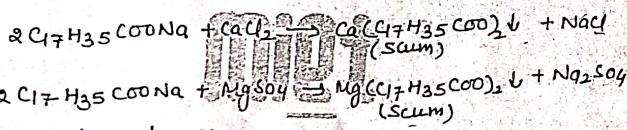


Lecture - 27

Potable (drinking) water:- Potable water, also known as drinking water, comes from surface + ground sources + is treated to levels that meet standards for consumption.

Hardness of water:- " Hardness of water is defined as the soap consuming capacity of water"

- Chlorides, carbonates, bicarbonates + sulphates of Ca^{+2} , Mg^{+2} + Fe^{+2} causes hardness.
- Hard water reacts with soap to produce white precipitate or scum.



expression of Hardness:

- Parts per million (PPM).
- Milli grams per liter (mg/l).
- Claude's degree ($^{\circ}\text{CH}$)
- French degree ($^{\circ}\text{Fr}$)

Boiler feed water:- During conversion of water into steam in boiler, the dissolved solids are not removed. All the impurities are deposited in form of scale + sludge within the boiler + causes boiler troubles.

- Priming or wet steam: The carrying out of water droplets with steam drum is called " priming "

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

scale:- Scales are hard sticky deposits on the walls of boiler.

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

caustic-embrittlement:- The NaOH causes cracks in boiler walls. The formation of cracks in boiler due to NaOH is called embrittlement.

Boiler corrosion:- It is the decay of the boiler material due to environmental factors.

Internal Treatment of water

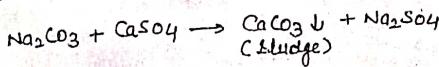
In this method water is treated inside the boiler. This is corrective method. To convert the scale forming substance into sludge forming substance. also called conditioning method.

- Carbonate conditioning
- Calgon conditioning
- Phosphate treatment

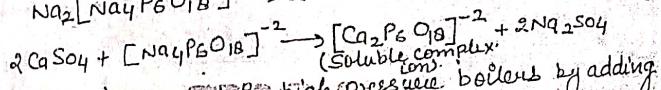
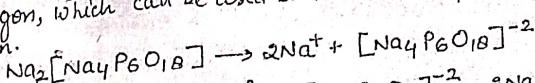
B. Tech I Year [Subject Name: Engineering Chemistry]

Ques-1 Discuss the different methods of internal treatment for boiler feed water (2014-2015)

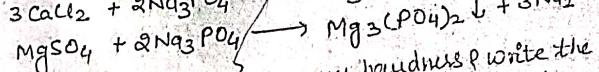
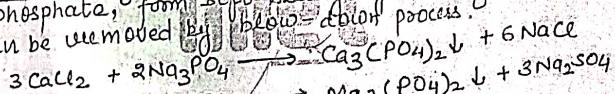
Carbonate conditioning:- Used in low pressure boilers. Boiler water is treated with Na_2CO_3 .



Calgon conditioning:- Sodium hexa-metaphosphate $\text{Na}_2[\text{Na}_4\text{P}_6\text{O}_{18}]$ is called calgon, which can be used to convert CaSO_4 into soluble complex ion.

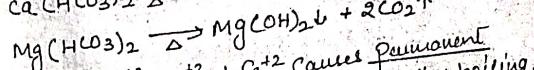
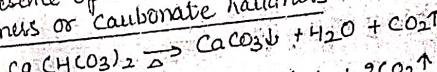


Phosphate conditioning:- Used in high pressure boilers by adding sodium phosphate, form soft sludge of $\text{Ca} + \text{Mg}$ phosphates which can be removed by blow-down process.



Ques-2 What is permanent & temporary hardness & write the constituent responsible for them & how can they be removed? (2014-2015) (2015-2016)

M.g.n.f Due to the presence of bicarbonates & carbonates of $\text{Ca} + \text{Mg}$, temporary hardness or carbonate hardness arises.



Chlorides & sulphates of Ca^{2+} , Mg^{2+} & Fe^{2+} cause permanent hardness or non-carbonate hardness. It can't be removed by boiling. Can be removed by Zeolite, Lime-Soda etc.

B. Tech I Year [Subject Name: Engineering Chemistry]

Ques-2 Describe sludge scale or explain the process of scale & sludge formation in boilers. How can this be prevented & or distinguished between scale & sludge. (2014-15) (2016-2017) (2018-2019)

Ans:-

Sludge	Scale
It's soft, loose & slimy precipitate	It forms hard deposits
They form non-adherent deposits & can be easily removed.	They stick firmly to the inner surfaces of the boiler & are very difficult to remove.
Formed by CaCl_2 , MgCl_2 , MgCO_3 , $\text{MgCO}_3 \cdot \text{H}_2\text{O}$.	Formed by substance like CaCO_3 , Mg(OH)_2 etc.
Formed at comparatively colder portion of the boiler.	Formed at heated portion of the boiler.
Less dangerous.	Chances of explosion are there.
Can be removed by blow-down operations.	Can not be removed by blow-down operations.

Ques-4 Why is calgon conditioning better than phosphate conditioning? (2015-2016) (2017-18) (2018-2019)

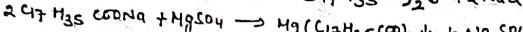
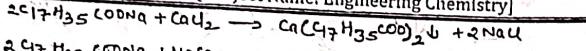
Ans:- calgon conditioning

Explanation:- In calgon conditioning the added calgon forms soluble complex compound with Ca^{2+} , thereby it prevents the scale & sludge formation water. This soluble complex does not cause any problem in boilers. On the other hand, in phosphate conditioning precipitate of calcium-phosphate is formed. Although this precipitate is non-adherent & soft. It has to be removed by frequent blow down operations.

Ques-5 Define hardness. Why it's conventional to express hardness in terms of CaCO_3 at the international level & write other units also. How are they inter-related? OR why hardness of water is expressed in terms of CaCO_3 equivalence? (2015-2016) (2018-2019)

Ans:- "Soap consuming capacity of water" is known as hardness of water. Chlorides, carbonates, bicarbonates & sulphates of Ca^{2+} , Mg^{2+} & Fe^{2+} cause hardness. When hard water reacts with soap to produce white scum or precipitates.

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Both temporary & permanent hardness are expressed in ppm (parts per million) of $CaCO_3$. The choice of $CaCO_3$ is due to the fact that—

- 1- $CaCO_3$ molecular weight is 100 & equivalent weight is 50.
- 2- It's most insoluble salt in water.

Ques-6 What is potable water? what are the chemical requirements? (2016-2017)

- Ans:-
- 1- It should be colourless, clean & odourless.
 - 2- It should be free from bacteria & impurities.
 - 3- It should be cool & pleasant to taste.
 - 4- It should be free from dissolved gases like CO_2 , H_2S , NH_3 etc. & poisonous minerals like Lead (Pb), Arsenic (As), manganese (Mn)
 - 5- Hardness should be less than 500 ppm.
 - 6- Chloride ion content should be less than 250 ppm.
 - 7- Fluoride ion content should be less than 1.5 ppm.
 - 8- Total dissolved solids (TDS) content should be less than 500 ppm.
 - 9- pH of potable water should be 6.5 - 8.5.

Ques-7 A sample of water was found to contain 40.5 mg/L $Ca(HCO_3)_2$, 46.5 mg/L $Mg(HCO_3)_2$, 32.1 mg/L $CaCO_3$, 27.6 mg/L $MgSO_4$, 22.45 mg/L $NaCl$, 19.0 mg/L $MgCl_2$ & 4.8 mg/L $NaHCO_3$. Calculate the temporary & permanent hardness of water sample (2016-2017).

