

FUELDULONG'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

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

e.g. Calculate the GCV & HCV 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  $\rightarrow$  % O =  $100 - \% [C + H + S + N + \text{ash}] = 100 - 100 = 0$  (zero)

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

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

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

$$\text{LCV} = \text{HCV} - 0.09 H \times 587$$

$$\text{LCV} = 9,650.4 - 0.09 \times 8 \times 587 \text{ cal/g}$$

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

$$\text{LCV} = 9,227.76 \text{ cal/g}$$

Bomb calorimeter  
 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  $3^\circ C$ . Calculate the HCV of the fuel. Given that the water eq. of calorimeter etc. = 180 g.  
 Sol<sup>n</sup>  $HCV = \frac{(W+w)(t_2-t_1)}{m} = \frac{(1800+180) \times 3}{0.85} = 6988.23 \text{ cal/g.}$

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. =  $2.3^\circ C$   
 Cooling correction =  $0.047^\circ C$   
 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 HCV.

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

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

Since the fuel contains 6.5% H  
 $LCV = HCV - (0.09 \times H \times 587) = 6197.6 - 0.09 \times 6.5 \times 587$   
 $= 6258.54.27 \text{ cal/g.}$

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. =  $2.5^\circ C$   
 Cooling correction =  $0.02^\circ C$   
 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  $NH_3 = 50 - 23.2 = 26.8 \text{ mL}$   
(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  $NH_2SO_4$ . 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  $NH_2SO_4$  neutralised by  $NH_3 = 45 - 11.5 = 33.5 \text{ mL}$

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

### 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  $105-110^\circ C$ , the residue weighed 1.10 g. The crucible next was covered with a vented lid and strongly heated for exactly 7 min. at  $950 \pm 20^\circ C$ . 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 weigh 0.21 g. Calculate the ash content, moisture content, volatile matter and % of fixed carbon.

Soln. wt of moisture in coal =  $1.40 - 1.10 = 0.30 \text{ gm}$ .

wt of Volatile matter =  $1.10 - 1.00 = 0.10 \text{ gm}$ .

wt of ash =  $0.21 \text{ gm}$ .

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

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

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

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

### 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.

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

$$= [7433.66 + 345 \times H - 86.25 + 11.2]$$

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

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

$$HCV = 9430 + 0.09 \times H \times 587 = 9430 + 52.83 \times H \quad \text{--- (ii)}$$

from (i) & (ii)

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

$$292.17 \times H = 2071.45$$

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

$$\begin{aligned} HCV &= (7358.55 + 345 \times H) \\ &= 7358.55 + (345 \times 7.089) \\ &= \underline{9804.6 \text{ Kcal/kg}} \end{aligned}$$

2nd method.

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

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

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

$$\% H = \underline{3.5}$$

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

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

$$\begin{aligned} HCV &= 9430 + (0.09 \times 3.5 \times 587) \\ &= \underline{9614 \text{ Kcal/kg}} \end{aligned}$$

Q. Calculate the GCV & NCV of the coal having the following composition:-  
 $C = 85\%$ ,  $H = 7\%$ ,  $S = 1\%$ ,  $N = 2\%$ , ash =  $4\%$  & heat capacity of steam =  $2458 \text{ J/g}$ .

$$\begin{aligned}\% O &= 100 - (C + N + S + H + \text{ash}) \\ &= 100 - (85 + 2 + 1 + 7 + 4) = 1\%.\end{aligned}$$

$$\begin{aligned}\text{GCV} &= \frac{1}{100} [8080 \times C + 34400 (H - \frac{O}{8}) + 2240 S] \\ &= \frac{1}{100} [8080 \times 85 + 34500 (7 - \frac{1}{8}) + 2240 \times 1] \\ &= \frac{1}{100} [686800 + 237187.5 + 2240] \\ &= 9262.27 \text{ cal/g}\end{aligned}$$

$$\text{Heat capacity of steam} = 2458 \text{ J/g} = \frac{2458}{4.184} = \frac{588 \text{ cal}}{1 \text{ g}} \quad \left[ 1 \text{ J} = \frac{1}{4.184} \text{ cal} \right]$$

$$\begin{aligned}\text{NCV} &= \text{GCV} - 0.09 \times H \times 588 \\ &= 9262.27 - 0.09 \times 7 \times 588 \\ &= \underline{\underline{8891.81 \text{ cal/g}}}.\end{aligned}$$

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



NOTE: Water eq. of a calorimeter is defined as the no. of calories required to heat the calorimeter by  $1^{\circ}\text{C}$ . If  $M$  is the mass of the calorimeter and  $S$  is 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  $= M_1 S_1 + M_2 S_2 + \dots$  (water equivalent calculation)

Q. The following data were obtained in a bomb calorimeter experiment.

Wt of coal burnt  $= 0.994 \text{ g}$

Wt of water in calorimeter  $= 2592 \text{ g}$

Wt of Bomb, calorimeter etc.  $= 3940 \text{ g}$

Rise in temp.  $= 2.732^{\circ}\text{C}$

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  $= 587 \text{ cal/g}$ ).

