

UNIT 4 (Hardness of water, Fuels and Combustion)

SHORT QUESTIONS

Q1. Define Hardness. Why is it conventional to express hardness in terms of CaCO_3 at the international level? Write other units also. OR Why hardness of water is expressed in terms of CaCO_3 equivalents. Give different units of hardness with their interrelation. (2018-19, 2015-16)

Ans. Hardness is defined as soap consuming property which is due to excess amount of salts of calcium, magnesium and other elements dissolved in water.

Hardness of water is expressed in terms of CaCO_3 because of the following reasons:

1. Molecular weight of CaCO_3 is 100 (Equivalent wt is 50) which makes the calculation easy.
2. CaCO_3 is most insoluble salt that can be precipitated in water treatment.

Units of hardness:

1. Parts per million (ppm)
2. Milligrams per litre (mg/L)
3. Degree french ($^\circ\text{F}$)
4. Degree Clarke ($^\circ\text{Cl}$)

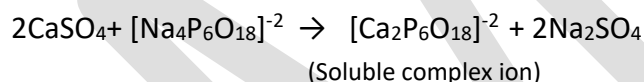
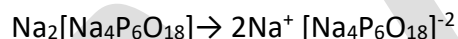
$$1\text{ppm} = 1\text{mg/L} = 0.1^\circ\text{F} = 0.07^\circ\text{Cl}$$

Q2. Show with the help of reactions how scale formation can be prevented by calgon conditioning. OR What is calgon conditioning? Explain.(2018-19, 2017-18)

Ans. Calgon Conditioning: Calgon means calcium gone.

Sodium hexa-meta phosphate $\text{Na}_2[\text{Na}_4\text{P}_6\text{O}_{18}]$ is called calgon.

It reacts with calcium ion and forms a water soluble compound.



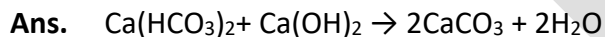
Q3. Explain why value of GCV is greater than NCV? (2018-19, 2011-12)

Ans. In GCV latent heat of steam is also included whereas NCV is calculated as:

$$\text{NCV} = \text{GCV} - \% \text{H} \times .09 \times \text{Latent heat of steam}$$

It clearly shows that GCV is greater than NCV.

Q4. Why does magnesium bicarbonate requires double the amount of lime for softening as compared to calcium bicarbonate? (2018-19)



Q5. Explain when will the value of GCV=NCV? (2017-18)

Ans. LCV will be equal to GCV when the percentage of hydrogen is zero.

$$\text{LCV} = \text{GCV} - 0.09(\% \text{H}) \times \text{Latent heat of steam}$$

$$\text{LCV} = \text{GCV} - 0.09(0) \times \text{Latent heat of steam}$$

$$\text{LCV} = \text{GCV} - 0$$

$$\text{LCV} = \text{GCV}$$

Q6. Define Gross Calorific Value and Net Calorific Value. (2017-18, 2016-17, 2014-15)

Ans. Higher or gross calorific value: HCV is “the total amount of heat produced, when unit mass/volume of the fuel has been burnt completely and the products of combustion have been cooled to room temperature”(i.e., 15°C or 60°F).

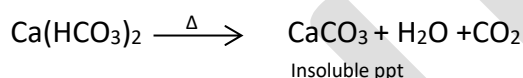
Lower or net calorific: LCV is “the net heat produced, when unit mass /volume of the fuel is burnt completely and the products are permitted to escape”.

$$\text{NCV} = \text{GCV} - \% \text{ H} \times .09 \times \text{Latent heat of steam}$$

Q7. How many types of hardness is there? OR What is meant by temporary and permanent hardness? How can they be removed? OR What is permanent hardness? Write the constituents responsible for it. (2015-16, 2014-15)

Ans. There are two types of hardness: Temporary hardness and permanent hardness.

Temporary hardness: Hardness in water due to presence of bicarbonates and carbonates of calcium and magnesium is known as Temporary hardness. It can be removed by mere boiling of water.



Permanent hardness: Hardness in water due to presence of chlorides, and sulphates of calcium and magnesium and traces of other heavy metal ion is known as permanent hardness.

It cannot be removed by boiling of water and requires certain special treatment methods like Zeolite method, Ion exchange process, Lime soda process etc.

Q8. How boiling removes the temporary hardness?

Ans. On boiling all the bicarbonates of calcium and magnesium dissolved in water which are responsible for temporary hardness are converted into their insoluble carbonates which can be easily filtered off.

**Q9. Distinguish between scales and sludges. OR Describe sludge and scales OR**

Explain the process of scale and sludge formation in boilers. How can this be prevented? (2016-17, 2014-15)

Ans.

Sludge	Scale
It is soft, loose and slimy precipitate.	It forms hard deposits.
They form non-adherent deposits and can be easily removed.	They stick firmly to the inner surface of the boiler and are very difficult to remove.
They are formed by substances like CaCl_2 ,	They are formed by substances like CaSO_4 ,

MgCl₂, MgSO₄, MgCO₃, etc.

They are formed at comparatively colder portions of the boiler.

They decrease efficiency of boiler but are less dangerous.

They can be removed by blow down operation.

Mg(OH)₂ etc.

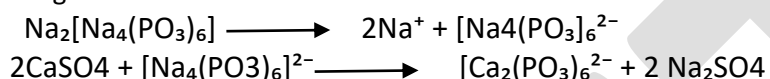
They are formed at heated portions of the boiler.

They decrease efficiency of boiler and chances of explosion are also there.

They can't be removed by blow down operation.

Q10. Why is calgon conditioning better than phosphate conditioning? (2018-19, 2017-18, 2015-16, 2012-13)

Ans. In calgon Conditioning, the added calgon forms soluble complex compound with CaSO₄, thereby it prevents the scale and sludge formation in water.



This soluble complex does not cause any problem in boilers. On the other hand, in phosphate conditioning, Sodium phosphate is added to the boiler water so that precipitate of calcium phosphate is formed, which forms sludge and needs frequent blow down operations to remove it.

Q11. What is meant by calorific value of a fuel? What are its units? (2015-16, 2014-15)

Ans. Calorific value of a fuel is "the total quantity of heat liberated, when a unit mass (or volume) of the fuel is burnt completely." Its units are: calorie, Kilo Calorie, BTU (British Thermal Units)

Q12. Define the following terms: Water recovery and Solute rejection. (2012-13)

Ans. The terms water recovery and solute rejection are used with reference to Reverse Osmosis.

Water Recovery: It means that in reverse osmosis the pure water is recovered by applying hydrostatic pressure, more than osmotic pressure on the side of impure water. The pure water is forced to move on the other side of semi permeable membrane leaving behind the dissolved salts and impurities.

Solute Rejection: In reverse osmosis the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side. The solute is thus rejected.

Q13. What is Langelire index (LI)? Mention its significance. (2012-13)

Ans. The Langelire index (LI) is the difference between the actual (measured) pH and the calculated pH of water. It gives an approximate measure of the degree of saturation of calcium carbonate in water.

Significance: The sign and magnitude of the Langelier index show the water's tendency to form or dissolve scale and thus to inhibit or encourage corrosion.

Q14. Name different forms of coal and arrange them in ascending order of %carbon. (2011-12)

Ans.

Types of coal	Wood	Peat	Lignite	Bituminous	Anthracite
Percentage of carbon	50	50-60	60-70	80-90	90-98

Q14. What do you mean by caustic embrittlement? (2014-15)

Ans. . Caustic embrittlement:-

The formation of cracks in boilers due to NaOH is called caustic embrittlement.

Prevention of caustic embrittlement:-

a) By using sodium phosphate or sodium sulphate for softening instead of Na₂CO₃.

b) By adding tannin or lignin to boiler water.

Q15. Why should an ideal fuel have moderate ignition temperature? (2014-15)

Ans. Ignition Temperature: It is the minimum temperature at which fuel catches fire or ignites.

An ideal fuel must have moderate ignition temperature as if it would have too high ignition temperature it would not catch fire easily and will be difficult to ignite. On the other hand if ignition temperature is too low then there would be chances of accidents as it would catch fire even at room temperature.

Q16. Chemical formula of zeolite is $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot x\text{SiO}_2 \cdot y\text{H}_2\text{O}$ (2010-11)

Q17. Relation between HCV and LCV is: $\text{LCV} = \text{HCV} - 0.09\text{H}$ (2010-11)

Q18. Hard water does not give lather with soap because it forms scum (a white curdy precipitate). (2009-10)

Q19. Hardness of water is expressed in terms of equivalent of CaCO_3 . (2009-10)

Q20. Why zeolite softener is not recommended for obtaining feed water for high pressure boilers? (2017-18)

Ans. Water obtained through zeolite softener has high amount of sodium salts which is not suitable for high pressure boilers.

Q21. What is coal? On what basis the coal should be classified? (2013-14)

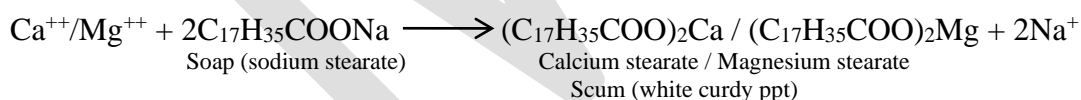
Ans. Coal is a carbonaceous material. It is a fossil fuel that is made by the debris of wood and vegetable remains buried under the earth for millions of years.

Coal is classified on the basis of elements like carbon, hydrogen, nitrogen, sulphur, oxygen, and on the basis of volatile matter, moisture, and ash content present in coal.

Q22. Hard water does not give lather with soap because it forms A white curdy precipitate known as scum. (2009-10)

Q23. Why soap does not give lather with hard water? Write chemical reaction in support of your answer. (2011-12)

Ans. Hard water does not give lather with soap because soap reacts with calcium and magnesium salts present in water to give white curdy precipitate known as scum.