Impurity	Quantity (mg/L)	Eq. wt.	Hardness
$Ca(HCO_3)_2$	40.5 mg/L	81	$= 40.5 \times \frac{50}{81} = 25$
$Mg(HCO_3)_2$	46.5 mg/L	73	$= 46.5 \times \frac{50}{73} = 31.8$
$CaCO_3$	32.1 mg/L	60	$= 32.1 \times \frac{50}{60} = 26.8$
$MgSO_4$	27.6 mg/L	60	$= 27.6 \times \frac{50}{60} = 23$
$NaCl$	22.45 mg/L	55.5	$= 22.45 \times \frac{50}{55.5} = 20.27$
$MgCl_2$	19.0 mg/L	47.5	$= 19 \times \frac{50}{47.5} = 20$

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Ques-6 What is calgon conditioning? Explain or show with the help of reaction, how scale formation can be prevented by calgon conditioning. (2017-2018) (2018-19)

Ans:- Explained in Question No-1

Ques-7 100 ml of water sample has hardness to 12.5 mg/L $MgSO_4$ solutions, calculate the hardness of this water sample. (2018)

Ans:- NIVI of water sample = $N_1 V_2$ of $MgSO_4$

$$N_1 \times 100 = 0.8 \times 12.5$$

$$N_1 = 0.1$$

Hardness = $N_1 \times$ Equivalent weight of $CaCO_3$

$$\text{Hardness} = 0.1 \times 50$$

$$= 0.5 \text{ PPM}$$

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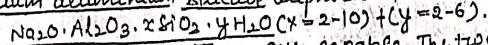
Lecture No: 27

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Lecture - 28(External treatment of water)

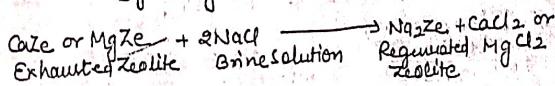
External treatment involves reducing impurities from the water that exists outside the bodies. This method is needed when the impurities are present in high concentration. There are various methods of external treatment such as -

Zeolite OR Perlmutt method :- The chemical formula of zeolite is hydrated sodium aluminium silicate represented as -



Zeolite can be written as Na_2Ze . These are capable. The two Na^+ ions replaced by one Ca^{+2} or Mg^{+2} ions.

Working:- It involves 2 steps:-

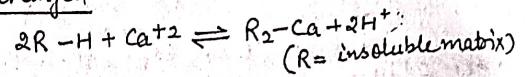
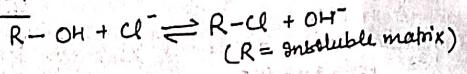
1. Water softening :-2. Regeneration :- By using concentrated brine solution

Ion Exchange Resins - These are high molecular weight, insoluble cross-linked organic polymers having porous structure.

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

Working - Ion exchange resins consist of a column

- cation Exchanger column.
- Anion Exchanger column.

Reactions:Step-I Water softeningCation exchangeAnion exchangeReverse Osmosis :-

Pressure higher than osmotic pressure is applied on the concentrated solution side so that the flow of the solvent is reversed. This method is applicable mainly for the desalination of sea water separated through a semipermeable membrane.

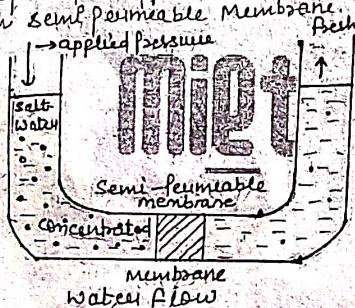
B. Tech I Year [Subject Name: Engineering Chemistry]

Ques-1 Explain reverse osmosis process! (2014-15) (2016-17) (2018-19)

Ans:- 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 the dilute solution. This method is applicable mainly for the desalination of sea water. Sea water & pure water are separated by a semi-permeable membrane.

Method!: Sea water or polluted water is filled in reverse osmosis cell. Pressure of 200 p.s.i. is applied on water to force the solvent to flow through semi-permeable membrane.



Ques-2 What are Ion-Exchange Resins? How will you purify water using the same? calculate the lime & soda needed for softening 50,000 L of water containing the following salts. The following salts $\text{CaSO}_4 = 13.6 \text{ mg/L}$; $\text{MgCl}_2 = 9.5 \text{ mg/L}$; $\text{Mg}(\text{HCO}_3)_2 = 7.3 \text{ mg/L}$; $\text{Ca}(\text{HCO}_3)_2 = 16.2 \text{ mg/L}$. Given that the molar mass of $\text{Ca}(\text{HCO}_3)_2$ is 162 & that of MgCl_2 is 95.

Ans:- Ion Exchange Resin!:- Used for producing demineralised or deionised water. These are high molecular weight, insoluble cross-linked organic polymers having porous structure.

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There are two types of Ion-exchangers.

(i) **Cation Exchange Resin**: Have loosely held H^+ ions exchanged by hardness producing cations (Ca^{2+} , Mg^{2+}).

(ii) **Anion Exchange Resin**: Have loosely held OH⁻ ions exchanged by hardness producing anions (Cl^- , SO_4^{2-}).

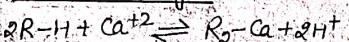
Principle!: They are capable of exchanging hardness (cations as well as anions) in water with their H^+ & OH^- .

Working!: Ion exchange process consists of two stages:

(i) Cation Exchange column (ii) Anion Exchange column

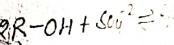
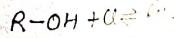
Reactions! Step I - Water Softening

Cation Exchange! -



R^2 = Insoluble Matrix

Anion Exchange



R^2 = Insoluble Matrix

Step-II Regeneration of Ion-Exchangers!

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

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

Advantages!:-

- 1. No Ionic impurities
- 2. Occupies less space
- 3. Easy to operate
- 4. Negligible cost

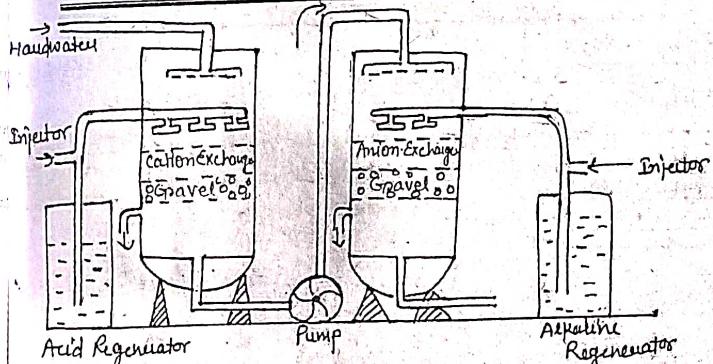
Limitations!:-

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

Numerical:-

* Numerical will be solved in L-Space

Lecture No: 28



Q4-3 What are Ion Exchange units? With the help of neat sketch, discuss Ion-Exchange process for water softening. Compare its merit over Zeolite process. (2014-15) (2016-17) (2018-19)

Ans:- Discussed in Question 12

Ion-Exchange-process	Zeolite Process
Remove all positive + negative ions from water.	Removes only cations causing hardness in water.
No Sodium salts in treated water	Treated water contains high amount of sodium salts.
Initial cost is high	Initial cost is lower
Running cost is higher	Running cost is lower, as NaCl is very cheap
Acidic water can be purified	Acidic water can't be purified
We can use hot water.	We can't use hot water.
1-2 ppm hardness can be achieved	15 ppm Hardness can be achieved

M.Qn Q4-4 The hardness of water sample (10,000 L) was completely removed by passing through a Zeolite Softener. The zeolite softener then required 200 L of NaCl solution containing 150 g./L of NaCl for regeneration. Find out the hardness of water sample (2014-2015) (2017-2018)

Ans:- 200 L of NaCl contains = 200×1.50
= 30,000 gm. NaCl

$$\text{CaCO}_3 \text{ Equivalent} = 30,000 \times \frac{50}{58.5}$$

$$= 25641.025 \text{ gm/L}$$

$$\text{Hardness of } 10,000 \text{ L of water} = 25641.025 \times \frac{1000}{10,000}$$

Ans = 2564.1025 ppm

M.Qn Q4.5 What do you mean by term Permutit? Explain Zeolite process of water softening. (2014-15), (2015-16) (2017-18) (2018-19)

Ans:- The word permutit means boiling stone. Zeolites are hydrated sodium alumina silicates. They have porous structure with molecular formula $\text{Na}_2\text{Ze}(\text{Al}_2\text{O}_3)\text{Si}_2\text{O}_7 \cdot 4\text{H}_2\text{O}$.
 $Cx = 2 \text{ to } 10 + Y = 2 \text{ to } 6$.

