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## Unit 4: Water Technology and Fuels & Combustion

This unit covers two main areas: **Water Technology**, focusing on water quality, hardness, boiler issues, and purification methods, and **Fuels and Combustion**, dealing with the classification, properties, analysis, and combustion of various fuels.

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### I. Water Technology

Water is an essential resource, and its quality is crucial for both domestic and industrial applications. This section delves into the concepts of water hardness, associated problems, and various softening techniques.

#### 1. Sources and Impurities of Water

- **Concept Overview:** Natural water sources contain various impurities depending on their origin and the environment they pass through. These impurities can be dissolved gases, dissolved minerals, suspended solids, and organic matter.
- **Detailed Explanation:** Water ( $\text{H}_2\text{O}$ ) is an excellent solvent, and as it traverses through the earth's crust, it dissolves minerals, salts, and gases, picking up various impurities.
  - **Sources:** Surface water (rivers, lakes) and groundwater (wells, springs).
  - **Impurities:**
    - **Dissolved Salts:** Carbonates, bicarbonates, sulfates, and chlorides of calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ) are common. Sodium and potassium salts may also be present.
    - **Dissolved Gases:** Carbon dioxide ( $\text{CO}_2$ ), oxygen ( $\text{O}_2$ ), nitrogen ( $\text{N}_2$ ), and hydrogen sulfide ( $\text{H}_2\text{S}$ ).
    - **Suspended Solids:** Clay, silt, sand, organic matter, and microorganisms.
    - **Colloidal Impurities:** Finely divided silica, clay, and organic decomposition products.
- **Real-life Examples:** Waterborne diseases like cholera and typhoid are linked to biological impurities, while fluoride and arsenic problems are major concerns in drinking water in some regions.

#### 2. Hardness of Water

- **Definition:** Hardness of water is its property of preventing lather formation with soap. It is primarily caused by the presence of dissolved salts of calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ).

- **Types of Hardness:**
  - **Temporary Hardness:** Caused by the presence of dissolved bicarbonates of calcium and magnesium ( $\text{Ca}(\text{HCO}_3)_2$  and  $\text{Mg}(\text{HCO}_3)_2$ ). It can be removed by simple boiling.
    - **Chemical Reactions (Boiling):**
      - $\text{Ca}(\text{HCO}_3)_2(\text{aq}) \xrightarrow{\text{Heat}} \text{CaCO}_3(\text{s})\downarrow + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
      - $\text{Mg}(\text{HCO}_3)_2(\text{aq}) \xrightarrow{\text{Heat}} \text{Mg}(\text{OH})_2(\text{s})\downarrow + 2\text{H}_2\text{O}(\text{l}) + 2\text{CO}_2(\text{g})$
  - **Permanent Hardness:** Caused by the presence of dissolved sulfates and chlorides of calcium and magnesium ( $\text{CaSO}_4$ ,  $\text{CaCl}_2$ ,  $\text{MgSO}_4$ ,  $\text{MgCl}_2$ ). This type of hardness cannot be removed by boiling.
- **Significance:** Understanding water hardness is critical for various applications, as it influences water treatment processes for domestic and industrial uses, and helps in the routine control of softening methods.

### 3. Boiler Troubles

- **Concept Overview:** In industries, boilers use large quantities of water for steam generation. Hard water, when heated, can lead to several problems collectively known as "boiler troubles". These issues reduce boiler efficiency, increase maintenance costs, and can lead to dangerous operational conditions.
- **Detailed Explanation and Disadvantages:**
  - **a) Scale Formation:**
    - **Definition:** Scales are hard, strongly adhering coatings on the inner surface of boilers. They are formed by the decomposition of bicarbonates and the deposition of calcium sulfate ( $\text{CaSO}_4$ ) at high temperatures.
    - **Disadvantages of Scale Formation:**
      1. **Wastage of Fuel:** Scales are poor conductors of heat. Their presence reduces the heat transfer efficiency from the furnace to the boiler water, requiring more fuel to maintain the desired steam output. This leads to significant fuel waste.
      2. **Lowering of Boiler Efficiency:** Reduced heat transfer means less steam production per unit of fuel, directly lowering the overall efficiency of the boiler.
      3. **Danger of Explosion:** When scales crack due to uneven expansion (as the inner surface is very hot while the outer surface is cooler due to slow heat transfer), the water suddenly comes into contact with the superheated metal. This can cause a sudden flash of steam (known as "bagging" or "blistering") leading to an explosion.
      4. **Decrease in Working Life of Boiler:** Overheating of boiler parts due to scale insulation can weaken the metal, leading to cracks and failures, thereby shortening the boiler's lifespan.
  - **b) Sludge Formation:**