LONG ANSWERS

Q1. With the help of neat diagram, explain the working of bomb calorimeter. OR

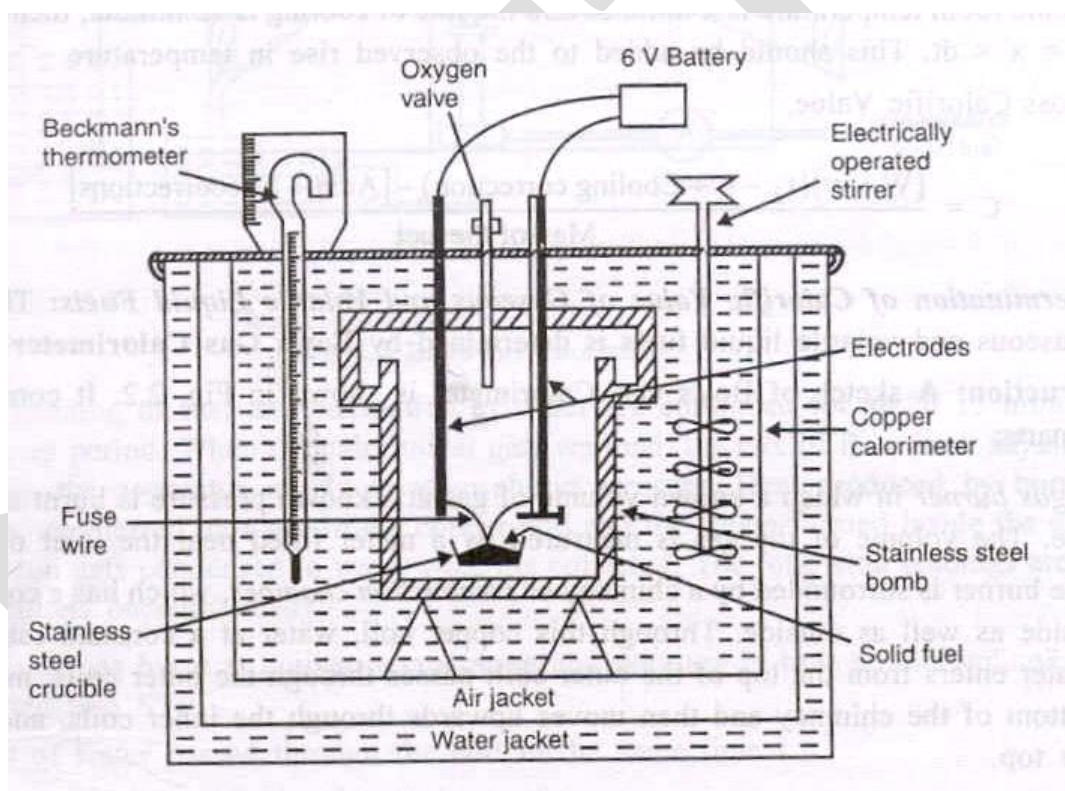
How the calorific value of solid fuel is determined using bomb calorimeter? (2018-19, 2017-18, 2015-16)

Ans. BOMB CALORIMETER:

Principle: A known amount of the fuel is burnt in excess of oxygen and heat liberated is transferred to a known amount of water. The calorific value of the fuel is then determined by applying the principle of calorimetry i.e. Heat gained = Heat lost

Construction: Bomb calorimeter consists of:

1. A strong stainless steel pot fitted with a lid.
2. Two electrodes
3. One oxygen inlet.
4. One of the electrodes is attached to the crucible having fuel.
5. Fuel sample is weighed and burnt in high pressure oxygen (25-30 atm).
6. Stainless steel or copper calorimeter.
7. Stirrer for uniform circulation of water.
8. Beckmann thermometer (0.01°C changes in temperature can be easily
9. Water and air jackets to avoid heat losses.
10. 6 V battery to start combustion of fuel.



BOMB CALORIMETER

Working of bomb calorimeter:

1. Weigh fuel sample and keep it in crucible.
2. Fix the lid tightly of bomb pot.
3. Fill the bomb with oxygen (25-30 atm pressure).
4. Place the bomb in calorimeter.
5. Add known volume of water in the calorimeter.
6. Keep the thermometer and stirrer in the water.
7. Place the calorimeter in the water jacket.
8. Put the plastic cover on top and make electrical connections.

9. Stir for 5 minutes and note the initial temperature of water.
10. Pass the current to heat the wire so that the fuel catches fire.
11. Note the maximum temperature reached.

Calculations:

Let weight of the fuel sample taken = x g

Weight of water in the calorimeter = W g

Water equivalent of the Calorimeter, stirrer, bomb, thermometer = w g

Initial temperature of water = $t_1^\circ\text{C}$

Final temperature of water = $t_2^\circ\text{C}$

GCV= Gross calorific value

$$\text{GCV} = \frac{(W+w) (t_2-t_1)}{x}$$

Net Calorific value or Lower calorific value (LCV) = GCV- 0.09H 587 cal/gm

Corrections: For accurate results the following corrections are also included:

- **Acid corrections** must be made for the heat liberated in the bomb by the formation of H_2SO_4 and HNO_3
- **Cooling correction:** As the temperature rises above the room temperature, the loss of heat does occur due to radiation, and the highest temperature recorded will be slightly less than that obtained. A temperature correction is therefore necessary.
- If the time taken for the water in the calorimeter to cool down from the maximum temperature attained, to the room temperature is x minutes and the rate of cooling is dt/min, then the cooling correction = x dt This should be added to the observed rise in temperature.
- **Fuse wire correction:** Heat liberated by combustion of magnesium wire must be subtracted.
- **Cotton thread correction:** For the proper combustion of fuel some cotton threads are kept in the crucible, so heat liberated due to this must be subtracted.

Therefore, Gross calorific value

$$= (W+w)(t_2-t_1+\text{Cooling correction}) - [\text{Acid} + \text{fuse corrections}] / \text{Mass of the fuel.}$$

$$\text{GCV} = \frac{(W+w)(t_2-t_1+C_c) - (C_A+C_f+C_{CT})}{x}$$

C_A = Acid correction

C_f = fuse wire correction

C_{CT} = cotton thread correction

C_c = cooling correction

Q2. What is rank of coal? Describe proximate and ultimate analysis of coal. OR Write short note on usefulness of proximate analysis. OR What parameters are determined in proximate analysis of a coal? Explain each. (2017-18, 2016-17, 2012-13, 2009-10)

Ans. Coal is given a ranking depending upon the carbon content of the coal from wood to anthracite.

Types of coal	Percentage of carbon	Calorific value (K.Cal/Kg)	Characteristics	Applications
Wood	50	4000-4500	Dried wood of trees	Domestic fuel
Peat	50-60	4125-5400	Brown fibrous jelly like mass	Used if deficiency of high rank coal is prevailing For steam generation in thermal power plants
Lignite	60-70	6500-7100	Soft, brown coloured, lowest ranked coal	In making coal gas and Metallurgical coke
Bituminous	80-90	8000-8500	Pitch black to dark grey coal	In households and for steam raising
Anthracite	90-98	8650-8700	Highest ranked coal	

In order to assess the quality of coal the following two types of analysis are made: Proximate analysis and Ultimate analysis.

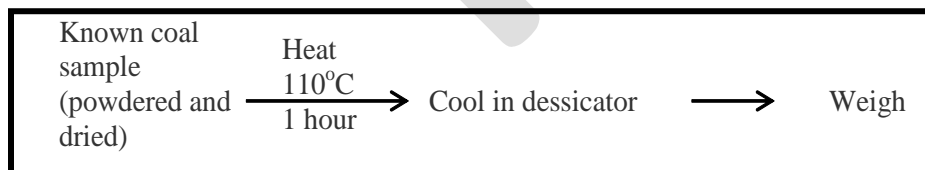
Proximate Analysis

It includes the determination of moisture, volatile matter, ash and fixed carbon.

- This gives quick and valuable information for commercial classification and determination of suitability for a particular industrial use.
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Moisture%

All moisture in coal escapes on heating coal at 110°C for 1h.



$$\text{Moisture \%} = \frac{\text{loss in weight}}{\text{Weight of coal sample}} \times 100$$

Volatile matter %

At 925°C in muffle furnace, coal undergoes thermal degradation to form volatile matter.

Moisture free coal left in first experiment $\xrightarrow[7 \text{ min}]{\text{heat } 925^{\circ}\text{C}}$ Cool the crucible in dessicator \longrightarrow Weigh

$$\text{VM \%} = \frac{\text{weight of volatile matter}}{\text{Weight of coal sample}} \times 100$$

Ash %

The residual coal in the above experiment is heated and burned above 750°C for 30 min. The ash is left behind. Cool and weigh.

$$\text{Ash \%} = \frac{\text{weight of Ash}}{\text{Weight of coal sample}} \times 100$$

$$\text{\%Fixed carbon} = 100 - (\text{moisture\%} + \text{volatile matter\%} + \text{ash\%})$$

Moisture:

- Moisture lowers the calorific value of coal.
- Presence of excessive moisture quenches (extinguish) fire in the furnace.

Volatile Matter:

The high volatile content gives long flames, high smoke and relatively low heating values. Reduces calorific value of coal.

Ash:

It reduces the calorific value of coal.

It lower the rate of combustion.

High ash leads to large heat losses and leads to formation of ash lumps.

Fixed Carbon:

Higher the percentage of fixed carbon, greater its calorific value

The percentage of fixed carbon helps in designing the furnace and shape of the fire-box because it is the fixed carbon that burns in the solid state.

Ultimate analysis of coal:

Analysis of coal in which % of C, H, O, N, S elements are found out is known as ultimate analysis.

Determination of C and H

Known coal sample (powdered and dried) $\xrightarrow[\text{oxygen}]{\text{Heat}}$ C is converted to CO_2 and H to H_2O \longrightarrow Gaseous products are absorbed by pre-weighed U-tubes containing anhydrous CaCl_2 which absorbs H_2O and KOH which absorbs CO_2 .

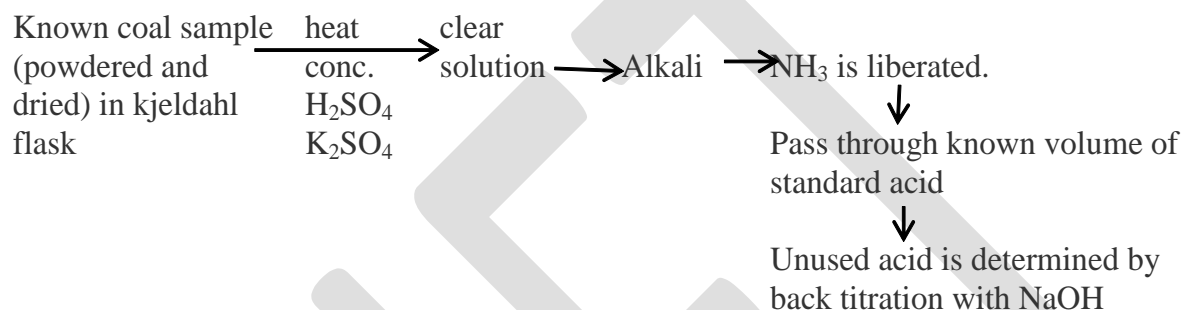
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Increase in weight is calculated

$$\% \text{ C} = \frac{\text{Weight of CO}_2 \text{ formed} \times 12 \times 100}{\text{Weight of coal sample} \times 44}$$

$$\% \text{ H} = \frac{\text{Increase in Weight of CaCl}_2 \text{ tube} \times 2 \times 100}{\text{Weight of coal sample} \times 18}$$

Determination of N (kjeldahl method):



$$\% \text{ N} = \frac{\text{Volume of acid} \times \text{Normality} \times 1.4}{\text{Weight of coal sample}}$$

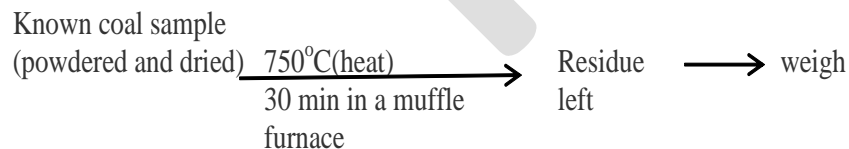
Determination of S:



BaSO_4 is filtered, dried and weighed.

$$\% \text{ S} = \frac{\text{Weight of BaSO}_4 \text{ precipitate} \times 32 \times 100}{\text{Weight of coal sample} \times 233}$$

% Ash



$$\% \text{ Ash} = \frac{\text{Weight of residue} \times 100}{\text{Weight of coal sample}}$$

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

Importance of Ultimate Analysis

- Carbon: greater the % carbon in coal, better is the coal quality and calorific value.
- Hydrogen: Hydrogen is in the form of moisture and volatile matter. It decreases the calorific value and quality of coal.
- Nitrogen: Nitrogen has no calorific value. A good quality coal should have negligible N%.
- Sulphur: Corrosive effect and pollutant. A good quality coal should have low S%.
- Oxygen: Decreases the calorific value of coal, decreases the coal quality.