Represented as Na_2Ze (Ze = the insoluble framework; Na = loosely held sodium ions)

Principle of Zeolite process:- They exchange their loosely held sodium ions irreversibly with the hardness producing cations in water ($\text{Ca}^{+2} + \text{Mg}^{+2}$)

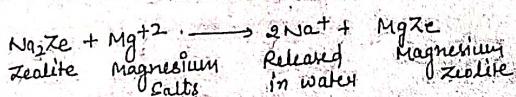
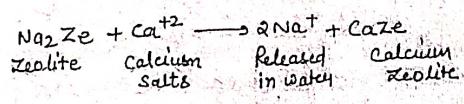
Working:- It involves 2 steps:-

1- Water Softening

2- Regeneration

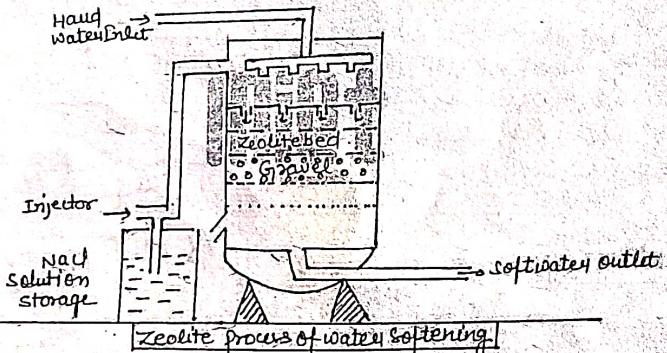
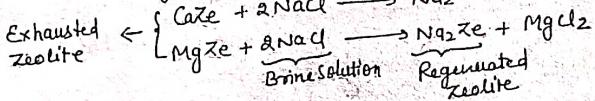
B. Tech I Year [Subject Name: Engineering Chemistry]

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 + operation is clean.
- 4- Automatically adjusts itself according to the hardness of water.
- 5- Equipment is compact + operation is easy.

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Disadvantages:-

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

Limitations:-

- 1- Turbid water cannot be treated.
- 2- Acidic water cannot be treated.
- 3- Hot water cannot be treated.
- 4- If used for heavy metal ions like Fe^{+3} or Al^{+3} zeolite can not be regenerated.

Ques-6 a zeolite softener was 90% exhausted by removing hardness completely when 10,000 litres of hard water were passed through it. The exhausted zeolite bed required 1 litres of 3% of NaCl solution for its complete regeneration calculate the hardness of water/solution (2016-17)

Ans:- 3% NaCl solution = $\frac{30 \text{ gm}}{100 \text{ gm}} \times 1000 \times 30 = 9000 \text{ gm}$
Amount of NaCl = $\frac{9000 \text{ gm}}{200 \text{ ml}} = 6000 \text{ gm}$

$$\text{CaCO}_3 \text{ equivalents} = 6000 \times \frac{50}{58.5}$$

$$= 5120.20 \text{ gm}$$

$$\text{Hardness of } 10,000 \text{ L of water} = 5120.20 \times \frac{1000}{10,000}$$

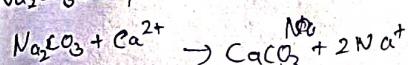
$$= 569.80 \text{ ppm}$$

* Hardness is always defined for 1 lit of H_2O + what the % of exhausted zeolite that should not be included in the calculation of hardness of sample.

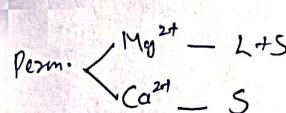
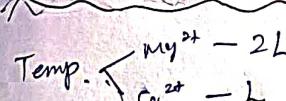
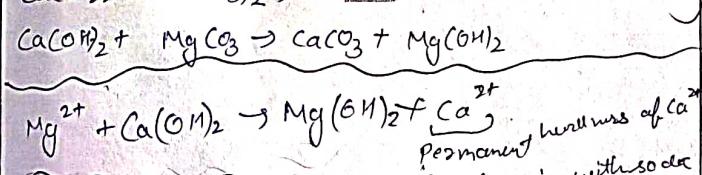
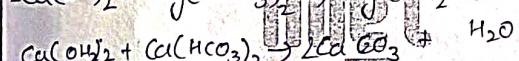
Ques-7 why zeolite softener is not recommended for obtaining feed water for high pressure boilers (2017-18)

Ans:- Sodium zeolite water softens the hard water by removing Ca + Mg hardness salts by replacing those ions with Na, so that the water becomes soft. But usually the TDS increases with the anions (SO_4^{2-} , CO_3^{2-}) of the above minerals that combines with Na. What we need is demineralized water for high pressure boilers which is not possible in zeolite process.

$\text{Na}_2\text{CO}_3 \rightarrow$ permanent hardness due to Ca^{2+} & its compound.



$\text{Ca(OH)}_2 \rightarrow$ Temp. hardness due to $\text{Ca}(\text{HCO}_3)_2$, $\text{Mg}(\text{HCO}_3)_2$



Te / 18
Date

Topic
Lime
Soda

Lecture - 29

Lime - Soda Process

Principle:-

- * By adding calculated amounts of lime $\text{Ca}(\text{OH})_2$ + 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 $\text{Mg}(\text{OH})_2$ which can be easily filtered out.

$$\text{Lime} = \frac{74}{100} \left[\text{temp Ca salts} + 2 \times \text{temp Mg salts} + \text{permanent salts of } (\text{Mg}^{2+} + \text{Fe}^{2+} + \text{Al}^{3+}) + \text{CO}_2 + \text{HCl/H}_2\text{SO}_4 + \text{HCO}_3^- - \text{NaAlO}_2 \text{ (all in terms of } \text{CaCO}_3 \text{ equivalent)} \right]$$

$$\times \frac{100}{\% \text{ purity}} \times \frac{\text{Volume of water}}{10^6} \text{ in kg}$$

$$\text{soda} = \frac{106}{100} \left[\text{permanent } (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Fe}^{2+} + \text{Al}^{3+}) \text{ HCl/H}_2\text{SO}_4 - \text{HCO}_3^- \right] \text{ all in terms of } \text{CaCO}_3 \text{ equivalent}$$

$$\times \frac{100}{\% \text{ purity}} \times \frac{\text{Volume of water}}{10^6} \text{ in kg}$$

Ques:- What is the basic principle of Lime-Soda process? A water sample, using $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ as a coagulant at the rate of 139 ppm gave the following results on analysis: Ca^{2+} 160 ppm, CO_2 = 08 ppm, Mg^{2+} = 72 ppm, HCO_3^- = 440 ppm. Calculate the lime + soda required to soften 100,000 litres of water. (2014-15) (2015-16) (2017-18)

Principle:- By adding calculated amounts of lime $\text{Ca}(\text{OH})_2$ + soda Na_2CO_3 .

all the calcium salts are precipitated out as calcium carbonate
all the magnesium salts are precipitated as magnesium hydroxide $\text{Mg}(\text{OH})_2$ which can be easily filtered out

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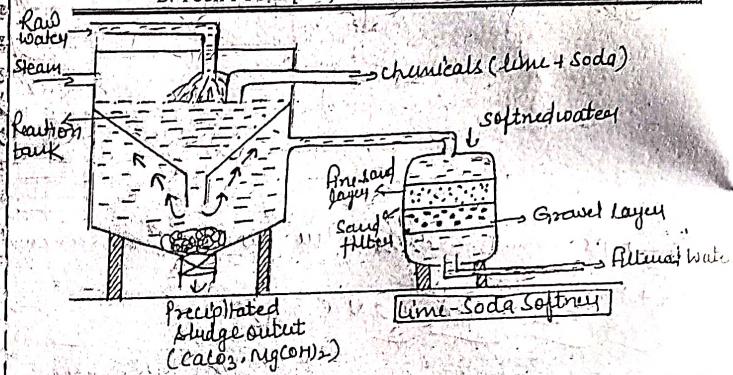
Working! - following reactions are involved.

