac{(W+w)(t_2-t_1)}{x} = \frac{(2592+386.12)(2.732)}{0.994} = 8185.3 \text{ cal/g}$$

$$NCV = HCV - 0.09H \times 587 \text{ cal/g}$$
$$= 8185.3 - 0.09 \times 8 \times 587 \text{ cal/g}$$
$$= 8185.3 - 422.64 \text{ cal/g} = 7762.6 \text{ cal/g}$$

Ultimate Analysis

Q. Calculate S% in coal when 0.55 g of coal is combusted in Bomb calorimeter. Solution from Bomb on treatment with $BaCl_2$ solution forms 0.025 g $BaSO_4$.

Soln $$S\% = \frac{\text{Wt of } BaSO_4 \text{ ppt}}{\text{Wt of coal}} \times \frac{32}{233} \times 100$$

$$= 62\%.$$

Q. Calculate GCV and NCV of coal having the following compositions :-
C = 85%, H = 7%, S = 1%, N = 2% ash = 4% and heat capacity of steam = 2458 J/g

Soln % of O = 100 - (C% + N% + S% + H% + Ash%)

$$= 100 - (85 + 2 + 1 + 7 + 4) = 1\%$$

$$GCV = \frac{1}{100}\left[8080 \times C + 34500\left(H - \frac{O}{8}\right) + 2240 \times S\right]$$

$$= \frac{1}{100}\left[8080 \times 85 + 34500\left(7 - \frac{1}{8}\right) + 2240 \times 1\right]$$

$$= \frac{1}{100}\left[686800 + 237187.5 + 2240\right]$$

$$= 9262.27 \text{ Cal/g}$$

Heat capacity of steam = 2458 J/g

1 Cal = 4.18 J

or 4.18 J = 1 cal

$$2458 \text{ J} = \frac{1}{4.18} \times 2458 = 588 \text{ cal/g}$$

$$NCV = GCV - \frac{9}{100} \times H \times \text{Latent heat of steam}$$

$$= 9262.27 - \frac{9}{100} \times 7 \times 588$$

$$= 8891.81 \text{ Cal/g}.$$

Combustion

Combustion is an exothermic chemical reaction which is accompanied by the development of heat and light at a rapid rate, leading to the rise in temp.

Fuel + O_2 → Products + heat
(more heat content) (lower heat content)

for eg. C + O_2 → CO_2 + 394 KJ
(12 g)

The amount of O_2 required and air required for calculated combustion of a certain amount of fuel are calculations are done on the basis of mole concept.

- C + O_2 → CO_2
  (12 g) (32 g)
- S + O_2 → SO_2
  (32 g) (32 g)
- H_2 + $\frac{1}{2}O_2$ → H_2O
  (2 g) (16 g)

- CH_4 + $2O_2$ → CO_2 + $2H_2O$
  (16 g) (64 g)
  1 vol 2 vol.
- C_2H_6 + $\frac{7}{2}O_2$ → $2CO_2$ + $3H_2O$
  (30 g) (112 g)
  1 vol $\frac{7}{2}$ vol.
- C_3H_8 + $5O_2$ → $3CO_2$ + $4H_2O$
  1 vol 5 vol
- CO + $\frac{1}{2}O_2$ → CO_2
  (28 g) (16 g)
  1 vol $\frac{1}{2}$ vol.

Following facts are taken into account :-

1- 1 gm-mole of a gas (molar mass) at STP ($0^\circ C$ (T) & 760 mm (P)) occupies 22.4 L volume.

2- Air contains 21% O_2 by volume & 23% O_2 by wt.

3- O_2 required for combustion = Theoritical O_2 req. − O_2 present in fuel.

4- H_2, S, CO, CH_4, C_2H_6, C_2H_4, S_2H_2 are combustible matter and requires O_2/air for combustion. While N_2, ash & CO_2 present in fuel are non-combustible hence do not take any O_2/air.

5- The mean molar mass of air = 28.94 g/mol.

For Solid & Liquid fuels :-

1. $\text{wt of } O_2 \text{ req.} = \frac{32}{12} \times C + 8 \times H + S - O$ g O_2 by wt
(g)

Where C, H, S & O are quantities (%) of elements in fuel in g.

2. $\text{wt of air req.} = \frac{\text{wt of } O_2 \text{ req.} \times (100 + \%\text{ excess air req.})}{23}$
(g)

3. $\text{Volume of } O_2 \text{ req.} = \frac{22.4}{32} \times \text{wt of } O_2 \text{ req.}$
(L)

4. $\text{Volume of air req.} = \frac{\text{Vol. of } O_2 \text{ req.} \times (100 + \%\text{ excess air})}{21}$
(L)

Numericals :-

Q. calculate the wt and volume of air required for the combustion of 1 kg of carbon.

Soln. $C + O_2 \rightarrow CO_2$
12g 32g

(1) wt of O_2 req. $= \frac{32}{12} \times 1000\,g = 2667\,g.$

(2) wt of air req. $= \frac{\text{wt of } O_2 \text{ req.} \times (100 + \%\text{ excess air})}{23}$

$= \frac{2667 \times 100}{23} = 11590\,g. = 11595\,g$

(3) Vol. of $O_2 = \frac{22.4}{32} \times \text{wt of } O_2 \text{ req.}$

$= \frac{22.4}{32} \times 2667 = 1866.9\,L.$

4. Vol. of air $= \frac{\text{Vol. of } O_2 \text{ req.} \times 100 + \%\text{ excess air}}{21}$
O_2

$= \frac{1866.9 \times 100}{21} = 8890\,L. = 8.89\,m^3$

8888.9.