Q3. What are ion exchange resins? With the help of neat sketch, discuss ion exchange process for water softening. Compare its merit over zeolite process. (2018-19, 2016-17, 2014-15)

Ans. ION EXCHANGE RESINS FOR WATER SOFTENING:

*Used for producing demineralised or deionised water.

These are high molecular weight, insoluble, cross linked, organic polymers having porous structure.

There are two types of ion exchangers:

a) **Cation Exchange resins**: Have loosely held H^+ ions which are reversibly exchanged by hardness producing cations (Ca^{2+} and Mg^{2+}) in water.

b) **Anion Exchange resins**: Have loosely held OH^- ions which are reversibly exchanged by hardness producing anions (Cl^- , SO_4^{2-} and HCO_3^-) in water.

Principle: These are capable of exchanging hardness producing ions (cations as well as anions) in water with their H^+ and OH^- ions.

Working:

Ion exchange process consists of two columns-**Cation exchanger column** and **anion exchanger column**.

Reactions:

Step 1: Water Softening

Cation exchanger $-2\text{R}-\text{H} + \text{Ca}^{+2} \rightleftharpoons \text{R}_2-\text{Ca} + 2\text{H}^+$ (R = insoluble matrix)

$2\text{R}-\text{H} + \text{Mg}^{+2} \rightleftharpoons \text{R}_2-\text{Mg} + 2\text{H}^+$

Anion exchanger $-\text{R}-\text{OH} + \text{Cl}^- \rightleftharpoons \text{RCl} + \text{OH}^-$ (R = insoluble matrix)

$2 \text{R}-\text{OH} + \text{SO}_4^{2-} \rightleftharpoons \text{R}_2\text{SO}_4 + \text{OH}^-$

Step 2: Regeneration of ion exchangers:

Regeneration of cation exchanger by acid: $\text{R}_2-\text{Ca} + 2\text{H}^+ \rightleftharpoons 2\text{R}-\text{H} + \text{Ca}^{+2}$

Regeneration of anion exchanger by base: $\text{RCl} + \text{OH}^- \rightleftharpoons \text{R}-\text{OH} + \text{Cl}^-$

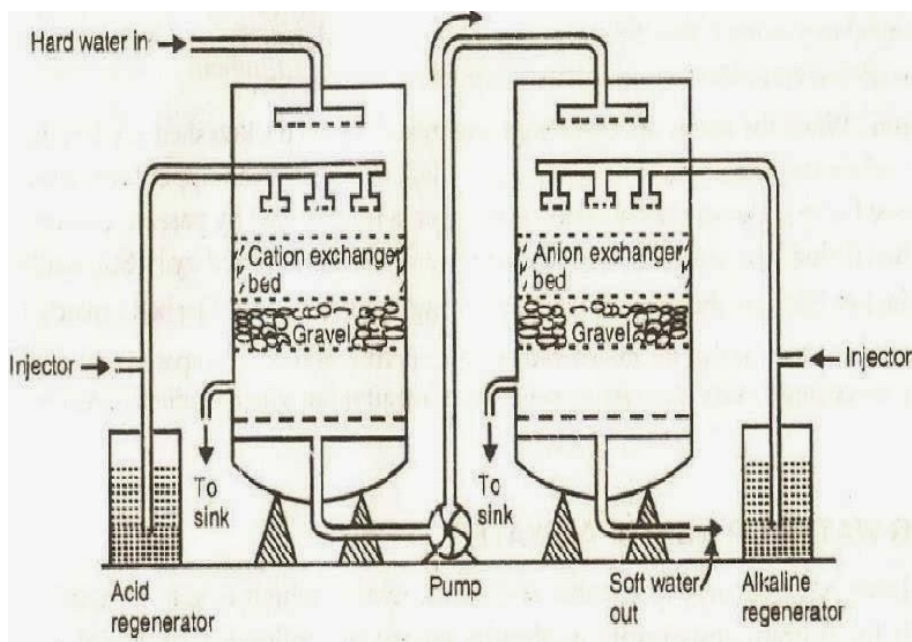
Advantages:

1. Gives water of zero hardness and no ionic impurities.
2. Occupies less space.
3. Easy to operate
4. Negligible running cost.

Limitations:

1. Initial cost is high.
2. Used for small scale treatment of water.

Note: Water must be passed first through cation exchanger and then through anion exchanger as the alkaline water generated by anion exchanger destroys the cation exchanger, whereas the acidic water generated by cation exchanger does not harm the anion exchanger.



Comparison of Zeolite and Ion Exchange resin for water softening:

ION EXCHANGE PROCESS	ZEOLITE PROCESS
1. Removes all positive and negative ions from water	Removes only cations causing hardness in water.
2. No sodium salts in treated water.	Treated water contains high amount of sodium salts.
3. Initial cost is high.	Initial cost is lower.
4. Running cost is higher.	Running cost is lower, as NaCl is very cheap.
5. Acidic water can be purified.	Acidic water cannot be purified as it spoils zeolite.

Q3. What is hardness of water? What do you mean by term permutit? Describe zeolite or permutit process for water softening. (2018-19, 2017-18, 2015-16, 2014-15, 2013-14, 2010-11, 2009-10)

Ans. ZEOLITE OR PERMUTIT METHOD OF WATER TREATMENT

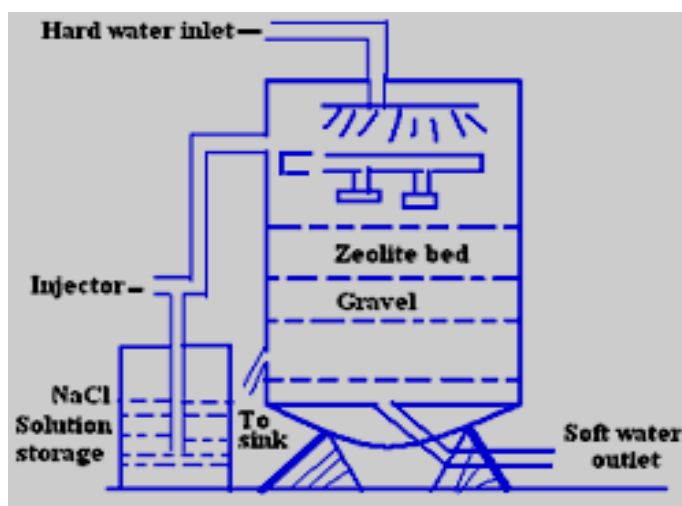
The word permutit means boiling stone.

Zeolites are **hydrated sodium alumina silicates**.

They have porous structure with molecular formula $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot x\text{SiO}_2 \cdot y\text{H}_2\text{O}$ ($x=2$ to 10 & $y=2$ to 6).

They are **represented as Na_2Ze** (Ze = the insoluble framework; Na = loosely held sodium ions).

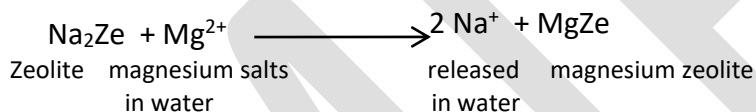
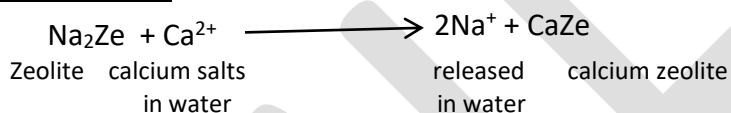
Principle of zeolite process: They exchange their loosely held sodium ions reversibly with the hardness producing cations in water (Ca^{+2} and Mg^{+2}).



Zeolite process of water softening

Working: It involves two steps:

1. **Water softening:**



2. **Regeneration:** By using concentrated brine solution (10% NaCl).



Advantages:

1. Only 10 ppm hardness is left behind.
2. No sludge formation.
3. Requires less time and operation is clean.
4. Automatically adjusts itself according to the hardness of water.
5. Equipment is compact, maintenance and operation is easy.

Disadvantages:

1. Removes cationic impurities; anions are left behind in water.
2. Treated water contains more sodium salts.

Limitations:

1. Turbid water cannot be feeded.
2. Acidic water cannot be feeded.
3. Hot water cannot be used.
4. If used for heavy metal ions like Fe^{+3} or Al^{+3} etc., zeolites cannot be regenerated.

Q4. Explain reverse osmosis with its advantages. (2018-19, 2016-17, 2015-16, 2014-15)

Ans. Reverse Osmosis (RO) or super filtration

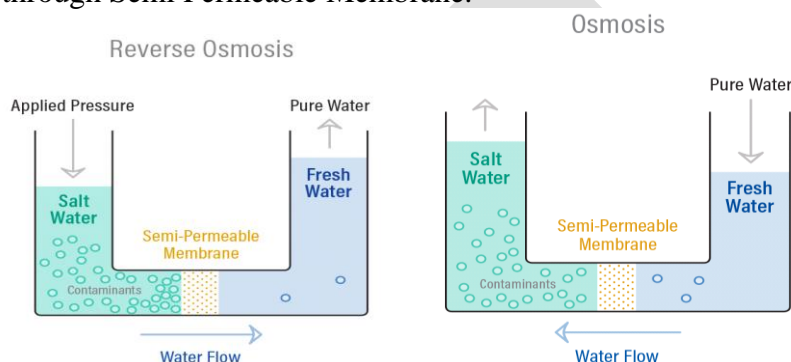
It is a process to demineralize or deionize water by pushing it under pressure through a semi-permeable membrane (reverse of osmosis).

Osmosis: solvent from dilute solution passes to the concentrated solution through a semi permeable membrane to equalize the concentration of both.

Reverse Osmosis: pressure higher than osmotic pressure is applied on the concentrated solution side so that the flow of the solvent is reversed, i.e. from concentrated solution to dilute solution.

This method is applicable mainly for the desalination of sea water. Sea water and pure water are separated by a semi-permeable membrane.

Method: Sea water or polluted water is filled in reverse osmosis cell. Pressure of 200 psi is applied on water to force the solvent to flow through Semi Permeable Membrane.



Advantages:

1. Removes up to 99% of the dissolved salts (ions), particles, colloids, organics, bacteria and pathogens from water.
2. Removes both ionic and non-ionic impurities.
3. Requires extremely low energy.
4. Low cost process.
5. Very effective in treating brackish, surface and ground water.
6. Simple to operate.
7. Pure water for high pressure boilers can be obtained.

Q5. What are the characteristics of a good fuel? (2014-15, 2011-12)

Ans. Characteristics of Good Fuel:

- Suitability: The fuel selected should be most suitable for the process.
- Should have high Calorific value
- Ignition Temperature: A good fuel should have moderate ignition temperature (temperature at which fuel catches fire).
- Moisture content should be low.
- Noncombustible and volatile matter content should be low.
- Rate of combustion: It should be moderate.
- Cost of fuel should be reasonable
- Should not produce pollution.
- Transportation and storage should be easy.

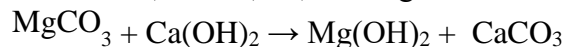
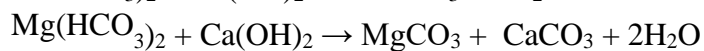
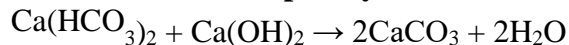
Q6. Explain the basic principle of lime-soda process. OR Explain lime-soda process for softening of water. (2017-18, 2015-16, 2014-15)

Ans. Principle: By adding calculated amounts of lime Ca(OH)_2 and soda Na_2CO_3 :

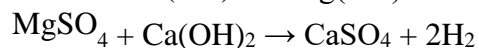
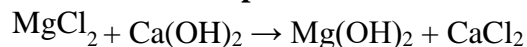
- * All the calcium salts are precipitated out as calcium carbonate CaCO_3 .
- * All the magnesium salts are precipitated as magnesium hydroxide Mg(OH)_2 which can be easily filtered off.