Constituent	Reactions	Need
$\text{Ca}(\text{HCO}_3)_2$	$\text{Ca}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 \rightarrow 2\text{CaCO}_3 \downarrow + 2\text{H}_2\text{O}$	L
$\text{Mg}(\text{HCO}_3)_2$	$\text{Mg}(\text{HCO}_3)_2 + 2\text{Ca}(\text{OH})_2 \rightarrow 2\text{CaCO}_3 \downarrow + \text{Mg}(\text{OH})_2 \downarrow + 2\text{H}_2\text{O}$	2L
CaCl_2	$\text{CaCl}_2 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 \downarrow + 2\text{NaCl}$	S
CaSO_4	$\text{CaSO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 \downarrow + \text{Na}_2\text{SO}_4$	S
MgSO_4	$\text{MgSO}_4 + \text{Ca}(\text{OH})_2 \rightarrow \text{Mg}(\text{OH})_2 \downarrow + \text{CaSO}_4$ $\text{CaSO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 \downarrow + \text{Na}_2\text{SO}_4$	L+S
MgCl_2	$\text{MgCl}_2 + \text{Ca}(\text{OH})_2 \rightarrow \text{Mg}(\text{OH})_2 \downarrow + \text{CaCl}_2$ $\text{CaCl}_2 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 \downarrow + 2\text{NaCl}$	L+S
CO_2	$\text{CO}_2 + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCO}_3 \downarrow + \text{H}_2\text{O}$	L
HCO_3^-	$\text{HCO}_3^- + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCO}_3 \downarrow + \text{H}_2\text{O} + \text{CO}_3^{2-}$	L-S
FeSO_4	$\text{FeSO}_4 + \text{Ca}(\text{OH})_2 \rightarrow \text{Fe}(\text{OH})_2 \downarrow + \text{CaSO}_4$ $\text{Fe}(\text{OH})_2 + \text{H}_2\text{O} + \text{O}_2 \rightarrow \text{Fe}(\text{OH})_3 \downarrow$ $\text{CaSO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3 \downarrow + \text{Na}_2\text{SO}_4$	L+S
$\text{Al}_2(\text{SO}_4)_3$	$2\text{Al}_2(\text{SO}_4)_3 + 8\text{Ca}(\text{OH})_2 \rightarrow 2\text{Al}(\text{OH})_3 \downarrow + 3\text{CaSO}_4$ $3\text{CaSO}_4 + 3\text{Na}_2\text{CO}_3 \rightarrow 3\text{CaCO}_3 \downarrow + 9\text{Na}_2\text{SO}_4$	L+S
NaAlO_2	$\text{NaAlO}_2 + \text{H}_2\text{O} \rightarrow \text{Al}(\text{OH})_2 \downarrow + \text{NaOH}$ $2\text{NaOH} = 1\text{ equivalent to } \text{Ca}(\text{OH})_2$	-L
$\text{MgCO}_3 \rightarrow 2\text{L}$	$\text{H}^+ \rightarrow \frac{1}{2}\text{L} + \frac{1}{2}\text{S}$	
$\text{Ca}^{2+} \rightarrow \text{S}$	$\text{H}^+ \rightarrow \frac{1}{2}\text{L} + \frac{1}{2}\text{S}$	
$\text{Mg}^{2+} \rightarrow \text{L+S}$	$\text{H}_2\text{SO}_4 \rightarrow \text{L+S}$	

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Impurity	Quantity (mg/L)	Eq. wt	CaCO ₃ Equivalent (mg/L)	Loss
Ca^{2+}	160	20	$160 \times \frac{50}{20} = 400$	S
Mg^{2+}	72	12	$72 \times \frac{50}{12} = 300$	L+S
CO_2	80	22	$80 \times \frac{50}{22} = 180$	L
HCO_3^-	400	61	$400 \times \frac{50}{61} = 400$	L-S
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	139	189	$139 \times \frac{50}{189} = 50$	L+S

$$\text{Lime} = \frac{74}{100} [\text{Mg}^{2+} + \text{HCO}_3^- + \text{CO}_2 + \text{FeSO}_4 \cdot 7\text{H}_2\text{O}] \text{ all as CaCO}_3 \text{ eq. wt} \times \frac{100,000}{106}$$

$$= \frac{74}{100} [300 + 400 + 200 + 50] \times \frac{100,000}{106}$$

$$= 70,300 \text{ Kg}$$

$$\text{Soda} = \frac{106}{100} [\text{Ca}^{2+} + \text{Mg}^{2+} - \text{HCO}_3^- + \text{FeSO}_4 \cdot 7\text{H}_2\text{O}] \text{ all as CaCO}_3 \text{ eq. wt} \times \frac{1,00,000}{106}$$

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

$$= 87,1 \text{ Kg}$$

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B. Tech I Year [Subject Name: Engineering Chemistry]

Quesiton-6 calculate the quantities of lime (74%) + soda (94%) required for cold softening of 125,000 L of water with the following analysis, using 10 ppm of NaAlO₂ as coagulant. Analysis of raw water: Ca²⁺ = 160 ppm, Mg²⁺ = 48 ppm, CO₂ = 66 ppm, HCO₃⁻ = 264 ppm, H⁺ = 20 ppm, NaCl = 4.7 ppm. Analysis of treated water: CO₃²⁻ = 45 ppm, OH⁻ = 68 ppm. (2018-19)

Answer:

Dissolved	Quantity	Eq. wt	CaCO ₃ Eq (Mg/L)	Lime
Ca ²⁺	160	20	$160 \times \frac{50}{20} = 400$	S
Mg ²⁺	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	$68 \times \frac{50}{17} = 200$	L+S
NaAlO ₂	10	82	$10 \times \frac{50}{82} = 6.09$	-L
NaCl	4.7	—	No Hardness	—

$$\text{Lime} = \frac{74}{100} \left[\text{Mg}^{2+} + \text{CO}_2 + \text{HCO}_3^- + \text{H}^+ - \text{NaAlO}_2 \right] \text{all as CaCO}_3 \times \frac{100}{\text{eq.}} \times \frac{\text{Vol. lit.}}{10^6}$$

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

$$= 107.53 \text{ Kg}$$

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

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

$$= 97.39 \text{ Kg}$$

Question-7 A sample of water gave the following data on analysis: Ca²⁺ = 20 ppm, Mg²⁺ = 25 ppm, CO₂ = 30 ppm, HCO₃⁻ = 150 ppm, H⁺ = 10 ppm. Calculate the amount of lime (67%) + soda (91%) required to soften 10⁶ L of water. (2018-19)

Answer: Procedure explained in — 7
lime = 101.44 kg soda = Not Required

Question-8 calculate the quantities of lime + soda required for cold softening of 125,000 L of water with following analysis, using 10 ppm of NaAlO₂ as coagulant. Analysis of raw water: Ca²⁺ = 160 ppm, Mg²⁺ = 48 ppm, CO₂ = 66 ppm, HCO₃⁻ = 264 ppm, H⁺ = 20 ppm, NaCl = 4.7 ppm. Analysis of treated water: CO₃²⁻ = 45 ppm, OH⁻ = 68 ppm. (2019-2020)

Answer: lime = 220 kg Procedure explained in Question No - 6

$$\text{lime} = 220 \text{ Kg}$$

$$\text{soda} = 938.8 \text{ Kg}$$

Ques + 50 ml a sample of water required 12.5 ml of $\frac{N}{50} H_2SO_4$ at phenolphthalein end point. An additional 2.5 ml of $\frac{N}{50} H_2SO_4$ was used at methyl orange end point.

Calculate the different types of alkalinity present in the water sample.

Solution:

Phenolphthalein alkalinity :

Volume of acid used $A = 12.5 \text{ ml}$.

Water % acid

$$N_1 V_1 = N_2 V_2$$

$$N_1 \times 50 = \frac{1}{50} \times 12.5 \quad [A = V_2 = 12.5]$$

$$N_1 = \frac{1}{250} \times 12.5$$

$$\therefore \text{Strength in terms of } CaCO_3 \text{ equation} = \frac{1}{250} \times 12.5 \text{ gm/lit.}$$

$$\therefore \text{Phenolphthalein alkalinity} = \frac{1}{250} \times 12.5 \times 50 \text{ mg/l.}$$

Methyl orange alkalinity

$$\text{Further acid used} = B = 2.5$$

$$\text{Total Volume of acid used} = A + B$$

$$= 12.5 + 2.5 = 15.0 \text{ ml.}$$

Water % Acid.

$$N_3 V_3 = N_4 V_4 \quad [A + B = V_4 = 15.0 \text{ ml.}]$$

$$N_3 \times 50 = \frac{1}{50} \times 15.0$$

$$N_3 = \frac{1}{50} \times 15.0$$

$$\therefore \text{Strength in terms of } CaCO_3 \text{ equation} = \frac{1}{50} \times 15 \times 50 \text{ gm/lit.} \\ = 300 \text{ ppm.}$$

$$\text{Relation: } p(250 \text{ ppm}) > \frac{1}{2} M \left(\frac{1}{2} = 150 \right)$$

Nature:

$$OH^- \text{ alkalinity} = 29 - M = 29 - 250 - 300 \\ = 300 \text{ ppm.}$$

$$\begin{aligned} \text{CO}_3^{2-} \text{ alkalinity} &= 2(M-P) \\ &= 2(350 - 250) \\ &= 10 \text{ ppm.} \end{aligned}$$

Ans: 100 ml of water sample, on titration with $\text{N}_{\frac{1}{50}} \text{ H}_2\text{SO}_4$ using phenolphthalein as indicator, gave the end point when 10 ml of acid were run down. Another lot of 100 ml of the sample also required 10 ml of the acid at methyl orange end point. What is the alkalinity of the sample? Comment on its nature.