- **Definition:** Sludges are soft, loose, slimy precipitates formed within the boiler. They are typically caused by substances that remain soluble in cold water but become insoluble upon heating, like  $\text{MgCO}_3$ ,  $\text{MgSO}_4$ , and  $\text{CaCl}_2$ .
- **Disadvantages (not explicitly detailed in sources for sludge, but implied context):** Sludges tend to accumulate in cooler, less agitated parts of the boiler, reducing efficiency and potentially leading to localized corrosion. They can also get carried with steam, causing issues in other equipment.
- **Prevention of Boiler Troubles (Internal Treatment):**
  - **Calgon Treatment:** Involves adding sodium hexametaphosphate ( $\text{NaPO}_3$ )<sub>6</sub> (Calgon) to the water. It forms a soluble complex with  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions, preventing their precipitation as scale.
  - **Phosphate Treatment:** Involves adding sodium phosphate ( $\text{Na}_3\text{PO}_4$ ) to precipitate calcium and magnesium as soft, easily removable phosphates.
    - **Chemical Reaction:**  $\text{MgSO}_4 + 2\text{Na}_3\text{PO}_4 \rightarrow \text{Mg}_3(\text{PO}_4)_2\downarrow + 3\text{Na}_2\text{SO}_4$

#### 4. Techniques for Water Softening (External Treatment)

These methods are used to remove hardness-causing ions from water before it enters the boiler or for other applications requiring soft water.

- **a) Lime-Soda Process:**
  - **Concept Overview:** This process involves adding calculated amounts of lime ( $\text{Ca}(\text{OH})_2$ ) and soda ( $\text{Na}_2\text{CO}_3$ ) to hard water to precipitate calcium and magnesium hardness as insoluble carbonates and hydroxides, respectively.
  - **Detailed Explanation (Continuous Cold Lime-Soda Process):**
    - Hard water is mixed with lime and soda in a reaction tank. Mixing promotes the precipitation reactions.
    - The water then passes through a sedimentation tank where the precipitates settle down.
    - Finally, the softened water is filtered to remove any remaining suspended particles.
  - **Important Chemical Reactions:**
    - **Removal of Temporary Hardness:**
      - $\text{Ca}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 \rightarrow 2\text{CaCO}_3\downarrow + 2\text{H}_2\text{O}$
      - $\text{Mg}(\text{HCO}_3)_2 + \text{Ca}(\text{OH})_2 \rightarrow \text{MgCO}_3 + 2\text{H}_2\text{O}$
      - $\text{MgCO}_3 + \text{Ca}(\text{OH})_2 \rightarrow \text{Mg}(\text{OH})_2\downarrow + \text{CaCO}_3\downarrow$
    - **Removal of Permanent Hardness:**
      - $\text{CaSO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3\downarrow + \text{Na}_2\text{SO}_4$
      - $\text{MgCl}_2 + \text{Ca}(\text{OH})_2 \rightarrow \text{Mg}(\text{OH})_2\downarrow + \text{CaCl}_2$
      - $\text{CaCl}_2 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3\downarrow + 2\text{NaCl}$
      - $\text{MgSO}_4 + \text{Ca}(\text{OH})_2 \rightarrow \text{Mg}(\text{OH})_2\downarrow + \text{CaSO}_4$
      - $\text{CaSO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{CaCO}_3\downarrow + \text{Na}_2\text{SO}_4$