Working: Following reactions are involved:

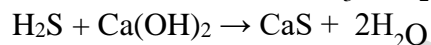
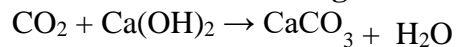
1. Lime removes all the temporary hardness.



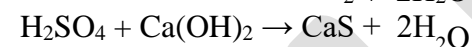
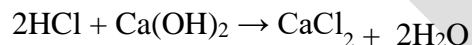
2. Lime removes all the permanent hardness of magnesium salts.



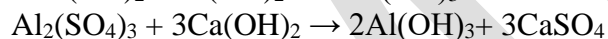
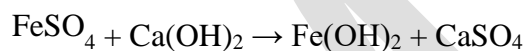
3. Lime removes the dissolved gases.



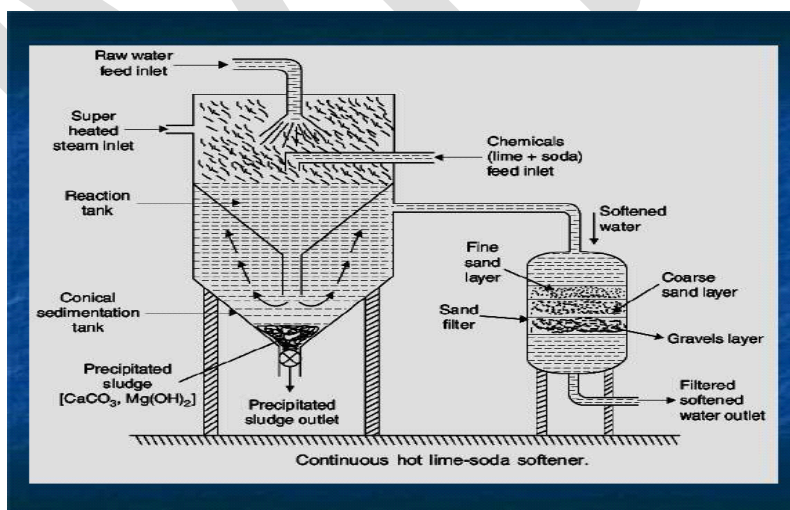
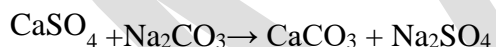
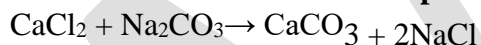
4. Lime removes free mineral acids.



5. Lime removes dissolved iron and aluminium salts.



6. Soda removes all soluble calcium permanent hardness.



Q7. Discuss different methods for internal treatment for boiler feed water. (2014-15)

Ans. INTERNAL TREATMENT OF WATER

*In this method water is treated inside the boiler.

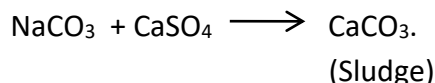
*This is a corrective method.

Principal involved: To convert the scale forming substances into sludge forming substances.

*Also called conditioning method.

1. Carbonate conditioning: Used in low pressure boilers.

Boiler water is treated with NaCO_3 .

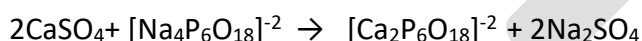
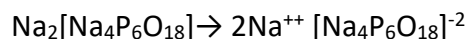


2. Calgon Conditioning:

Calgon means calcium gone.

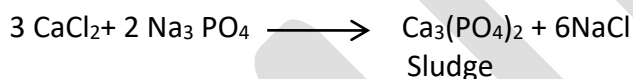
Sodium hexa-meta phosphate $\text{Na}_2[\text{Na}_4\text{P}_6\text{O}_{18}]$ is called calgon.

It reacts with calcium ion and forms a water soluble compound.



(Soluble complex ion)

3. Phosphate conditioning: It is applied to high pressure boilers.



Q8. Discuss the problems created by hard water in boilers. (2009-10)

Ans. Boiler Troubles: If the hard water is fed directly to the boilers, following troubles arises:

1. Priming or Wet Steam Formation: - The carrying out of water droplets with steam in steam drum is called "priming".

Causes: (i) Large amount of dissolved solids.

(ii) High steam velocities.

(iii) Sudden boiling.

(iv) Faulty boiler design.

(v) Sudden increase in steam production rate.

(vi) The high levels of water in boilers.

Prevention of priming: -

(i) Fitting mechanical steam purifiers

(ii) Avoiding rapid change in steaming rate

(iii) Maintaining low water levels in boilers and

(iv) Using soft water.

2. Foaming: - Formation of stable bubbles at the surface of water in the boiler is called foaming.

Reason: Due to the presence of oil drops, alkalies etc.

Prevention of Foaming:-

(i) Adding antifoaming chemicals like castor oil.

- (ii) Oil can be removed by adding sodium aluminates or alum.
- (iii) Using soft water.

3. Scale & sludge formation:-

Sludge: The muddy solid deposited at the bottom of the boiler is called sludge.

Causes of the sludge:- The sludge is caused by MgCO_3 , MgCl_2 , CaCl_2

Disadvantages of sludges: -

1. Wastage of heat and fuel.
2. Chocking of the pipes.

Prevention of sludge formation: -

- (1) By using soft water.
- (2) Blow down operation.

Scale: - Scales are hard sticky deposits on the inner walls of boiler. The scales are very difficult to remove.

Causes of Scale:-

Due to presence of $\text{Ca}(\text{HCO}_3)_2$, $\text{Mg}(\text{HCO}_3)_2$, CaSO_4 , SiO_2 , CaSiO_3 etc. in water.

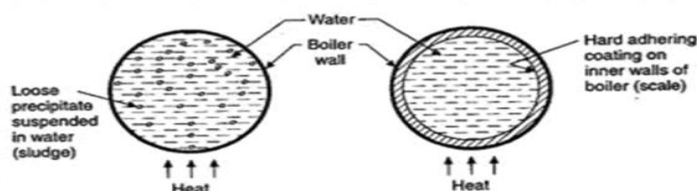
Disadvantages of Scale: - (1) Loss of heat and fuel.

2. Weakening of boiler material.
- 3) May result in explosion of boiler.

Removal of Scales:-

- (1) Soft scales can be removed by scrapper.
- (2) By giving thermal shocks.
- (3) Using 5-10% HCl Solution or EDTA solution.

Sludge and Scale formation :



4. Caustic embrittlement:-

The formation of cracks in boilers due to NaOH is called caustic embrittlement.

Prevention of caustic embrittlement:-

- a) By using sodium phosphate or sodium sulphate for softening instead of Na_2CO_3 .
- b) By adding tannin or lignin to boiler water.

5. Boiler Corrosion: It is the decay of the boiler body material due to environmental factors.

Disadvantages:

- a) Reduced life of boiler.
- b) Increased cost of repairs and maintenance.
- c) Leakage of joints.

Prevention:

- a) By removal of oxygen using hydrazine, sodium sulphate etc.
- b) By removal of CO₂: By adding ammonia.
- c) pH should be adjusted between 8.5 to 9

Q9. Explain priming and foaming.

Ans. Explained in question no. 8.

Q10. What is potable water? What are its chemical requirements? (2016-17)

Ans. Water that is fit for human consumption is known as potable water. The chemical requirement of potable water is as follows:

- a) It should be colourless, odourless and clear.
- b) It should be perfectly cool.
- c) It should have pleasant taste.
- d) It should be free from objectionable gases like CO₂, H₂S etc.
- e) It should be free from heavy metals such as Pb, Mn, Cr, As salts etc.
- f) pH should be about 8.0
- g) It should be reasonably soft.
- h) Turbidity: less than 10 ppm.
- i) Free chlorine: less than 0.1 to 0.2 ppm.
- j) Dissolved solids: less than 500 ppm.
- k) Should be free from pathogens.

Q11. Differentiate between lime-soda process and ion exchange process. (2018-19)

Ans.

SODA LIME PROCESS	ION EXCHANGE PROCESS
1. Large scale treatment process.	Small scale treatment process.
2. Residual hardness left in treated water.	Water with zero hardness is produced.
3. Initial calculations for lime and soda requirement is to be done.	Process adjusts itself according to the hardness present in water.
4. Sludge formation is there.	No sludge formation.
5. Regeneration not required.	Regeneration is required when ion exchanger is exhausted.

NUMERICALS

Q1. A water sample contains 408 mg of CaSO₄ per litre. Calculate the hardness in terms of CaCO₃ equivalent.

Ans. Hardness = Strength of hardness producing subs. \times $\frac{\text{Chemical equivalents of CaCO}_3}{\text{Chemical equivalents of hardness producing substance}}$

$$= 408 \text{ mg/L} \times \frac{50}{68}$$

$$= 300 \text{ mg/L} = 300 \text{ ppm}$$

Q2. 100 ml of water sample has a hardness equivalent of 12.5 mL of 0.08 N MgSO₄. What is its hardness in ppm? (2017-18, 2011-12)

Ans. N_1V_1 of water sample = N_2V_2 of $MgSO_4$

$$N_1 \times 100 = .08 \times 12.5$$

$$N_1 = .01$$

$$\text{Hardness} = N_1 \times \text{Equivalent weight of } CaCO_3$$

$$\text{Hardness} = .01 \times 50$$

$$= .5 \text{ ppm}$$

Q3. Calculate the carbonate and non-carbonate hardness of a sample of water containing the dissolved salts as given below in mg/l:

$Mg(HCO_3)_2 = 7.3$; $Ca(HCO_3)_2 = 40.5$; $CaSO_4 = 13.6$; $MgCl_2 = 21.75$; $NaCl = 50$ (2013-14)

Ans. Conversion into $CaCO_3$ equivalent.:

Constituents	Amount (mg/L)	Multiplication factor	$CaCO_3$ equivalent
$Ca(HCO_3)_2$	40.5	50/81	$40.5 \times 50/81 = 25 \text{ mg/L}$
$Mg(HCO_3)_2$	7.3	50/73	$7.3 \times 50/73 = 5 \text{ mg/L}$
$CaSO_4$	13.6	50/68	$13.6 \times 50/68 = 10 \text{ mg/L}$
$MgCl_2$	21.75	50/47.5	$21.75 \times 50/47.5 = 22.9 \text{ mg/L}$

$$\begin{aligned} \text{Carbonate hardness} &= Ca(HCO_3)_2 + Mg(HCO_3)_2 \\ &= 25 + 5 = 30 \text{ mg/L} \end{aligned}$$

$$\begin{aligned} \text{Non Carbonate hardness} &= CaSO_4 + MgCl_2 \\ &= 10 + 22.9 = 32.9 \text{ mg/L} \end{aligned}$$

$$\begin{aligned} \text{Total Hardness} &= \text{Carbonate hardness} + \text{Non Carbonate hardness} \\ &= 30 + 32.9 = 62.9 \text{ mg/L} \end{aligned}$$

Q4. A sample of water on analysis was found to contain the following impurities:

Impurity	Quantity (mg/L)	Mol. Wt.
$Ca(HCO_3)_2$	4	162
$Mg(HCO_3)_2$	6	146
$CaSO_4$	8	136
$MgSO_4$	10	120

Calculate the temporary, permanent and total hardness of water in ppm, degree french and degree clarke.