Solution: Phenolphthalein alkalinity:

$$\text{Volume of acid used} = A = 10 \text{ ml.}$$

Water ∇_1 Acid.

$$N_1 V_1 = N_2 V_2.$$

$$N_1 \times 100 = \frac{1}{50} \times 10 \quad [A = V_2].$$

$$N_1 = \frac{1}{50} \times \frac{10}{100}.$$

$$\begin{aligned} \text{Strength in terms} &= \frac{1}{50} + \frac{10}{100} \times 50 \text{ gm/l.} \\ \text{of } \text{CaCO}_3 \text{ equivalent} &= \frac{1}{50} + \frac{10}{100} \times 50 \times 10^3 \text{ mg/l.} \\ &= 100 \text{ mg/l.} \end{aligned}$$

$$\text{Phenolphthalein alkalinity} = P = 100 \text{ ppm.}$$

Methyl orange alkalinity:

Another lot of 100 ml of the sample also required 10 ml of the acid.

$$\begin{aligned} \text{Volume of acid used at} &= (A+B) = 10 \text{ ml.} \\ \text{Methyl orange end point} & \end{aligned}$$

Water ∇_1 Acid

$$N_1 V_1 = N_2 V_2. \quad [A+B = V_2 = 10 \text{ ml.}]$$

$$N_1 \times 100 = \frac{1}{50} \times 10.$$

$$N_1 = \frac{1}{50} \times \frac{10}{100}.$$

$$\therefore \text{Strength in terms of } \text{CaCO}_3 \text{ equivalent} = \frac{1}{50} \times \frac{10}{100} \times 50 \text{ gm/l.}$$

$$\therefore \text{Methyl orange alkalinity} = M = \frac{1}{50} \times \frac{10}{100} \times 50 \times 1000 \text{ mg/l.}$$

$$M = 100 \text{ mg/l.} = 100 \text{ ppm.}$$

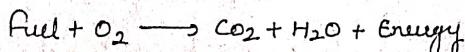
$$P = M.$$

Nature of alkalinity:

The alkalinity of water is only due to offi-

Lecture - 30

Introduction:- A fuel is a substance that contains carbon, hydrogen undergoes combustion in presence of oxygen to give large amount of energy.



Classification of fuel on the basis of occurrence fuel is classified into 2 categories -

- Natural / Primary fuels! - These fuels are naturally found.
- Artificial / Secondary fuels! - They are synthesized by primary fuels.

Characteristics of a Good / Ideal fuel! - While selecting an ideal fuel for domestic or industrial purpose we should keep in mind that the fuel selected must possess the following characteristic properties.

Gross calorific value (GCV)

Net calorific value (NCV)

Determination of GCV of solid, liquid fuels by Bomb Calorimeter

Known weight of solid/liquid fuel is burnt in the absence of excess oxygen in the closed pot, & the products of combustion are cooled, to get GCV of the fuel.

Theoretical calculation of calorific value of coal! -

The calorific value of a fuel can be calculated by Dulong's formula in the percentages of the constituent elements are known.

Coal! Coal is highly combustible matter formed from vegetable matter buried in geomorphic changes, under pressure, by action of aerobic & anaerobic bacteria for a long time. It is chiefly composed of C, H, N & O besides non-combustible inorganic matter.

Analysis of coal! Two types of analysis

- ① Proximate analysis
- ② Ultimate analysis

Rank of coal! On the basis of % of C, coal can be classified into following categories

- 1 - Wood
- 2 - Peat
- 3 - Lignite
- 4 - Bituminous
- 5 - Anthracite

Mgmp B. Tech I Year [Subject Name: Engineering Chemistry]

Q4-1 calculate GCV of the coal sample having C = 80%, H = 9%, O = 4%, N = 1.5% S = 2.5% + Ash = 3%.
(2014-15) (2017-18) (2018-19)

Ans! - $GCV = \frac{1}{100} [0.80 \times 0 + 34500(H\%) - \frac{O\%}{8}] + 2240.5\%$

$$= \frac{1}{100} [0.80 \times 80 + 34500(9 - \frac{4}{8}) + 2240 \times 2.5]$$

$$= 9452.5 \text{ cal/gm}$$

$$\text{NCV} = GCV - 0.09(H\%) \times 507$$

$$= 9452.5 - 0.09(9) \times 507$$

$$= 9977.03 \text{ cal/gm}$$

Q4-2 why should an ideal fuel have moderate ignition temperature?
(2014-15)

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

Mgmp Q4-3 In an experiment in a Bomb's calorimeter, a solid fuel of 0.90 g is burnt. It's observed that increase of fuel of temperature is 3.8°C of 4000 gm of water. The fuel contains 1% of H. calculate the HCV + LCV value (water equivalent of calorimeter is 30.5 gm, latent heat of steam = 507 cal/gm)
(2015-16)

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Ans! - $x = 0.9 \text{ gm}, w = 30.5 \text{ gm}, W = 4000 \text{ gm}$
 $\gamma.H = 1, \text{ Latent heat of water} = 507 \text{ cal/gm}$
 $t_2 - t_1 = 3.8^\circ\text{C}$

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

$$= \frac{(4000+30.5)(3.8)}{0.9}$$

$$= 10514.44 \text{ cal/gm}$$

$$\text{LCV} = \text{HCV} - 0.09(H\%) \times 507$$

$$= 10514.44 - 0.09(1) \times 507$$

$$= 10461.61 \text{ cal/gm}$$

Mgmp Q4-4 How the calorific value of solid fuel is determined using bomb calorimeter? Draw a neat diagram
Bomb's calorimeter (2015-16) (2017-18) (2019-20)

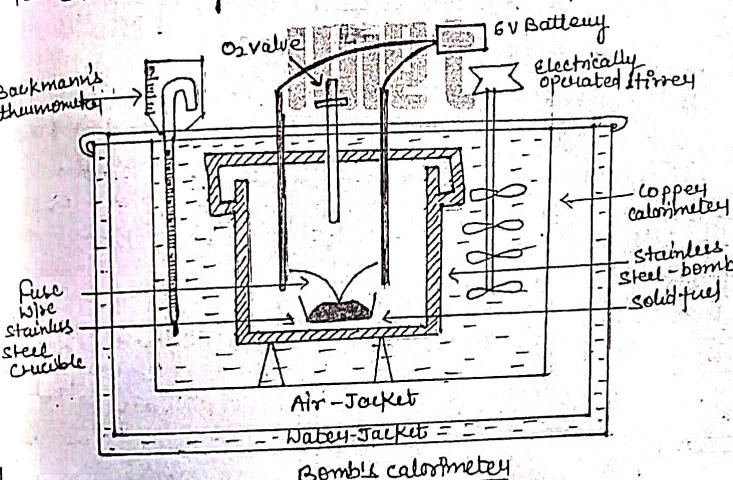
Ans! - Bomb's calorimeter:-

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

construction: Bomb's 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 holding fuel.

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- 5 - Fuel sample is weighed + 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 seen).
- 9 - Water + air jackets to avoid heat losses.
- 10 - 6V battery to start combustion of fuel.



Working of Bomb's calorimeter

- 1 - Weigh fuel sample + 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.

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- 6 - Keep the thermometer + stirrer in the water.
- 7 - Place the calorimeter in the water jacket.
- 8 - Put the plastic cover on the top + make electrical connections.
- 9 - Stir for 5 minutes + note the initial temperature of water.
- 10 - Note the maximum temperature reached.

Calculations:

Let weight of the fuel sample taken = $w\text{g}$.

Weight of water in the calorimeter = $W\text{g}$.

Water equivalent of the calorimeter = $w\text{g}$.

Stirrer, bomb, thermometer = $t_1^{\circ}\text{C}$

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

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

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

N.D.M.P. NCV = GCV - 0.09 \times H \% \times 587 \text{ cal/g}
Ques. Sample of coal contain C = 92%, H = 6% + ash = 1% The following data was obtained when the above coal was tested in bomb calorimeter.

1 - Wt. of coal burnt = 0.92 g.

2 - Wt. of water taken = 2200 g.

3 - Water equivalent of bomb calorimeter = 550 g.

4 - Fuel wise correction = 10.0 cal.

5 - Acid correction = 50.0 cal.