$1\,cm^3 = 1\,mL$
$1\,dm^3 = 1\,L$
$1\,m^3 = 1000\,L$
$= 1$ KiloLitre
or $1\,L = \frac{1}{1000}\,m^3$

8, 18, 25
35, 36
38,

2. Calculate the mass of air needed for complete combustion of 5 kg of coal containing 80% C, 15% H₂ rest O₂. (3)

Soln: 5 kg coal contains C = $\frac{80}{100} \times 5 = 4$ kg = 4000 g

H = $\frac{15}{100} \times 5 = 750$ g

Rest Oxygen = 100 − (80+15) = 5%

= $\frac{5}{100} \times 5 = 250$ g.

O_2 req. for combustion = ~~Theoritical~~

$\frac{32}{12} \times C + 8 \times H + S - O$ g O_2.

= $\frac{32}{12} \times 4000 + 8 \times 750 + 0 - 250$

= 16416.7 g

wt of air req. = $\frac{O_2 \text{ req. (wt)} \times (100 + \% \text{ excess air})}{23}$

= $\frac{16416.7 \times 100}{23} = 71376.8$ g

= 71.3768 kg.

(3) Percentage composition of coal sample is :- C = 80%, H_2 = 4%. O_2 = 3%, N_2 = 3%, S = 2%, Ash = 5%, ~~moisture~~ 3%. Calculate the quantity of air needed for complete combustion of 1 kg of coal, if 60% excess air is supplied.

Soln: 1 kg coal contains :- C = 800 g, H = 40 g, S = 20 g, O = 30 g

(N_2, Ash, ~~moisture~~ are not taken)

Net O_2 req. = $\left(\frac{32}{12} \times 800 + 8 \times 40 + 20\right) - 30 = 2443.3$ g

($\frac{32}{12} \times 800$: C; 8×40 : H; 20 : S; 30 : O)

Air req. = $\frac{\text{wt of } O_2 \text{ req.} \times (100 + \% \text{ excess air})}{23}$

= $\frac{2443.3 \times (100+60)}{23} = 16996.9$ g

= 16.99 kg.

For gaseous fuels :-

- Vol. of O_2 req. (m^3) = Vol. of component in gaseous fuel (m^3) × Vol. of O_2 req. per m^3 vol. of gas component

Volume of Air req. = $\frac{\text{Vol. of } O_2 \text{ req. } (m^3) \times (100 + \%\text{ excess air})}{21}$

Q. A LNG has following composition -
Propane = 30%, butane = 35%, Pentane = 15%,
Hexane = 16%, CO = 3% & H_2O = 1%
Find 5% excess air volume and wt req. for combustion of $2 m^3$ of gas

Sol^n. vol. of propane = $\frac{30}{100} \times 2 = 0.6\ m^3$

butane = $\frac{35}{100} \times 2 = 0.7 m^3$

pentane = $\frac{15}{100} \times 2 = 0.3 m^3$

vol. of hexane = $\frac{16}{100} \times 2 = 0.32\ m^3$

vol. of CO = $\frac{3}{100} \times 2 = 0.06 m^3$

Vol. of O_2 req. = $0.6 \times 5 = 3 m^3$

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$
1 vol . 5 vol.

$C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O$
1 6.5 $\longrightarrow 0.7 \times 6.5 = 4.55 m^3$

$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$
1 8 vol $\longrightarrow 0.3 \times 8 = 2.4 m^3$

$C_6H_{14} + 9.5O_2 \rightarrow 6CO_2 + 7H_2O$
1 9.5 $\longrightarrow 0.32 \times 9.5 = 3.04 m^3$

$CO + 0.5O_2 \rightarrow CO_2$
1 0.5 $\longrightarrow 0.06 \times 0.5 = 0.03 m^3$

Total O_2 req $= 13.02 m^3$.

Vol. of air req. (m^3) = $\frac{\text{Vol. of } O_2\ (m^3) \times 100 + \%\text{ excess air}}{21}$

$= \frac{13.02 m^3 \times 100 + 5}{21} = 65.1 m^3$ air

Wt of air req. (kg) = 22.4 L of air = 28.94 g

$(1 m^3 = 1000 L)$

$65.1 \times 1000 L = \frac{28.94}{22.4} \times 65.1$

$= 84.10$ kg