Ans. Conversion into $CaCO_3$ equivalent.:

Constituents	Amount (mg/L)	Multiplication factor	$CaCO_3$ equivalent
$Ca(HCO_3)_2$	4	50/81	$4 \times 50/81 = 2.47 \text{ mg/L}$
$Mg(HCO_3)_2$	6	50/73	$6 \times 50/73 = 4.11 \text{ mg/L}$

CaSO ₄	8	50/68	8 × 50/68 = 5.88 mg/L
MgSO ₄	10	50/60	10 × 50/60 = 8.33 mg/L

Temporary hardness is due to bicarbonates of calcium and magnesium

So, Temporary hardness = 2.47 + 4.11 = 6.58 mg/L

As, 1 mg/L = 1 ppm = 0.1 °Fr = 0.07 °Cl

Hence temporary hardness = 6.58 mg/L = 6.58 ppm

= 6.58 × 0.1 = 0.658 °Fr

= 6.58 × 0.07 = 0.46 °Cl

Permanent hardness in this case is due to CaSO₄ and MgSO₄

So, permanent hardness = 5.88 + 8.33 = 14.21 mg/L

= 14.21 ppm = 14.21 × 0.1 = 1.421 °Fr

= 14.21 × 0.07 = 0.995 °Cl

Q5. Calculate temporary, permanent and total hardness of water sample that is analysed as: Mg(HCO₃)₂ = 7.3 mg/l, : Ca(HCO₃)₂ = 8.1 mg/l, MgCl₂ = 9.5 mg/l and CaSO₄ = 6.8 mg/l (2016-17)

Ans.

Impurity	Quantity (mg/L)	Eq. Wt.	CaCO ₃ Equi. (mg/l)
Ca(HCO ₃) ₂	8.1	81	$8.1 \times \frac{50}{81} = 5$
Mg(HCO ₃) ₂	7.3	73	$7.3 \times \frac{50}{73} = 5$
MgCl ₂	9.5	47.5	$9.5 \times \frac{50}{47.5} = 10$
CaSO ₄	6.8	68	$6.8 \times \frac{50}{68} = 5$

Temporary Hardness = Hardness due to [Ca(HCO₃)₂ + Mg (HCO₃)₂]

= 5 + 5 = 10 ppm

Permanent Hardness = Hardness due to [MgCl₂ + CaSO₄]

= 10 + 5 = 15 ppm

Total Hardness = Temporary Hardness + Permanent Hardness

= 10 + 15 = 25 ppm

Q7. By passing 50 litres of NaCl solution containing 250 gm/litre of NaCl, an exhausted zeolite softener bed was regenerated. Calculate the litres of hard water sample (hardness equal to 200 ppm as CaCO₃) which can be softened by regenerated bed of zeolite softener.

Ans. Total amount of NaCl used = 50 × 250 = 12,500 gm

CaCO₃ equivalents or Hardness in ppm = 12,500 × $\frac{50}{1000}$

58.5 Vol. of water

$$200 = 12,500 \times \frac{50}{58.5} \times \frac{1000}{200}$$

58.5 Vol. of water

$$\begin{aligned}\text{Vol. of water} &= 12,500 \times \frac{50}{58.5} \times \frac{1000}{200} \\ &= 53418.80 \text{ L}\end{aligned}$$

Q8. In an experiment in a bomb calorimeter, a solid fuel of 0.90 g is burnt. It is observed that increase in temp is 3.8°C of 4000g of water. The fuel contains 1 % of H. Calculate HCV and LCV. Water equivalent of calorimeter = 385g (2015-16)

Ans. $x = 0.9 \text{ g}$, $w = 385 \text{ g}$, $W = 4000 \text{ g}$
 $\%H = 1$, Latent heat of water = 587 cal/g, $t_2 - t_1 = 3.8^\circ\text{C}$

$$\begin{aligned}\text{HCV} &= \frac{(W+w)(t_2-t_1)}{x} \\ &= \frac{(4000+385)(3.8)}{0.9} = 18514.44 \text{ cal/g} \\ \text{LCV} &= \text{HCV} - 0.09(\%H)(587) \\ &= 18514.44 - 0.09(1)(587) = 18461.61 \text{ cal/g}\end{aligned}$$

Q9. On burning 0.83 g of a fuel in a bomb calorimeter, temperature of 3500 g of water increased from 26.5 to 29.2 °C. Water equivalent of calorimeter and Latent heat of water are 385 g and 587 cal/g respectively. If the fuel contains 0.7% hydrogen, calculate its gross and net calorific value.

Ans. $x = 0.83 \text{ g}$, $w = 385 \text{ g}$, $W = 3500 \text{ g}$
 $\%H = 0.7$, Latent heat of water = 587 cal/g, $t_2 - t_1 = 29.2 - 26.5 = 2.7^\circ\text{C}$

$$\begin{aligned}\text{HCV} &= \frac{(W+w)(t_2-t_1)}{x} \\ &= \frac{(3500+385)(2.7)}{0.83} = 12637.95 \text{ cal/g} \\ \text{LCV} &= \text{HCV} - 0.09(\%H)(587) \\ &= 12637.95 - 0.09(0.7)(587) = 12600.97 \text{ cal/g}\end{aligned}$$

Q 10. A sample of coal contains C= 93%, H=6%, ash= 1%. The following data was obtained when the above coal was tested in bomb calorimeter: wt. of coal burnt= 0.92 g, wt. of water taken= 2200 g, water equivalent of bomb calorimeter= 550 g, rise in temp= 2.42 ° C, Fuse wire correction= 10.0 cal, acid correction= 50.0 cal. Calculate gross and net calorific value of coal, assuming the latent heat of condensation of steam as 580 cal/g.

Ans.

$$\begin{aligned}\text{HCV} &= \frac{(W+w)(t_2-t_1) - (C_A + C_F)}{x} \\ &= \frac{(2200 + 550)(2.42) - (50 + 10)}{0.92} \\ &= \frac{(2750)(2.42) - (60)}{0.92}\end{aligned}$$

$$= \frac{6595}{0.92}$$

$$= 7168.4782 \text{ cal/g}$$

$$\begin{aligned} \text{LCV} &= \text{GCV} - .09 \% \text{H} \times \text{latent heat of steam} \\ &= 7168.4782 - .09 \times 6 \times 580 \\ &= 7168.4782 - 313.2 \\ &= 6855.2782 \text{ cal/g} \end{aligned}$$

Q11. 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.

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

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

$$\begin{aligned} \text{GCV} &= \frac{1}{100} [8080 (85) + 34500 (\frac{7 - 1}{8}) + 2240 (1)] = 9262.27 \text{ cal/g} \\ &= 9262.27 \times 4.18 \\ &= 38716.28 \text{ J/g} \end{aligned}$$

$$\text{NCV} = \text{GCV} - 0.09(\% \text{H})(2458) = 38716.38 - 0.09(7)(2458) = 37167.74 \text{ J/g}$$

Q12. 3.25 g of coal was kjeldahlized and NH₃ gas thus evolved was absorbed in 45 ml of 0.1 N H₂SO₄. To neutralize excess of acid, 11.5 ml of 0.1N NaOH was required. Calculate N%.

Ans. Weight of coal = 3.25 g
Vol of H₂SO₄ consumed = 45 - 11.5 = 33.5 ml

$$\% \text{N} = \frac{\text{Volume of acid} \times \text{Normality} \times 1.4}{\text{Weight of coal sample}}$$

$$= \frac{33.5 \times 0.1 \times 1.4}{3.25} = 1.443\%$$

Q12. 0.25 g coal sample on burning in combustion chamber in current of pure O₂ was found to increase weight of CaCl₂ U-tube by 0.08 g and KOH U-tube by 0.5 g. Find % of carbon and hydrogen in coal.

Ans. Weight of coal = 0.25 g
Increase in weight of KOH tube (Weight of CO₂) = 0.5 g
Increase in Weight of CaCl₂ tube (Weight of H₂O) = 0.08 g

$$\% \text{C} = \frac{\text{Weight of CO}_2 \text{ formed} \times 12 \times 100}{\text{Weight of coal sample} \times 44} = \frac{0.5 \times 12 \times 100}{0.25 \times 44} = 54.5\%$$

$$\% \text{H} = \frac{\text{Increase in Weight of CaCl}_2 \text{ tube} \times 2 \times 100}{\text{Weight of coal sample} \times 18} = \frac{0.08 \times 2 \times 100}{0.25 \times 18} = 3.55\%$$

Q13. Calculate the quantities of lime and soda required for softening of 20,000 litres of water containing salts in ppm (16.4 ppm NaAlO₂ used as a coagulant): Ca⁺² = 160 ppm; Mg⁺² = 72 ppm; HCO₃⁻ = 73.2 ppm; CO₂ = 44 ppm; Al₂(SO₄)₃ = 34.2 ppm and HCl = 36.5 ppm.

Impurity	Quantity (mg/L)	Eq. Wt.	CaCO ₃ Eq. (mg/l)	L or S
Ca ⁺⁺	160	20	$160 \times \frac{50}{20} = 400$	S
Mg ⁺⁺	72	12	$72 \times \frac{50}{12} = 300$	L + S
CO ₂	44	22	$44 \times \frac{50}{22} = 100$	L
HCO ₃ ⁻	73.2	61	$73.2 \times \frac{50}{61} = 60$	L – S
Al ₂ (SO ₄) ₃	34.2	57	$34.2 \times \frac{50}{57} = 300$	3L + 3S
NaAlO ₂	16.4	82	$16.4 \times \frac{50}{82} = 100$	-L
HCl	36.5	36.5	$36.5 \times \frac{50}{36.5} = 50$	L + S

$$\text{Lime} = \frac{74}{100} [\text{Mg}^{++} + \text{CO}_2 + \text{HCO}_3^- + 3\text{Al}_2(\text{SO}_4)_3 + \text{HCl} - \text{NaAlO}_2] \text{ all as CaCO}_3 \text{ eq.} \times \frac{\text{vol. of water}}{10^6}$$

$$= \frac{74}{100} [300 + 100 + 60 + 3 \times 300 + 50 - 100] \times \frac{20,000}{10^6}$$

$$= \frac{74}{100} [1310] \times \frac{20000}{10^6}$$

$$= 19.388 \text{ Kg}$$

$$\text{Soda} = \frac{106}{100} [\text{Ca}^{++} + \text{Mg}^{++} - \text{HCO}_3^- + \text{HCl} + 3\text{Al}_2(\text{SO}_4)_3] \text{ all as CaCO}_3 \text{ eq.} \times \frac{\text{vol. of water}}{10^6}$$

$$= \frac{106}{100} [400 + 300 - 60 + 50 + 3 \times 300] \times \frac{20000}{10^6}$$

$$= 33.708 \text{ Kg}$$

Q14. A sample of coal was found to have the following percentage composition: C = 75%, H= 5.2%, O = 12.1%, N = 3.2%, ash = 4.5%. Calculate minimum amount of air required for complete combustion of 1 kg of coal sample. (2015-16)

Ans. weight of C in 1 kg coal = $\frac{75}{100} \times 1000 \text{ g} = 750 \text{ g}$

H = $\frac{5.2}{100} \times 1000 \text{ g} = 52 \text{ g}$

O = $\frac{12.1}{100} \times 1000 \text{ g} = 121 \text{ g}$

$$\text{O}_2 \text{ quantity} = \left(\frac{32}{12} \text{C} + 8\text{H} + \text{S} - \text{O} \right) \text{ g}$$

$$= \left(\frac{32}{12} \times 750 + 8 \times 52 - 121 \right) \text{ g}$$

$$\begin{aligned}
 &= 2295 \text{ g} \\
 \text{Minimum amount of air} &= \text{Net O}_2 \times \frac{100}{23} \\
 &= 2295 \times \frac{100}{23} = 9978.26 \text{ g air}
 \end{aligned}$$

Q15. Calculate the volume of air required for complete combustion of 1m³ of gaseous fuel having the composition: CO=46%, methane=10%, hydrogen = 4%, C₂H₄ = 2%, N₂ = 1% and remaining being CO₂.