6 - Rise in temperature = 8.42°C

Calculate gross + net calorific value of the coal assuming the latent heat of condensation of steam as 580 cal/g. (2015-16)

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$$\begin{aligned}
 \text{Ans}-7 \quad GCV &= (W+w)(t_2-t_1+c_c) - (C_A + C_p + C_{CT}) \\
 &= (2200 + 570) (2.3 + 0.047) - (62.6 + 3.8 + 1.6) \\
 &= (2770) (2.347) - (68) \\
 &= \frac{6433.19}{1.029} = 6251.885 \text{ cal/gm}
 \end{aligned}$$

$$\begin{aligned}
 LCV &= HCV - 0.09(H\%) \times \text{Latent heat of steam} \\
 LCV &= 6251.885 - 0.09(6)(507) \\
 &= 6256.445 - 316.98 \\
 &= 5939.46 \text{ cal/gm}
 \end{aligned}$$

Qn-8 A sample of coal contains C=70%, O=20%, H=8%, S=1%, N=0.5% calculate GCV + HCV of coal. (2016-17) (2019-20)

Ans:- Method Explained in Question no-1

$$\begin{aligned}
 GCV &= 7575.9 \text{ cal/gm} \\
 NCV &= 7153.26 \text{ cal/gm}
 \end{aligned}$$

Qn-9 A sample of coal contains 60% = C, 33% = O, 6% = H, 0.5% = S, 0.2% = N + 0.3% Ash. Calculate GCV + NCV. (2016-17) (2017-18)

Ans:- method explained in Question no-1

$$\begin{aligned}
 GCV &= 5506.07 \text{ cal/gm} \\
 NCV &= 5189.09 \text{ cal/gm}
 \end{aligned}$$

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Qn-10 Explain when will the value of GCV = NCV (2017-18)

Ans- LCV will be equal to GCV when the % hydrogen is zero.

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

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

Qn-11 Explain why the value of GCV is greater than NCV. (2018-19)

Ans- GCV is the quantity of heat produced by combustion when the water produced by combustion is allowed to return to the liquid state. Since water releases heat when it condenses, GCV is clearly greater than NCV.

Qn-12 A coal sample has the following analysis by weight: C=90%, O=3%, S=0.5%, N=0.5%, Ash=0.5%. Net calorific value of the coal was found to be 8490.5 kJ/kg. Calculate the percentage of Hydrogen + gross calorific value? (2018-19).

$$GCV = \frac{1}{100} \left[80.80 \times C\% + 34500(H\% - \frac{1.0}{8}) + 2240 \times S\% \right]$$

$$= \frac{1}{100} \left[80.80 \times 90 + 34500(H\% - \frac{3}{8}) + 2240 \times 0.5 \right]$$

$$= 7272 + 345H - 129.375 + 1120 \text{ kcal/gm}$$

$$= 8262.62 + 345H \quad \text{--- (1)}$$

$$\begin{aligned}
 \text{Also, } GCV &= LCV + 0.09(H\%) \times \text{Latent heat of steam} \\
 &= 8490.5 + 0.09 \times H \times 507 \\
 &= 8490.5 + 52.03H \quad \text{--- (2)}
 \end{aligned}$$

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From 1+2

$$8262.62 + 345H = 8490.5 + 52.03H$$

$$345H - 52.03H = 8490.5 - 8262.62$$

$$292.17H = 227.88$$

$$H = \frac{227.88}{292.17} = 0.77\%$$

$$\text{So GCV} = 8262.62 + 345 \times 0.77$$

$$= 8262.62 + 265.65$$

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

Qn-13 A sample of coal contains C = 80%, H = 15%, + ash = 5%. The following data were obtained when above coal was tested in Bomb calorimeter: weight of coal burnt = 0.90 gm. Weight of water taken = 1000 gm. Water equivalent of Bomb calorimeter = 2500 gm, Rise in temperature = 2.5°C, pure wire correction = 0 cal, Acid correction = 50 cal, cooling correction = 0.02°C. Assuming that the latent heat of condensation is 580 cal/gm. Calculate net & gross calorific values of coal. (2019-20)

Ans:- Method explained in Question No-4

$$\text{GCV} = 7031.57 \text{ cal/gm}$$

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

Qn-14 ^{Imp} What is rank of coal. Describe proximate & ultimate analysis of coal. (2016-17) (2017-18)
Ans:- Coal analysis on the basis of % of C, H, N + s.
The various types of coal categories are following categories:-

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Type of coal	% of carbon	Calorific value	Characteristics
Wood	50	4000-4500	Dried wood of trees
Peat	50-60	4125-5400	Brown fibrous jelly like mass
Lignite	60-70	6500-7100	soft, brown coloured low rank coal
Bituminous	80-90	8000-8500	Black or dark grey coal
Anthracite	90-98	8650-9700	Highest rank coal

Remaining part of the question explained in Lecture No-31

LECTURE - 31

Analysis of Coal: coal is analysed in two ways:
Proximate and ultimate analysis.

Proximate analysis: The data varies with the procedure adopted and hence it is called proximate analysis. It determines the moisture, ash, volatile matter and fixed carbon of coal. It gives quick and valuable information for commercial classification of coal and use.

Ultimate analysis or elemental analysis:

In this following elements are analysed in coal:- % of C, % of H, % of N, % of O and % of S.

$$\text{Moisture \%} = \frac{\text{Weight of moisture}}{\text{Weight of coal sample}} \times 100$$

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

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

$$\% \text{ fixed Carbon} = 100 - (\text{moisture \%} + \text{V.M \%} + \text{ash \%})$$

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

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

$$\% \text{ N} = \frac{\text{Volume of acid} \times \text{Normality}}{\text{Weight of coal sample}} \times 100$$

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

Lecture - 31

Ques 1 What is rank of coal? Describe and ultimate analysis of coal and usefulness. (2016-2017) (2017-2018)

Answer - For ranking of coal refer lecture

Proximate analysis of coal :- Proximate and sample in which following things are determined

- (i) % Moisture
- (ii) % Volatile Matter
- (iii) % Ash content
- (iv) % Fixed carbon

This gives quick and valuable information for classification and determination of suitability for particular industrial use.

(v) % Moisture - All moisture in coal escapes coal at 110°C for 1 hour.

Procedure -

Known Coal Sample (powdered and dried) (weighed sample) $\xrightarrow[\text{1 hour}]{\text{Heat- } 110^\circ\text{C}}$ Cool in desiccator

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

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

Moisture free coal left in firebox $\xrightarrow[\text{expulsion}]{\text{Heat}} \xrightarrow[925^{\circ}\text{C}]{7 \text{ minute}} \text{Cool the crucible in desiccator} \longrightarrow \text{weigh}$

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

(iii) % Ash - The residual coal in above experiment is heated and burned above 750°C for 30 minutes. The ash is left behind. Cool and weigh

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

$$(iv) \% \text{ fixed Carbon} = 100 - (\% \text{ moisture} + \% \text{ volatile matter} + \% \text{ Ash})$$

Importance of proximate Analysis :-

Moisture :-

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

Volatile Matter :-

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

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Ash :-

- It reduces the calorific value of coal.
- It lowers 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 into H_2O \rightarrow Gaseous products are absorbed by preweighed U-tubes containing anhydrous CaCl_2 which absorbs H_2O and KOH which absorbs CO_2 .

Increase in weight is calculated.

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

$$\% \text{ H} = \frac{2}{18} \times \frac{\text{Increase in weight of calc tube}}{\text{weight of coal sample}} \times 100$$

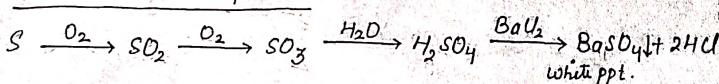
Determination of N (Kjeldahl method) :-

Known coal
Sample (powdered) $\xrightarrow[\text{K}_2\text{SO}_4]{\text{Heat}}$ Clear
and dried) in
Kjeldahl flask
 $\xrightarrow{\text{conc } \text{H}_2\text{SO}_4}$ Alkali $\longrightarrow \text{NH}_3$ is
liberated

Unused acid is
determined by back
titration with NaOH .
Pass through known
volume of standard
acid.

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

Determination of S :-



BaSO_4 is filtered, dried and weighed.

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

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% Ash :-

Known coal $\xrightarrow[30 \text{ minute}]{750^\circ \text{ (Heat)}}$ Residue left
Sample (powdered)
and dried)

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

Determination of O :-

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

Importance of ultimate analysis :-

- Carbon :- Greater the % carbon in coal, better is 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. Good quality coal should have low % nitrogen (% N).
- Sulphur :- Corrosive effect and pollutant. Quality coal should have low % S.
- Oxygen :- Decreases the calorific value of coal. decreases the coal quality.