Soln: Wt of fuel,  $x = 0.994 \text{ g}$

Wt of water,  $W = 2592 \text{ g}$

Wt of apparatus  $= 3940 \text{ g}$

Mean specific heat of apparatus  $= 0.098$

$\therefore$  Water eq. of apparatus,  $w = 3940 \times 0.098 = 386.12$

Rise in temp. of water  $= 2.732^{\circ}\text{C}$

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

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

$$= 8185.3 - 0.09 \times 8 \times 587 \text{ cal/g}$$

$$= 8185.3 - 422.64 \text{ cal/g} = 7762.6 \text{ cal/g}$$

### Ultimate Analysis

Q. Calculate S% in coal when 0.55 g of coal is combusted in Bomb Calorimeter. Solution from Bomb on treatment with  $\text{BaCl}_2$  solution forms 0.025 g  $\text{BaSO}_4$ .

Sol<sup>n</sup>

$$\text{S\%} = \frac{\text{wt of BaSO}_4 \text{ PPR}}{\text{wt of coal}} \times \frac{32}{233} \times 100$$
$$= 62\%$$

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

Sol<sup>n</sup>

$$\% \text{ of O} = 100 - (\text{C\%} + \text{N\%} + \text{S\%} + \text{H\%} + \text{Ash\%})$$
$$= 100 - (85 + 2 + 1 + 7 + 4) = 1\%$$

$$\text{GCV} = \frac{1}{100} [8080 \times \text{C} + 34500 (\text{H} - \frac{\text{O}}{8}) + 2240 \times \text{S}]$$
$$= \frac{1}{100} [8080 \times 85 + 34500 (7 - \frac{1}{8}) + 2240 \times 1]$$

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

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

Heat capacity of steam = 2458 J/g

$$1 \text{ Cal} = 4.18 \text{ J}$$

$$\text{or } 4.18 \text{ J} = 1 \text{ Cal}$$

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

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

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

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

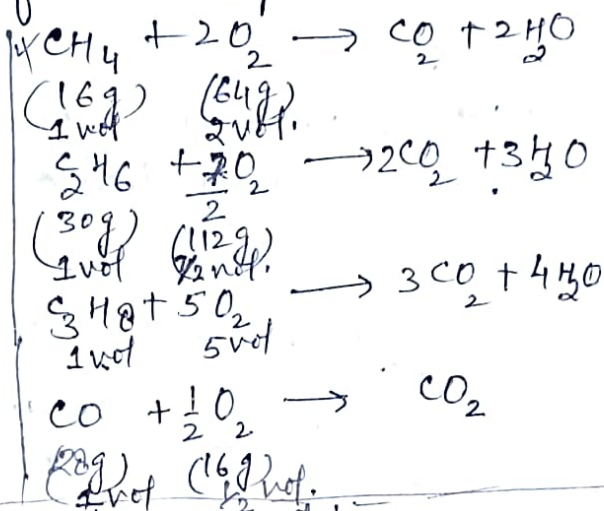
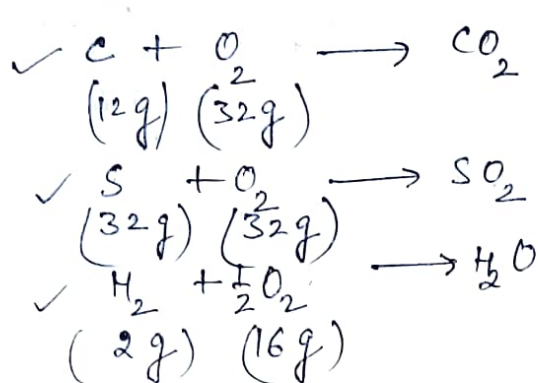
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## Combustion

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.



The amount of  $\text{O}_2$  required and air required for combustion of a certain amount of fuel are calculated on the basis of mole concept.



Following facts are taken into account! =

- 1- 1 gm mole of a gas (molar mass) at STP ( $0^\circ\text{C}$  &  $760\text{mm}$ ) occupies 22.4 L volume.  
(T) (P)
- 2- Air contains 21%  $\text{O}_2$  by volume & 23%  $\text{O}_2$  by wt.
- 3-  $\text{O}_2$  required for combustion = Theoretical  $\text{O}_2$  req. -  $\text{O}_2$  present in fuel.
- 4-  $\text{H}_2$ , S, CO,  $\text{CH}_4$ ,  $\text{C}_2\text{H}_6$ ,  $\text{C}_2\text{H}_4$ ,  $\text{C}_2\text{H}_2$  are combustible matters and require  $\text{O}_2$ /air for combustion. While  $\text{N}_2$ , ash &  $\text{CO}_2$  are present in fuel are non-combustible hence do not take any  $\text{O}_2$ /air.
- 5- The <sup>mean</sup> molar mass of air = 28.94 g/mol.