- **Removal of other impurities:**
      - $\text{CO}_2 + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCO}_3\downarrow + \text{H}_2\text{O}$
      - $\text{HCl} + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}$
      - $\text{Al}_2(\text{SO}_4)_3 + 3\text{Ca}(\text{OH})_2 \rightarrow 2\text{Al}(\text{OH})_3\downarrow + 3\text{CaSO}_4$
  - **Numerical Problem (Example from source):**
    - **Query:** Calculate the quantity of lime (74% pure) and soda (90% pure) for softening 50,000 liters of water containing:  $\text{Mg}(\text{HCO}_3)_2 = 50 \text{ mg/L}$ ,  $\text{MgCl}_2 = 6 \text{ ppm}$ ,  $\text{Ca}(\text{HCO}_3)_2 = 81 \text{ mg/L}$ ,  $\text{CO}_2 = 44 \text{ ppm}$ ,  $\text{Na}_2\text{SO}_4 = 10^\circ\text{Fr}$ ,  $\text{HCl} = 73 \text{ mg/L}$ ,  $\text{Al}_2(\text{SO}_4)_3 = 57 \text{ mg/L}$ .
    - *(Note: The source provides the problem but not the step-by-step solution. This would involve converting all hardness-causing impurities to  $\text{CaCO}_3$  equivalents and then calculating the required lime and soda based on stoichiometric reactions, accounting for purity.)*
  - **Comparison (Merits/Demerits over Ion Exchange - see below for Ion Exchange):**
    - Lime-soda process can produce water with residual hardness, requires careful chemical dosing, and generates sludge. Ion exchange offers better softening.
- **b) Zeolite Process:**
  - **Concept Overview:** Zeolites are hydrated sodium aluminum silicates ( $\text{Na}_2\text{OAl}_2\text{O}_3 \cdot x\text{SiO}_2 \cdot y\text{H}_2\text{O}$ ) capable of exchanging ions. In this process, hard water passes through a zeolite bed, and calcium and magnesium ions are replaced by sodium ions.
  - **Chemical Reaction:**  $\text{Na}_2\text{Ze} + \text{Ca}^{2+} \rightarrow \text{CaZe} + 2\text{Na}^+$ 
    - Similarly,  $\text{Na}_2\text{Ze} + \text{Mg}^{2+} \rightarrow \text{MgZe} + 2\text{Na}^+$  (not explicitly written for Mg, but implied by definition).
  - **Regeneration:** Exhausted zeolite is regenerated by treating it with a 10% NaCl brine solution.
    - **Chemical Reaction:**  $\text{CaZe} + 2\text{NaCl} \rightarrow \text{Na}_2\text{Ze} + \text{CaCl}_2$
- **c) Ion Exchange Resin Process:**
  - **Concept Overview:** This method uses synthetic organic resins to remove all dissolved ionic impurities, producing demineralized or deionized water. It involves two types of resins: cation exchange resins (H-form) and anion exchange resins (OH-form).
  - **Detailed Explanation:**
    - **Cation Exchange:** Hard water passes through a cation exchange resin (R-H), which exchanges  $\text{H}^+$  ions for  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , etc..
      - $2\text{R-H} + \text{Ca}^{2+} \rightarrow \text{R}_2\text{-Ca} + 2\text{H}^+$
    - **Anion Exchange:** The effluent from the cation exchanger (containing  $\text{H}^+$  and anions) then passes through an anion exchange resin ( $\text{R}'\text{-OH}$ ), which exchanges  $\text{OH}^-$  ions for  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ , etc..
      - $\text{R}'\text{-OH} + \text{Cl}^- \rightarrow \text{R}'\text{-Cl} + \text{OH}^-$

- **Regeneration:** Cation resins are regenerated with dilute acid (e.g., HCl), and anion resins with dilute alkali (e.g., NaOH).
  - **Merits:** Produces very high-quality soft water (demineralized water), suitable for sensitive industrial applications.
  - **Demerits:** Higher initial cost than lime-soda, and resins can be fouled by suspended solids or organic matter.
- **d) Reverse Osmosis Process:**
  - **Concept Overview:** Reverse osmosis (RO) is a membrane-based process that uses pressure to force water molecules through a semi-permeable membrane, leaving behind dissolved salts and impurities. It's used for desalination of brackish water.
  - **Detailed Explanation:** When pressure greater than osmotic pressure is applied to the concentrated side of a semi-permeable membrane, solvent (water) flows from the concentrated solution to the dilute solution. This effectively separates pure water from impurities.
  - **Application:** Widely used for producing drinking water from saline or brackish water and in industrial purification systems.