Lecture - 32

Ques 1 - A sample of coal was analysed as follows : Exactly 1.51 g of was weighed into a silica crucible. After heating for 1 hour at 110°C, the residue weighed 1.417 g. The crucible was then strongly heated for exactly 7 min. The residue weighed 0.526 g. The residue was at 950°C. The residue weight of residue was then heated until a constant weight of residue was obtained. The last residue was found to be 0.254 g. Calculate percentage result of above analysis. (2010-2011)

$$\text{solution} - \text{Weight of moisture} = 1.51 \text{ g} - 1.417 \text{ g} = 0.093 \text{ g}$$

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

$$= \frac{0.093}{1.51} \times 100 = 6.15\%$$

$$\text{Weight of volatile matter} = 1.417 - 0.526 = 0.891 \text{ g}$$

$$\% \text{ volatile matter} = \frac{0.891}{1.51} \times 100 = 58.87\%$$

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

$$= \frac{0.254}{1.51} \times 100 = 16.82\%$$

$$\% \text{ Oxygen} (\%, O) = 100 - (\% \text{ moisture} + \% \text{ volatile matter} + \% \text{ Ash})$$

$$= 100 - (6.15 + 58.87 + 16.82)$$

$$= 17.8\%$$

LECTURE - 33

Calculation of Air for combustion

Substances always combine in definite proportions. These proportions are determined by their molecular masses.



- 22.4 L of any gas at 0°C and 760 mm pressure (STP) has a mass equal to its 1 mole.

• Air contains 21% oxygen by volume and 79% nitrogen by mass.

• 28.94 g/mol is taken as molar mass of air.

$$O_2 \text{ required for combustion} = (\text{theoretical } O_2 \text{ required} - O_2 \text{ present in fuel})$$

- Dry flue gases meant products of combustion except moisture.

For solid and liquid fuel:

$$O_2 \text{ quantity} = \frac{(32C + 8H + S - O)}{12} \text{ kg}$$

where C, H, S and O are amounts of these elements in fuel.

$$\text{Air quantity} = \frac{O_2 \text{ quantity} \times (100 + \% \text{ excess air})}{23} \text{ kg}$$

For Gaseous fuel:

$$O_2 \text{ volume required} = \frac{\text{vol. of gas component}}{\text{vol. of gas per vol. of } O_2} \times \frac{\text{vol. of } O_2 \text{ per vol. of gas}}$$

$$\text{Air volume required} = \frac{\text{oxygen volume} (100 + \% \text{ excess air})}{21} \text{ cm}^3$$

Lecture - 33

- For efficient combustion, it is essential that the fuel must be brought into intimate contact with sufficient quantity of air or oxygen.
 - The combustible substances usually present in fuels, which enter into the combustion, are mainly C, H, S and O. But N, CO₂ and ash are incombustible matters present in the fuel.
 - At STP (273K, 1 atm) one mole of all gases occupy a volume of 22.4 litres.
 - Air contains 21% of oxygen by volume and 23% of oxygen by weight.
- MPT**
- Hence 1 m³ of oxygen will be supplied = $\frac{1 \times 100}{21}$ = 4.76 m³ of air.
- Similarly 1 kg of oxygen will be supplied = $\frac{1 \times 100}{23}$ = 4.35 kg of air.
- Molecular weight of air is 28.94 mol⁻¹

$$\text{Minimum oxygen required} = (\text{Theoretical O}_2) - (\text{O}_2 \text{ present in fuel})$$

Ques

Question 1 - Calculate the mass of air needed for complete combustion of 5.0 kg. of coal containing 80% carbon, 15% hydrogen and rest oxygen.

Solution - % O (present in coal) = $100 - (80 + 15) = 5\%$.
 weight of carbon (in coal) = $(5000 \text{ g}) \times \frac{80}{100}$
 $= 4000 \text{ g}$
 weight of hydrogen (in coal) = $(5000 \text{ g}) \times \frac{15}{100}$
 $= 750 \text{ g}$
 weight of oxygen (present in coal) = $(5000 \text{ g}) \times \frac{5}{100}$
 $= 250 \text{ g}$

Net O₂ Required = $\left[\frac{32}{12} \times C + 8 \times H - O \right] \text{ g}$
 $= \left[\frac{32}{12} \times (4000) + 8 \times 750 \right] - 250$
 $= [(10,666.67) + 6000] - 250 \text{ g}$
 $= 16,416.67 \text{ g}$

Weight of air (needed) = Net O₂ Required $\times \frac{100}{23}$
 $= 16,416.67 \times \frac{100}{23}$
 $= 71,376.02 \text{ g}$

Question 2 - Calculate the minimum weight of air required for complete combustion of fuel containing C = 90%, H = 3.5%, O = 3.0%, S = 0.5%, N = 0.5% and ash = rest of percentage.

Solution: (N and ash are not combustible, so no calculation required for them).

$$\text{Weight of C in 1 kg coal} = (1000 \text{ g}) \times \frac{90}{100} = 900 \text{ g}$$

$$\text{Weight of H in 1 kg coal} = (1000 \text{ g}) \times \frac{6.5}{100} = 65 \text{ g}$$

$$\text{Weight of S in 1 kg coal} = (1000 \text{ g}) \times \frac{0.5}{100} = 5 \text{ g}$$

$$\text{Weight of O in 1 kg coal} = (1000 \text{ g}) \times \frac{31.0}{100} = 310 \text{ g}$$

∴ Minimum weight of O_2 required for complete combustion

$$\text{of 1 kg coal} \\ = [900 \times \left(\frac{32}{12}\right) + 35 \times \left(\frac{16}{2}\right) + 5 \times \left(\frac{32}{32}\right) - 30] \text{ g} \\ = 2655 \text{ g}$$

$$\text{Minimum weight of air required} = (2655 \text{ g}) \times \frac{100}{23} \\ = 11543.48 \text{ g}$$

Ques 3. The percentage composition of coal sample is:-
 $C = 70\%$, $H_2 = 10\%$, $O_2 = 1\%$, $S = 5\%$, 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 duulong's formula. (2020-2021)

Solution-(i) 1 kg of coal contains, $C = 700 \text{ g}$, $H = 100 \text{ g}$, $O = 10 \text{ g}$, $S = 50 \text{ g}$, ash = 5 g and $N = 3 \text{ g}$.

$$\text{Minimum weight of } O_2 \text{ required} = [(700 \times \frac{32}{12}) + 100 \times \left(\frac{16}{2}\right) + 50 \times \left(\frac{32}{32}\right) \\ \div - 10] \text{ g}$$

$$= 2706.67 \text{ g}$$

$$\text{Minimum weight of air required} = 2706.67 \text{ g} \times \frac{100}{23} = 11768.02 \text{ g}$$

$$\text{Weight of air required with 40% excess} = 11768.02 \times \frac{160}{100} = 18828.88 \text{ g}$$

$$(ii) GCV = \frac{1}{100} [8,080 \times (\%C) + 34,500 (\%H - \frac{10}{8}) + 2240 \times \%S] \\ = \frac{1}{100} [8080 \times 70 + 34500 (10 - \frac{10}{8}) + 2240 \times 5] \\ = \frac{1}{100} [565600 + 34500 \times (9.875) + 11200] \\ = 9,174.075 \text{ kcal/kg}$$

$$\text{NCV} = [\text{GCV} - 0.09 \times \%H \times 587] \text{ kcal/kg} \\ = [9174.075 - (0.09 \times 10 \times 587)] \text{ kcal/kg} \\ = 8646.575 \text{ kcal/kg}$$

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Biomass \Rightarrow "Energy containing organic matter present in living organism, their waste and residue is termed as biomass".
For ex: cattle dung, plant waste / residue etc.

Bioenergy \Rightarrow "Bio-energy refers to various forms of energy generated from biomass by using biotechnological methods".
for example: Biogas, oil, ethanol, methanol, charcoal etc.

Biogas \Rightarrow
It is a mixture of gas produced by the microorganisms during the anaerobic fermentation of biodegradable materials.
Anaerobic fermentation is a biochemical process in which particular kinds of bacteria digest biomass in an oxygen-free environment resulting in production of CH_4 , CO_2 , H_2 and traces of other gases along with decomposed mass.

Composition of biogas.

Name of the gas	(%)
Methane (CH_4)	50-70
Carbon dioxide (CO_2)	30-40
Hydrogen (H_2)	10-15
Nitrogen	2-1
Water Vapour (H_2O)	0.3
Hydrogen Sulphide (H_2S)	Trace

Raw Materials for Biogas Fermentation

Biogas is produced mainly from:-
 Cow dung
 Sewage
 Crop residues
 Vegetable wastes
 Water hyacinth
 Poultry droppings.

Biogas Plant Types

Biogas plants basically are of two types:

1. Floating Dome Type [Floating Gas Holder Type]:
for example - KVIC-type (KVIC - Khadi Village Industries Commission).
2. Fixed Dome Type:
for example - Ocenabandhu model KVIC type Biogas plant.