Ans.

Fuel	Composition	Combustion reaction	Vol of O ₂ (m ³)
CO	$\frac{46}{100} \times 1 = 0.46 \text{ m}^3$	$\text{CO} + 1/2 \text{O}_2 \longrightarrow \text{CO}_2$	$0.46 \times \frac{1}{2} = 0.23$
CH ₄	$\frac{10}{100} \times 1 = 0.1 \text{ m}^3$	$\text{CH}_4 + 2 \text{O}_2 \longrightarrow \text{CO}_2 + 2\text{H}_2\text{O}$	$0.1 \times 2 = 0.2$
H ₂	$\frac{4}{100} \times 1 = 0.04 \text{ m}^3$	$\text{H}_2 + 1/2 \text{O}_2 \longrightarrow \text{H}_2\text{O}$	$0.04 \times \frac{1}{2} = 0.02$
C ₂ H ₄	$\frac{2}{100} \times 1 = 0.02 \text{ m}^3$	$\text{C}_2\text{H}_4 + 3 \text{O}_2 \longrightarrow 2\text{CO}_2 + 2\text{H}_2\text{O}$	$0.02 \times 3 = 0.06$

$$\text{O}_2 \text{ Quantity} = 0.23 + 0.20 + 0.02 + 0.06 = 0.51 \text{ m}^3$$

$$\text{Volume of air needed for complete combustion} = 0.51 \times \frac{100}{21} = 2.43 \text{ m}^3 \text{ air}$$

Q16. A sample of coal contain C= 91 %, H= 5.5%, N= 2.5%, and ash= 2%. The following data were obtained when above coal was tested in bomb calorimeter: (2015-16)

Weight of coal burnt= 1.029 g

Weight of water taken= 570 g

Water equivalent of bomb and calorimeter= 2200 g

Rise in temperature= 3.3°C

Fuse wire correction= 3.8 cal

Acid correction= 62.6 cal

Cotton thread correction= 1.6 cal

Cooling correction= .047 °C

Assuming that the latent heat of condensation is 587 cal/gm, calculate net and gross calorific values of coal. (2018-19)

$$\begin{aligned}
 \text{Ans. GCV} &= \frac{(W+w)(t_2-t_1+C_c) - (C_A+C_f+C_{CT})}{X} \\
 &= \frac{(570 + 2200)(3.3 + .047) - (62.6 + 3.8 + 1.6)}{1.029} \\
 &= \frac{(2770)(3.347) - (68)}{1.029} \\
 &= \frac{9203.19}{1.029} = 8943.81 \text{ cal}
 \end{aligned}$$

$$\text{LCV} = \text{HCV} - 0.09(\%H) \text{ Latent heat of steam}$$

$$\begin{aligned} \text{LCV} &= 8943.81 - 0.09(5.5) (587) \\ &= 8943.81 - 290.565 \\ &= 8653.245 \text{ cal} \end{aligned}$$

Q15. Calculate the quantities of lime (74%) and soda (94%) required for cold softening of 125,000 L of water with the following analysis, using 10 ppm of NaAlO_2 as coagulant. Analysis of raw water: $\text{Ca}^{+2} = 160$ ppm, $\text{Mg}^{+2} = 48$ ppm, $\text{CO}_2 = 66$ ppm, $\text{HCO}_3^- = 264$ ppm, $\text{H}^+ = 20$ ppm, $\text{NaCl} = 4.7$ ppm.

Analysis of treated water: $\text{CO}_3^{-2} = 45$ ppm, $\text{OH}^- = 68$ ppm. (2018-19)

Ans.

Impurity	Quantity (mg/L)	Eq. Wt.	CaCO_3 Eq. (mg/l)	L or S
Ca^{++}	160	20	$160 \times \frac{50}{20} = 400$	S
Mg^{++}	48	12	$48 \times \frac{50}{12} = 200$	L + S
CO_2	66	22	$66 \times \frac{50}{22} = 150$	L
HCO_3^-	264	61	$264 \times \frac{50}{61} = 216.39$	L – S
H^+	20	1	$20 \times \frac{50}{1} = 100$	L + S
CO_3^{-2}	45	30	$45 \times \frac{50}{30} = 75$	S
OH^-	68	17	$68 \times \frac{50}{17} = 200$	-
NaAlO_2	10	82	$10 \times \frac{50}{82} = 6.09$	-L
NaCl	4.7	-	No Hardness	-

$$\text{Lime} = \frac{74}{100} [\text{Mg}^{++} + \text{CO}_2 + \text{HCO}_3^- + \text{H}^+ - \text{NaAlO}_2] \text{ all as } \text{CaCO}_3 \text{ eq.} \times \frac{100}{\% \text{ purity}} \times \frac{\text{vol. of water}}{10^6}$$

$$= \frac{74}{100} [200 + 150 + 216.39 + 100 - 6.09] \times \frac{100}{74} \times \frac{125000}{10^6}$$

$$\begin{aligned} &= \frac{74}{100} [660.3] \times \frac{100}{74} \times \frac{125000}{10^6} \\ &= 82.53 \text{ Kg} \end{aligned}$$

$$\text{Soda} = \frac{106}{100} [\text{Ca}^{++} + \text{Mg}^{++} - \text{HCO}_3^- + \text{CO}_3^{-2} + \text{OH}^-] \text{ all as } \text{CaCO}_3 \text{ eq.} \times \frac{100}{\% \text{ purity}} \times \frac{\text{vol. of water}}{10^6}$$

$$= \frac{106}{100} [400 + 200 - 216.39 + 100 + 75] \times \frac{100}{94} \times \frac{125000}{10^6}$$

$$= 78.74 \text{ Kg}$$

Q16. A sample of water gave the following data on analysis: Ca^{+2} = 20 ppm, Mg^{+2} = 25 ppm, CO_2 = 30 ppm, HCO_3^- = 150 ppm, K^+ = 10 ppm. Calculate the amount of lime (87%) and soda (91% pure) required to soften 10^6L of water. (2018-19)

Ans.

Impurity	Quantity (mg/L)	Eq. Wt.	CaCO_3 Equiv. (mg/l)	L or S
Ca^{++}	20	20	$20 \times \frac{50}{20} = 50$	S
Mg^{++}	25	12	$25 \times \frac{50}{12} = 104.16$	L + S
CO_2	30	22	$30 \times \frac{50}{22} = 68.18$	L
HCO_3^-	150	61	$150 \times \frac{50}{61} = 122.95$	L - S
K^+	10	19	No Hardness	-

$$\begin{aligned} \text{Lime} &= \frac{74}{100} [\text{Mg}^{++} + \text{CO}_2 + \text{HCO}_3^-] \text{ all as } \text{CaCO}_3 \text{ eq.} \times \frac{100}{\% \text{ purity}} \times \frac{\text{vol. of water}}{10^6} \\ &= \frac{74}{100} [104.16 + 68.18 + 122.95] \times \frac{100}{87} \times \frac{10^6}{10^6} \\ &= \frac{74}{100} [295.29] \times \frac{100}{87} \\ &= 251.16 \text{ Kg} \end{aligned}$$

$$\begin{aligned} \text{Soda} &= \frac{106}{100} [\text{Ca}^{++} + \text{Mg}^{++} - \text{HCO}_3^-] \text{ all as } \text{CaCO}_3 \text{ eq.} \times \frac{100}{\% \text{ purity}} \times \frac{\text{vol. of water}}{10^6} \\ &= \frac{106}{100} [50 + 104.16 - 122.95] \times \frac{100}{91} \times \frac{10^6}{10^6} \\ &= \frac{106}{100} [31.21] \times \frac{100}{91} \\ &= 36.35 \text{ Kg} \end{aligned}$$

Q17. A coal sample has following analysis by weight: C= 90%, O= 3%, S= 0.5%, N=0.5% and ash= 2.5. Net calorific value of the coal was found to be 8490.5 Kcal/Kg. Calculate the percentage of hydrogen and gross calorific value. (2018-19)

Ans. .

$$\begin{aligned} \text{GCV} &= \frac{1}{100} [8080 \% \text{C} + 34500 (\% \text{H} - \frac{\% \text{O}}{8}) + 2240 \% \text{S}] \\ &= \frac{1}{100} [8080 \times 90 + 34500 (\% \text{H} - \frac{3}{8}) + 2240 \times 0.5] \\ &= 7272 + 345 \text{ H} - 129.375 + 1120 \text{ Kcal/Kg} \\ &= 8262.62 + 345 \text{ H} \dots\dots\dots 1 \\ \text{Also, GCV} &= \text{LCV} + .09 \% \text{H} \times \text{latent heat of steam} \end{aligned}$$

$$= 8490.5 + .09 H \times 587$$

$$= 8490.5 + 52.83 H \quad \dots\dots\dots 2$$

From 1 and 2

$$8262.62 + 345 H = 8490.5 + 52.83 H$$

$$345 H - 52.83 H = 8490.5 - 8262.62$$

$$292.17 H = 227.88$$

$$H = \frac{227.88}{292.17} = .77\%$$

$$\text{So, GCV} = 8262.62 + 345 \times .77$$

$$= 8262.62 + 265.65$$

$$= 8528.27 \text{ Kcal/Kg}$$

Q18. A sample of water contain the following impurities: $\text{Ca}^{+2} = 20 \text{ ppm}$, $\text{Mg}^{+2} = 18 \text{ ppm}$, $\text{HCO}_3^- = 183 \text{ ppm}$, $\text{SO}_4^{2-} = 24 \text{ ppm}$. Calculate the lime and soda needed for softening. (2017-18, 2015-16)

Ans.

Impurity	Quantity (mg/L)	Eq. Wt.	CaCO_3 Equiv. (mg/l)	L or S
Ca^{++}	20	20	$20 \times \frac{50}{20} = 50$	S
Mg^{++}	18	12	$18 \times \frac{50}{12} = 75$	L + S
HCO_3^-	183	61	$183 \times \frac{50}{61} = 150$	L - S
SO_4^{2-}	24	80	No Hardness	-

Lime = $\frac{74}{100} [\text{Mg}^{++} + \text{HCO}_3^-]$ all as CaCO_3 eq.

$$= \frac{74}{100} [75 + 150] = 166.50 \text{ g}$$

Soda = $\frac{106}{100} [\text{Ca}^{++} + \text{Mg}^{++} - \text{HCO}_3^-]$ all as CaCO_3 eq.

$$= \frac{106}{100} [50 + 75 - 150] = \frac{106}{100} [-25] = -26.50 \text{ g}$$

Soda is not required.