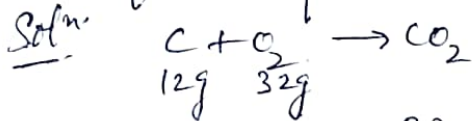


For Solid & Liquid fuels:-

1.  $\text{Wt of } O_2 \text{ req. (g)} = \frac{32}{12} \times C + 8 \times H + S - O$  g  $O_2$  by wt  
where C, H, S & O are quantities (%) of elements in fuel in g.
2.  $\text{Wt of air req. (g)} = \frac{\text{Wt of } O_2 \text{ req. (g)} \times (100 + \% \text{ excess air req.})}{23}$
3.  $\text{Volume of } O_2 \text{ req. (L)} = \frac{22.4}{32} \times \text{Wt of } O_2 \text{ req. (g)}$
4.  $\text{Volume of air req. (L)} = \frac{\text{Vol. of } O_2 \text{ req. (L)} \times (100 + \% \text{ excess air})}{21}$

Numericals:-

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



①  $\text{Wt of } O_2 \text{ req.} = \frac{32}{12} \times 1000g = 2667g.$

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

$= \frac{2667 \times 100}{23} = 11595.6g. = 11595g$

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

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

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

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

8888.9.

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

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% H and rest  $O_2$ . (3)

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

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

Rest Oxygen =  $100 - (80 + 15) = 5\%$   
 $= \frac{5}{100} \times 5 = 250 \text{ g}$

$O_2$  req. for combustion = ~~Theoretical~~

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

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

$= 16416.7 \text{ g}$

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

$= \frac{16416.7 \times 100}{23} = 71376.8 \text{ g}$   
 $= 71.3768 \text{ kg}$

③ Percentage composition of coal sample is :-  
 C = 80%, H = 4%,  $O_2$  = 3%,  $N_2$  = 3%, S = 2%, Ash = 5%,  
 moisture = 2%. 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,  $O_2$  = 30 g  
 ( $N_2$ , Ash, moisture are not taken)

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

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

$= \frac{2443.3 \times (100 + 60)}{23} = 16996.9 \text{ g}$   
 $= 16.99 \text{ kg}$

For gaseous fuels :-

$$\text{Vol. of } O_2 \text{ req. (m}^3\text{)} = \frac{\text{Vol. of component in gaseous fuel (m}^3\text{)} \times \text{Vol. of } O_2 \text{ req. per m}^3 \text{ Vol. of gas. fuel component}}{1}$$

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

Q. A LNG has following composition -

Propane = 30%, butane = 35%, pentane = 15%,

Hexane = 16%, CO = 3% &  $H_2O = 1\%$

Find 5% excess air volume req. for combustion of 2 m<sup>3</sup> of gas

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

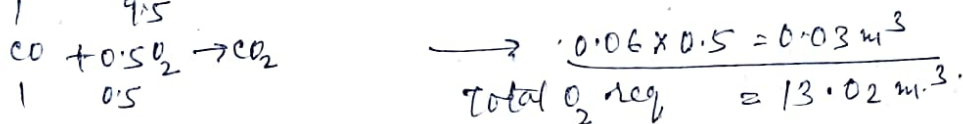
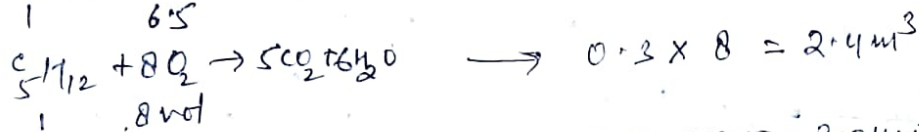
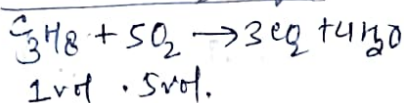
butane =  $\frac{35}{100} \times 2 = 0.7 \text{ m}^3$

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

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

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

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



$\rightarrow 0.06 \times 0.5 = 0.03 \text{ m}^3$   
Total  $O_2$  req =  $13.02 \text{ m}^3$

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

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

wt of air req. (kg) =  $22.4 \text{ L of air} = 28.94 \text{ g}$   
(1 m<sup>3</sup> = 1000 L)  $65.1 \times 1000 \text{ L} = \frac{28.94 \times 65.1}{22.4} = 84.10 \text{ kg}$