Floating Gas Holder Type Biogas Plant

The floating gas holder type biogas plant consists of a dome shaped gas holder made of steel for collecting biogas. The dome shaped gas holder is not fixed but is movable and floats over the slurry present in the digester tank. Due to this reason, this biogas plant is called floating gas holder type biogas plant.

Slurry is prepared by mixing water in cattle dung in equal proportion in mixing tank. The slurry is then injected into a digester tank with the help of inlet pipe. The digester tank is a closed underground tank made up of bricks. Inside the digester tank, the complex

FIXED DOME TYPE BIOGAS PLANT



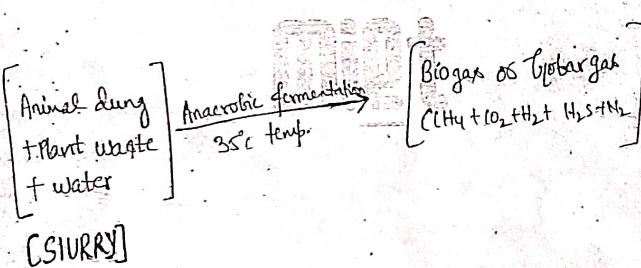
The fixed dome type biogas plant is illustrated in figure. It consists of following parts.

1. Digester tank.
2. Slurry mixing tank.
3. Spent slurry tank.

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In the digester, anaerobic fermentation starts with the release of biogas. It takes 30 to 60 days for the slurry to fill the digester, depending upon the temperature within the digester. During time the biogas formed is collected in the dome under pressure. When the pressure of biogas exceeds certain limit, the biogas forces the spent slurry into the overflow tank.

The biogas is withdrawn from the dome through an outlet pipe. Its flow is regulated by a gas valve.

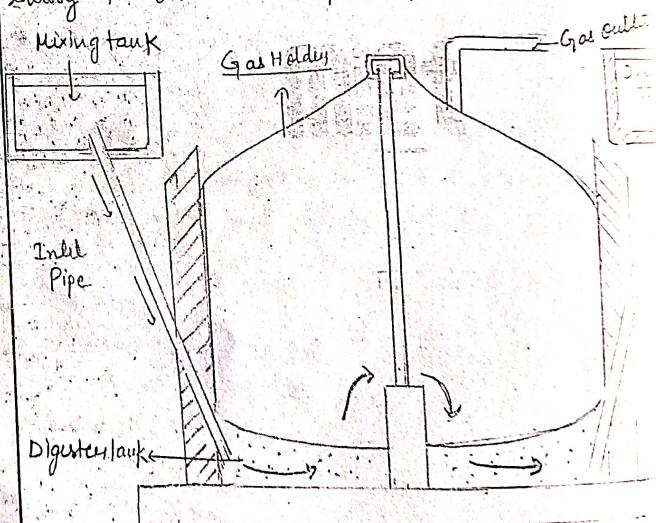


Composition of biogas \Rightarrow Biogas is a mixture of:

- Methane (CH_4) - 63%
- Carbon dioxide - (CO_2) - 30%
- Hydrogen (H_2), Hydrogen sulphide (H_2S) & Nitrogen (N_2)

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Carbon compounds present in the cattle dung break down into simpler substances by the action of anaerobic microorganisms in the absence of water. This anaerobic decomposition of complex carbon compounds present in cattle dung produces biogas and gets completed in about 60 days. The biogas so produced starts to collect in floating gas holder and is supplied to homes through pipes. Spent slurry is replaced from time to time with fresh slurry to continue the production of biogas.



• Digester tank → It is an underground tank. Its base and walls are made of bricks and cement. Its roof is made in the form of dome either with cement or bricks or with concrete. The dome collects the biogas. It is provided with an outlet for biogas. The outflow of the gas is controlled by a gas valve.

• Slurry mixing tank → On the left hand side of the digester is constructed a brick lined tank above the ground level. The bottom of this tank connects the digester through a brick lined channel near the base. The fresh slurry of animal dung and water in equal proportion is poured into the digester.

• Spent slurry tank → On the right hand side of the digester is constructed spent slurry tank, below the ground level. The base of this tank is connected to the base of the digester through a brick lined channel.

WORKING OF FIXED DOME Type BIOGAS PLANT

Every day the slurry of animal dung and water in equal proportion is poured into the mixing tank. The slurry flows into the digester.

Uses (Advantages) →

- Biogas is used for cooking and lighting in rural areas.
- Biogas is also used to run engines and for street lighting.
- It is eco-friendly as it does not produce any smoke (no air pollution).
- There is no storage problem for biogas as it is supplied by pipes from the gas plant.
- It is cheaper than most fuels.
- It has high Calorific Value [high heat producing capacity].
- The spent slurry can be used as excellent natural manure (fertilizer).

Note: → In our country the National Project on Biogas Development (NPBD) and Community / Institutional Biogas Programme promote and assist various biogas projects.

Meerut Institute of Engineering and Technology, Meerut

Topic-Wise Important Questions for AKTU End Semester Examinations

Subject Code: BAS102		Subject Name : Engg. Chemistry		Taught in :	1 Year / All
Unit No.	Topics	Q. No.	Question (Statement) - As Appeared in AKTU	Year	Marks
Unit-4	HARDNESS OF WATER	28	A sample of water was found to contain 40.5 mg/L $\text{Ca}(\text{HCO}_3)_2$, 46.5 mg/L $\text{Mg}(\text{HCO}_3)_2$, 32.1 mg/L CaSO_4 , 27.6 mg/L MgSO_4 , 22.45 mg/L CaCl_2 , 19.0 mg/L MgCl_2 and 4.8 mg/L NaCl . Calculate the temporary, permanent and total hardness of water sample.	2016-2017	5
	ZEOLITE PROCESS	29	What do you mean by term Permuntit? Explain zeolite process for water softening. b) 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.	2018-2019, 2021-2022	4, 6
	LIME-SODA PROCESS	30	What is the basic principle of Lime Soda process? Give its working. b) 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: $\text{Ca}^{+2} = 160 \text{ ppm}$, $\text{Mg}^{+2} = 48 \text{ ppm}$, $\text{CO}_3^{=2} = 66 \text{ ppm}$, $\text{HCO}_3^- = 264 \text{ ppm}$, $\text{H}^+ = 20 \text{ ppm}$, $\text{NaCl} = 4.7 \text{ ppm}$. Analysis of treated water: $\text{CO}_3^{=2} = 45 \text{ ppm}$, $\text{OH}^- = 68 \text{ ppm}$	2017-2018, 2021-2022	4, 6
	ION-EXCHANGE PROCESS	31	What are ion exchange resins? With the help of neat sketch, discuss ion exchange process for water softening. Compare its merit over zeolite process.	2018-2019	10
	ALKALINITY	32	What is the principle of EDTA method? Explain the estimation of hardness of water by complexometric method. 0.5g of CaCO_3 was dissolved in HCl and the solution made up to 500ml with distilled water. 50ml of the solution required 48ml of EDTA solution for titration. 50ml of hard water sample required 15ml of EDTA and after boiling and filtering required 10ml of EDTA solution. Calculate the hardness.		
	OSMOSIS	33	Write a short note on reverse osmosis.	2018-2019	5
	FUELS & CALORIFIC VALUE	34	What is meant by calorific value of a fuel? What are its units? or Define Gross Calorific Value and Net Calorific Value? Calculate GCV and LCV of the coal sample having C=80%, H = 9%, O=4%, N=1.5%, S=2.5% and Ash = 3%.	2017-2018, 2018-2019	5, 5
		35	How the calorific value of a solid fuel is determined using bomb calorimeter? Draw a neat diagram of bomb calorimeter.	2017-2018, 2019-2020, 2021-2022	2, 5, 10

Topic-Wise Important Questions for AKTU End Semester Examinations

S102 Topics	Q. No.	Subject Name : Engg. Chemistry Question (Statement) - As Appeared In AKTU	Taught In : I Year / All Branches		
			Year	Marks	Remarks
CALORIMETER	36	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.	2015-2016	10	
PROCESS	37	A sample of coal contains C = 70%, O = 20%, H = 8%, S = 1 %, N = 0.5%, ash= 0.5% Calculate GCV and NCV of coal	2019-2020	5	
USES OF COAL	38	What is rank of coal? Describe proximate and ultimate analysis of coal and its usefulness.	2017-2018	10	
	39	Calculate the mass of air needed for complete combustion of 5.0 kg of coal containing 80% carbon 15% hydrogen and rest Oxygen.	2015-2016	5	
	40	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.	2018-2019	6	
O-GAS	41	What is Biogas? How biogas is produced? With the help of diagram, explain Biogas Plant.	2016-17	7	NEW CONTENT