Q19. Calculate the minimum weight of air required for complete combustion of 1 Kg of fuel containing C= 90%, H= 3.5%, O= 3%, S= 0.5%, H_2O = 1%, N= 0.5% and ash= rest. (2017-18)

Ans. C= 900 g, H= 35 g, O= 30 g, S= 5 g, H_2O = 10 g, N= 5 g

$$\text{Net O}_2 = \frac{32}{12} C + 8 H + S - O$$

$$= \frac{32}{12} \times 900 + 8 \times 35 + 5 - 30$$

$$\begin{aligned}
 &= 2400 + 280 + 5 - 30 \\
 &= 2655 \text{ g} \\
 \text{Weight of air required} &= \text{Net O}_2 \times \frac{100}{23} \\
 &= 2655 \times \frac{100}{23} \\
 &= 11543.47 \text{ g}
 \end{aligned}$$

Q20. The hardness of 10,000 L of sample of water was completely removed by passing it through a zeolite softener. The zeolite softener then required 200 L of NaCl solution containing 150 gm/L of NaCl for regeneration. Find out the hardness of water sample. (2017-18, 2014-15)

Ans. 200 L of NaCl contains = $200 \times 150 = 30,000 \text{ g NaCl}$
 $\text{CaCO}_3 \text{ eq.} = 30,000 \times \frac{50}{58.5} = 25641.025 \text{ gm/L}$
 Hardness of 10,000 L of water = $25641.025 \times \frac{1000}{10,000} = 2564.1025 \text{ ppm}$

Q21. Calculate the amount of lime and soda required for softening 30000 liters of water, using 20 ppm of sodium aluminate as coagulant. Impurities in water are as follows: $\text{Ca}^{2+} = 160 \text{ ppm}$, $\text{Mg}^{2+} = 96 \text{ ppm}$, dissolved $\text{CO}_2 = 34 \text{ ppm}$ and $\text{HCO}_3^- = 403 \text{ ppm}$. (2017-18)

Ans.

Impurity	Quantity (mg/L)	Eq. Wt.	CaCO_3 Equiv. (mg/l)	L or S
Ca^{++}	160	20	$160 \times \frac{50}{20} = 400$	S
Mg^{++}	96	12	$96 \times \frac{50}{12} = 400$	L + S
HCO_3^-	403	61	$403 \times \frac{50}{61} = 330.32$	L - S
NaAlO_2	20	82	$20 \times \frac{50}{82} = 12.19$	-L
CO_2	34	22	$34 \times \frac{50}{22} = 77.27$	L

$$\begin{aligned}
 \text{Lime} &= \frac{74}{100} [\text{Mg}^{++} + \text{HCO}_3^- + \text{CO}_2 - \text{NaAlO}_2] \text{ all as CaCO}_3 \text{ eq.} \times \frac{\text{Vol. of water}}{10^6} \\
 &= \frac{74}{100} [400 + 330.32 + 77.27 - 12.19] \times \frac{30,000}{10^6} \\
 &= \frac{74}{100} (795.47) \times \frac{30,000}{10^6} \\
 &= 17.65 \text{ Kg}
 \end{aligned}$$

$$\begin{aligned}\text{Soda} &= \frac{106}{100} [\text{Ca}^{++} + \text{Mg}^{++} - \text{HCO}_3^-] \text{ all as CaCO}_3 \text{ eq.} \times \frac{\text{Vol. of water}}{10^6} \\ &= \frac{106}{100} [400 + 400 - 330.32] \times \frac{30000}{10^6} \\ &= 14.935 \text{ Kg}\end{aligned}$$

Q22. What is the basic principle of Bomb calorimeter? A 0.80 g sample of solid fuel was completely combusted in the excess of oxygen using bomb calorimeter. The rise in temperature of water in calorimeter was 2.5°C. Calculate the High calorific value of the fuel. If water taken in calorimeter is 2000 g and water equivalent of calorimeter is 2200 g. Also calculate low Calorific value. (Given: % Hydrogen in fuel = 2.2) (2017-18)

Ans. Principle of Bomb Calorimeter: A known amount of the fuel is burnt in excess of oxygen and heat liberated is transferred to a known amount of water. The calorific value of the fuel is then determined by applying the principle of calorimetry i.e. Heat gained = Heat lost

$$\begin{aligned}\text{GCV} &= \frac{(W+w)(t_2-t_1)}{X} \\ &= \frac{(2000 + 2200)(2.5)}{0.80} \\ &= \frac{10500}{0.80} = 13125 \text{ cal/gm}\end{aligned}$$

$$\begin{aligned}\text{LCV} &= \text{HCV} - 0.09(\%H) \text{ Latent heat of steam} \\ \text{LCV} &= 13125 - 0.09(2.2)(587) \\ &= 13125 - 116.226 \\ &= 13008.774 \text{ cal/gm}\end{aligned}$$

Q23. A zeolite softener was 90% exhausted by removing the hardness completely when 10,000 litres of hard water was passed through it. The exhausted zeolite bed required 200 litres of 3% sodium chloride solution for its complete regeneration. Calculate the hardness of water sample. (2017-18, 2016-17)

$$\begin{aligned}\text{Ans. } 3\% \text{ NaCl solution} &= 30 \text{ g/L NaCl} \\ \text{Amount of NaCl in 200 L} &= 200 \times 30 = 6000 \text{ g} \\ \text{CaCO}_3 \text{ equivalents} &= 6000 \times \frac{50}{58.5} = 5128.20 \text{ g} \\ \text{Hardness of 10,000 L of water} &= 5128.20 \times \frac{1000}{10,000} \times \frac{100}{\% \text{ Exhausted}} \\ &= 5128.20 \times \frac{1000}{10,000} \times \frac{100}{90} \\ &= 569.80 \text{ ppm}\end{aligned}$$

Q 24. On burning 0.3 gm of a solid fuel in a bomb calorimeter, the temperature of 3500 gm of water increased from 26.5° C to 29.2° C. Water equivalent of calorimeter and latent heat of steam are 385.0 gm and 587.0 cal/gm, respectively. If the fuel contains 0.7% hydrogen, calculate its gross and net calorific value. (2016-17)

$$\begin{aligned}\text{Ans. Wt. of coal (x)} &= 0.3 \text{ g} \\ W &= 3500 \text{ g}\end{aligned}$$

$$w = 385 \text{ g}$$

$$t_2 - t_1 = 29.2 - 26.5 = 2.7^\circ \text{ C}$$

$$\%H = 0.7$$

$$\text{Latent heat of steam} = 587 \text{ cal/g}$$

$$\text{HCV} = \frac{(W+w)(t_2-t_1)}{X}$$

$$= \frac{(3500+385)(2.7)}{0.3} = 34965 \text{ cal/g}$$

$$\text{LCV} = \text{HCV} - 0.09(\%H)(587)$$

$$= 34965 - 0.09(0.7)(587) = 34928.019 \text{ cal/g}$$

Q26. The percentage composition of coal is C= 85%, H= 5%, O=6%, N= 4%, S= 2%, ash= 5% and moisture= 3%. Calculate the minimum amount of air needed in combustion of 1 Kg of coal. (2016-17)

Ans. 1 Kg coal = 1000 g

$$C = \frac{85}{100} \times 1000 = 850 \text{ g}$$

$$H = \frac{5}{100} \times 1000 = 50 \text{ g}$$

$$O = \frac{6}{100} \times 1000 = 60 \text{ g}$$

$$N = \frac{4}{100} \times 1000 = 40 \text{ g}$$

$$S = \frac{2}{100} \times 1000 = 20 \text{ g}$$

$$\text{Net } O_2 = \frac{32}{12} C + 8H + S - O$$

$$= \frac{32}{12} \times 850 + 8 \times 50 + 20 - 60$$

$$= 2266.67 + 400 + 20 - 60$$

$$= 2626.67 \text{ g}$$

$$\text{Weight of air required} = \text{Net } O_2 \times \frac{100}{23}$$

$$= 2626.67 \times \frac{100}{23}$$

$$= 11420.29 \text{ g}$$

Q27. A sample of coal contains C= 70%, O= 20%, H= 8%, S= 1%, N= .5% and ash= .5%. Calculate GCV and NCV of coal. (2017-18, 2016-17)

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

$$\text{GCV} = \frac{1}{100} [8080 (70) + 34500 (8 - \frac{20}{8}) + 2240 (1)] = 7575.9 \text{ cal/g}$$

$$\begin{aligned}
 \text{NCV} &= \text{GCV} - 0.09(\%H)(587) \\
 &= 7575.9 - 0.09(8)(587) \\
 &= 7153.26 \text{ cal/g}
 \end{aligned}$$

Q28. A sample of coal contains C= 60%, O= 33%, H= 6%, S= 0.5%, N= 0.2% and ash= 0.3%. Calculate GCV and NCV of coal. (2018-19, 2017-18)

Ans.

$$\begin{aligned}
 \text{GCV} &= \frac{1}{100} [8080\%C + 34500 (\%H - \frac{\%O}{8}) + 2240\%S] \\
 \text{GCV} &= \frac{1}{100} [8080 (60) + 34500 (6 - \frac{33}{8}) + 2240 (0.5)] = 5506.07 \text{ cal/g}
 \end{aligned}$$

$$\begin{aligned}
 \text{NCV} &= \text{GCV} - 0.09(\%H)(587) \\
 &= 5506.07 - 0.09(6)(587) \\
 &= 5189.09 \text{ cal/g}
 \end{aligned}$$

Q29. Calculate the mass of air needed for combustion of 5 Kg of coal containing 80% Carbon, 15% hydrogen and rest oxygen. (2015-16)

Ans.

$$\begin{aligned}
 \text{Net O}_2 &= \frac{32}{12} \times 4000 + 8 \times 750 - 250 \\
 &= 10666.6 + 6000 - 250 \\
 &= 16416.66 \text{ g} \\
 \text{Weight of air} &= \text{Net O}_2 \times \frac{100}{23} \\
 &= 71376.52 \text{ g}
 \end{aligned}$$

Q30. Calculate GCV and NCV of coal having the following compositions: C = 80%, H = 9%, O = 4%, S = 2.5%, N = 1.5%, ash = 3% (2018-19)

Ans.

$$\begin{aligned}
 \text{GCV} &= \frac{1}{100} [8080\%C + 34500 (\%H - \frac{\%O}{8}) + 2240\%S] \\
 \text{GCV} &= \frac{1}{100} [8080 \times 80 + 34500 (9 - \frac{4}{8}) + 2240 \times 2.5] \\
 &= [6464 + (3105 - 172.5) + 56] \\
 &= 9452.5 \text{ cal/g} \\
 \text{NCV} &= \text{GCV} - 0.09(\%H)(587) \\
 &= 9452.5 - 0.09(9)(587) \\
 &= 8977.03 \text{ cal/g}
 \end{aligned}$$

Q31. A sample of water using $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ as coagulant at the rate of 139 ppm gave the following results on analysis $\text{Ca}^{++} = 160 \text{ ppm}$, $\text{Mg}^{++} = 72 \text{ ppm}$, $\text{CO}_2 = 88 \text{ ppm}$, $\text{HCO}_3^- = 488 \text{ ppm}$. Calculate lime and soda required to soften 1,00,000 L of water. (2015-16)

Ans.