## 5. Determination of Hardness and Alkalinity (Numerical problems)

- **Concept Overview:** Water hardness is typically expressed in terms of parts per million (ppm) of calcium carbonate ( $\text{CaCO}_3$ ) equivalent. Alkalinity is the water's capacity to neutralize acids. These are determined by titration methods.
- **Determination of Total Hardness (EDTA Method):**
  - **Principle:** Ethylenediamine tetraacetic acid (EDTA) forms a stable, soluble 1:1 complex with metal ions like  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . Eriochrome Black-T (EBT) is used as an indicator, which forms a wine-red complex with  $\text{Ca}^{2+}/\text{Mg}^{2+}$  ions. At the equivalence point, EDTA replaces the indicator from the metal-indicator complex, and the solution turns clear blue.
  - **Procedure:**
    1. **Preparation of Standard EDTA Solution:** Weigh a known amount of disodium salt of EDTA ( $\text{Na}_2\text{H}_2\text{Y}$ ) and dissolve it in ion exchange water to prepare a standard solution.
    2. **Titration:** Pipette out a specific volume (e.g.,  $25\text{ cm}^3$ ) of the hard water sample into a conical flask. Add  $\text{NH}_3\text{-NH}_4\text{Cl}$  buffer (to maintain pH 9-11, where EBT is effective) and a pinch of Eriochrome black-T indicator.
    3. **Titration against EDTA:** Titrate against the standard EDTA solution from a burette until the color changes from wine red to clear blue.
    4. **Calculation:** The volume of EDTA consumed is used to calculate the total hardness in ppm of  $\text{CaCO}_3$  equivalent. The process is carried out slowly near the end point to avoid error due to the kinetics of complex formation.
      - **(MV)Hard Water = (MV)EDTA** is the general formula for titration calculations.

- **Hardness in ppm  $\text{CaCO}_3$  equivalent = Molarity of Hard Water x Molecular Weight of  $\text{CaCO}_3$  (100).**
  - **Determination of Alkalinity:** Mentioned as a lab experiment. Involves titrimetric method (likely acid-base titration).
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## II. Fuels and Combustion

This section explores different types of fuels, their properties, methods of analysis, and the process of combustion.

### 1. Fuel Definition and Classification

- **Definition:** A fuel is any combustible substance containing carbon as a major constituent, which produces a significant amount of heat and light energy when burnt in air or oxygen. The process of burning is an exothermic oxidation reaction.
- **Classification:**
  - **Based on Occurrence (Origin):**
    - **Primary Fuels (Natural Fuels):** Found directly in nature. Examples: coal, petroleum, natural gas.
    - **Secondary Fuels (Derived Fuels):** Derived from primary fuels through various processes. Examples: coke, gasoline, coal gas.
  - **Based on Physical State:**
    - **Solid Fuels:** Coal, wood, coke.
    - **Liquid Fuels:** Petroleum, gasoline, diesel oil, power alcohol, biodiesel.
    - **Gaseous Fuels:** Natural gas, compressed natural gas (CNG), liquefied petroleum gas (LPG), producer gas, water gas, biogas.

### 2. Characteristics of a Good Fuel

- A good fuel should possess certain desirable characteristics for efficient and safe use. While the sources list this as a topic, specific detailed characteristics are not enumerated as bullet points, but generally include high calorific value, low moisture and ash content, moderate ignition temperature, and easy availability/storage.

### 3. Calorific Value

- **Definition:** The **total quantity of heat liberated** when a unit mass (or volume for gases) of a fuel is completely burnt in air or oxygen. Its S.I. unit is kJ/kg.
- **Types:**
  - **Gross Calorific Value (GCV) / Higher Calorific Value (HCV):** The total amount of heat produced when a unit quantity of fuel is completely burnt, and the

products of combustion are cooled down to the original temperature. This includes the latent heat of condensation of water vapor formed during combustion of hydrogen in the fuel.