Impurity	Quantity (mg/L)	Eq. Wt.	CaCO ₃ Equiv. (mg/l)	L or S
Ca ⁺⁺	160	20	$160 \times \frac{50}{20} = 400$	S
Mg ⁺⁺	72	12	$72 \times \frac{50}{12} = 300$	L + S
CO ₂	88	22	$88 \times \frac{50}{22} = 200$	L
HCO ₃ ⁻	488	61	$488 \times \frac{50}{61} = 400$	L - S
FeSO ₄ .7H ₂ O	139	139	$139 \times \frac{50}{139} = 50$	L + S

$$\text{Lime} = \frac{74}{100} [\text{Mg}^{++} + \text{HCO}_3^- + \text{CO}_2 + \text{FeSO}_4.7\text{H}_2\text{O}] \text{ all as CaCO}_3 \text{ eq.} \times \frac{\text{Vol. of water}}{10^6}$$

$$= \frac{74}{100} [300 + 400 + 200 + 50] \times \frac{1,00,000}{10^6}$$

$$= 70.300 \text{ Kg}$$

$$\text{Soda} = \frac{106}{100} [\text{Ca}^{++} + \text{Mg}^{++} - \text{HCO}_3^- + \text{FeSO}_4.7\text{H}_2\text{O}] \text{ all as CaCO}_3 \text{ eq.} \times \frac{\text{Vol. of water}}{10^6}$$

$$= \frac{106}{100} [400 + 300 - 400 + 50] \times \frac{1,00,000}{10^6}$$

$$= 37.1 \text{ Kg}$$

Q32. Calculate the weight and volume of air required for combustion of 3 Kg of carbon. (2011-12)

$$\text{Ans. Weight of air} = \text{Net O}_2 \times \frac{100}{23}$$

$$\text{Net O}_2 = \frac{32}{12} \times \text{C} = \frac{32}{12} \times 3000 = 8000 \text{ gm}$$

$$\text{Weight of air} = \text{Net O}_2 \times \frac{100}{23}$$

$$= 8000 \times \frac{100}{23} = 34782.6 \text{ gm}$$

$$\text{Volume of air} = \text{Net O}_2 \times \frac{100}{21}$$

$$\text{Net O}_2 = \frac{22.4}{32} \times 8000 = 5600 \text{ L}$$

$$\text{Volume of air} = \text{Net O}_2 \times \frac{100}{21}$$

$$= 5600 \times \frac{100}{21} = 26666.67 \text{ L}$$

Q33. 3.25 gm of coal was kjeldahlized and NH_3 gas thus evolved was absorbed in 45 ml of 0.1 N H_2SO_4 . To neutralize excess acid, 11.5 ml of 0.1 N NaOH was required. Determine the percentage of nitrogen in the coal sample. (2011-12)

Ans. Amount of acid used = Total amount of acid – Volume of NaOH used

$$= 45 - 11.5$$

$$= 33.5 \text{ ml}$$

$$\text{Percentage of nitrogen} = \frac{\text{Vol. of acid used} \times \text{Normality of acid} \times 1.4}{\text{Weight of coal sample}}$$

$$= \frac{33.5 \times 0.1 \times 1.4}{3.25}$$

$$= \frac{4.69}{3.25}$$

$$= 1.44 \%$$

Q34. A sample of coal containing 92% C, 5% H and 3% ash. When this coal was tested in laboratory for its calorific value in a bomb calorimeter, the following data were obtained:

Weight of coal burnt = 0.95 gm

Weight of water taken = 700 gm

Water equivalent of calorimeter = 2000 gm

Rise in temperature = 2.48°C

Cooling Correction = 0.02°C

Fuse wire correction = 10 Cal

Acid Correction = 60 Cal

Calculate the gross and net calorific value of coal in Cal/gm (Assume the latent heat of condensation as 580 Cal/gm) (2011-12)

Ans. $\text{GCV} = \frac{(W+w)(t_2-t_1+C_c) - (C_A+C_f+C_{CT})}{X}$

$$= \frac{(700 + 2000)(2.48 + 0.02) - (60 + 10)}{0.95}$$

$$= \frac{(2700)(2.50) - (70)}{0.95}$$

$$= \frac{6680}{0.95} = 7031.57 \text{ cal/gm}$$

$$\text{LCV} = \text{HCV} - 0.09(\%H) \text{ Latent heat of steam}$$

$$\text{LCV} = 7031.57 - 0.09(5)(580)$$

$$= 7031.57 - 261$$

$$= 6770.57 \text{ cal/gm}$$

Q35. A sample of coal was analysed as follows: Exactly 1.51 gm of was weighed into a silica crucible. After heating for 1 hr at 110°C , the residue weighed 1.417 gm. The crucible was then strongly heated for exactly 7 min at 950°C . The residue weighed 0.528 gm. The residue was then heated until a constant weight of residue was obtained. The last residue was found to be 0.254 gm. Calculate the percentage result of above analysis. (2010-11)

Ans. Weight of moisture = $1.51 \text{ gm} - 1.417 \text{ gm} = .093 \text{ gm}$

$$\begin{aligned}\text{Percentage of moisture: \% Moisture} &= \frac{\text{Wt. of moisture}}{\text{Wt. of coal sample}} \times 100 \\ &= \frac{0.093}{1.51} \times 100 \\ &= 6.15\%\end{aligned}$$

$$\text{Weight of Volatile matter} = 1.417 \text{ gm} - 0.528 \text{ gm} = .0.889 \text{ gm}$$

$$\begin{aligned}\% \text{Volatile matter} &= \frac{\text{Wt. of volatile matter}}{\text{Wt. of coal sample}} \times 100 \\ &= \frac{.0889}{1.51} \times 100 \\ &= 58.87\%\end{aligned}$$

$$\begin{aligned}\text{Percentage of Ash: \% Ash} &= \frac{\text{Wt. of ash}}{\text{Wt. of coal sample}} \times 100 \\ &= \frac{0.254}{1.51} \times 100 \\ &= 16.82\%\end{aligned}$$

$$\begin{aligned}\text{Percentage of oxygen} &= 100 - (\% \text{ Moisture} + \% \text{Volatile matter} + \% \text{ Ash}) \\ &= 100 - (6.51 + 58.87 + 16.82) \\ &= 100 - 82.2 \\ &= 17.8\%\end{aligned}$$

Q36. Calculate temporary, permanent and total hardness of water sample that is analysed as: $\text{Mg}(\text{HCO}_3)_2 = 7.3 \text{ mg/l}$, $\text{Ca}(\text{HCO}_3)_2 = 8.1 \text{ mg/l}$, $\text{MgCl}_2 = 9.5 \text{ mg/l}$ and $\text{CaSO}_4 = 6.8 \text{ mg/l}$ (2010-11)

Ans.

Impurity	Quantity (mg/L)	Eq. Wt.	CaCO_3 Equi. (mg/l)
$\text{Ca}(\text{HCO}_3)_2$	8.1	81	$\frac{8.1 \times 50}{81} = 5$
$\text{Mg}(\text{HCO}_3)_2$	7.3	73	$\frac{7.3 \times 50}{73} = 5$
MgCl_2	9.5	47.5	$\frac{9.5 \times 50}{47.5} = 10$
CaSO_4	6.8	68	$\frac{6.8 \times 50}{68} = 10$

$$\begin{aligned}\text{Temporary Hardness} &= \text{Hardness due to } [\text{Ca}(\text{HCO}_3)_2 + \text{Mg}(\text{HCO}_3)_2] \\ &= 5 + 5 = 10 \text{ ppm}\end{aligned}$$

$$\begin{aligned}\text{Permanent Hardness} &= \text{Hardness due to } [\text{MgCl}_2 + \text{CaSO}_4] \\ &= 10 + 10 = 20 \text{ ppm}\end{aligned}$$

$$\begin{aligned}\text{Total Hardness} &= \text{Temporary Hardness} + \text{Permanent Hardness} \\ &= 10 + 20 = 30 \text{ ppm}\end{aligned}$$

Q37. Following data was obtained in a bomb calorimeter experiment:

Weight of crucible= 3.649 gm

Weight of fuel= 1.029 gm

Weight of water in calorimeter 2200 gm

Water equivalent of calorimeter= 570 gm

Rise in temperature= 2.3°C

Cooling Correction= 0.047°C

Fuse wire correction= 3.8 Cal

Acid Correction= 62.6 Cal

Cotton thread correction= 1.6 Cal

Calculate GCV of fuel sample. If the fuel contains 6.0% H, determine the NCV (2010-11)

$$\text{Ans. GCV} = \frac{(W+w)(t_2-t_1+C_c) - (C_A+C_F+C_{CT})}{X}$$

$$= \frac{(2200 + 570) (2.3 + 0.047) - (62.6 + 3.8 + 1.6)}{1.029}$$

$$= \frac{(2770) (2.347) - (68)}{1.029}$$

$$= \frac{6433.19}{1.029} = 6251.885 \text{ cal/gm}$$

LCV = HCV - 0.09(%H) Latent heat of steam

$$\text{LCV} = 6251.885 - 0.09(6) (587)$$

$$= 6256.445 - 316.98$$

$$= 5939.46 \text{ cal/gm}$$

Q38. A sample of hard water has a hardness of 500 ppm. Express the hardness in °Clark and °French. (2009-10)

Ans. Hardness of water sample 500 ppm

$$\text{Hardness in } ^\circ\text{Clark} = 500 \times 0.07 ^\circ\text{Cl}$$

$$= 35 ^\circ\text{Cl}$$

$$\text{Hardness in } ^\circ\text{French} = 500 \times 0.1 ^\circ\text{Cl} = 50 ^\circ\text{F}$$

Q39. The percentage composition of coal sample is: C = 70%, H₂ = 10%, O₂ = 1%, S = 5%, ash = 0.5 and N = 0.3%.

i) Calculate the quantity of air needed for complete combustion of 1 Kg of coal, if 60% excess of air is supplied.

ii) Calculate the gross and net calorific value of coal using Dulong's formula. (2020-21)

Ans.i) (N and ash are not combustible, so no calculations required for them)

$$\text{Weight of C in 1 kg coal} = \frac{70}{100} \times 1000 \text{ g} = 700 \text{ g}$$

$$\text{Weight of H in 1 kg coal} = \frac{10}{100} \times 1000 \text{ g} = 100 \text{ g}$$

$$\text{Weight of S in 1 Kg coal} = \frac{5}{100} \times 1000 \text{ g} = 50 \text{ g}$$

$$\text{Weight of O in 1 kg coal} = \frac{1}{100} \times 1000 \text{ g} = 10 \text{ g}$$

$$\text{O}_2 \text{ quantity} = \left(\frac{32}{12} \text{C} + 8\text{H} + \text{S} - \text{O} \right) \text{ g} = \left(\frac{32}{12} \times 700 + 8 \times 100 + 50 - 10 \right) \text{ g} = 2730 \text{ g}$$

$$\text{Minimum amount of air} = \text{Net O}_2 \times \frac{100}{23} = 2730 \times \frac{100+60}{23} = 18,991.30 \text{ g air}$$

$$\begin{aligned} \text{ii) GCV} &= \frac{1}{100} \left[8080\text{C} + 34500 \left(\frac{\text{H}-\text{O}}{8} \right) + 2240\text{S} \right] \\ &= \frac{1}{100} \left[8080 \times 700 + 34500 \left(100 - \frac{10}{8} \right) + 2240 \times 50 \right] \\ &= 5656 + 34068.75 + 1120 \\ &= 40,844.75 \text{ g} \end{aligned}$$

$$\begin{aligned} \text{NCV} &= \text{GCV} - 0.09(\% \text{H}) \times \text{latent heat of steam} \\ &= 40,844.75 - 0.09 (10) \times 587 \\ &= 40,844.75 - 528.3 \\ &= 40316.45 \text{ g} \end{aligned}$$