- **Net Calorific Value (NCV) / Lower Calorific Value (LCV):** The net heat produced when a unit quantity of fuel is completely burnt, and the products of combustion are allowed to escape. The latent heat of water vapor is *not* recovered.
  - 1. **Relationship:  $NCV = GCV - (\text{Mass of H}_2\text{O formed} \times \text{Latent Heat of Steam})$ .**
  - 2. **Formula (based on %H):**  $NCV = GCV - 0.09H \times 587 \text{ kcal/kg}$  (where H is % of H<sub>2</sub> in the fuel and 587 cal/gm is latent heat of steam).
- **Theoretical Calculation (Dulong's Method):**
  - **Formula for GCV (kcal/kg):**  $GCV = (1/100) \times [8080 \times \%C + 34500 \times (\%H - \%O/8) + 2240 \times \%S]$ .
    - 1. This formula considers the heat produced by carbon, hydrogen (adjusted for oxygen already present in the fuel), and sulfur.
  - **Numerical Problem (Example from source):**
    - 1. **Query 1:** Calculate GCV and NCV of coal with C=85%, H=8%, S=1%, N=2%, Ash=4%, Latent heat of steam=587 cal/gm.
      - **GCV Calculation:**  $GCV = (1/100) \times [8080 \times 85 + 34500 \times (8 - 0/8) + 2240 \times 1] \text{ kcal/kg} = (1/100) \times [686800 + 276000 + 2240] = 9650.4 \text{ kcal/kg}$ .
      - **NCV Calculation:**  $NCV = GCV - 0.09 \times \%H \times \text{Latent heat of steam} = 9650.4 - 0.09 \times 8 \times 587 = 9650.4 - 422.64 = 9227.76 \text{ kcal/kg}$  (approx).
    - 2. **Query 2:** A 0.85g sample of solid fuel combusted in bomb calorimeter, temp rise 2.8°C. Water in calorimeter 2000g, water equivalent 2200g. Calculate HCV and LCV if %Hydrogen = 2.5%.
      - **HCV/GCV calculation from experiment:**
        - Heat released by fuel = Heat absorbed by water and calorimeter.
        - **$GCV = [(W + w) \times (T_2 - T_1) \times S] / m$ .**
          - Where W = weight of water (kg), w = water equivalent of calorimeter (kg), T<sub>2</sub>-T<sub>1</sub> = rise in temperature (°C), S = specific heat of water (4.187 kJ/kg/°C), m = weight of fuel sample (kg).
        - Applying given values (units conversion needed for calculation from source values which are in grams):
          - m = 0.85g = 0.00085 kg.
          - W = 2000g = 2 kg.
          - w = 2200g = 2.2 kg (Note: water equivalent is usually in g or kg, assuming it's water equivalent of calorimeter).

- $\Delta T = 2.8^{\circ}\text{C}$ .
- $S =$  (not explicitly given for calculation, but usually 1 cal/g $^{\circ}\text{C}$  or 4.187 J/g $^{\circ}\text{C}$ . Using kJ/kg/ $^{\circ}\text{C}$  for final answer in kJ/kg).
- $\text{GCV} = [(2 + 2.2) \times 2.8 \times S] / 0.00085$ . If  $S = 4.187 \text{ J/g}^{\circ}\text{C} \times 1000\text{g/kg} \times 1\text{kJ}/1000\text{J} = 4.187 \text{ kJ/kg}^{\circ}\text{C}$ .
- $\text{GCV} = [(2 + 2.2) \times 2.8 \times 4.187] / 0.00085 = [4.2 \times 2.8 \times 4.187] / 0.00085 = 49.33 / 0.00085 = 58035.29 \text{ kJ/kg}$  (This seems high for typical fuels, possibly unit conversion or specific heat value interpretation mismatch from source).
- *Self-correction: If water equivalent is in cal/g, and GCV in cal/g, let's use that unit from the source where 587 cal/gm is used as latent heat of steam for consistency.*
- $\text{GCV (cal/g)} = [(2000 + 2200) \times 2.8] / 0.85 = (4200 \times 2.8) / 0.85 = 11760 / 0.85 = 13835.29 \text{ cal/g}$ .

■ **LCV Calculation:**

- $\text{LCV} = \text{GCV} - (0.09 \times \%H \times \text{latent heat of steam})$ .
- Latent heat of steam = 587 cal/gm.
- $\text{LCV} = 13835.29 - (0.09 \times 2.5 \times 587) = 13835.29 - 132.075 = 13703.215 \text{ cal/g}$ .

● **Determination of Calorific Value (Bomb Calorimeter):**

- **Principle:** A **bomb calorimeter** is used to determine the **GROSS CALORIFIC VALUE (GCV)** of solid and liquid fuels under constant volume conditions. The fuel is combusted in a sealed bomb in an oxygen atmosphere, and the heat released is absorbed by water surrounding the bomb and the calorimeter itself.
- **Diagram Description:** A bomb calorimeter consists of a stainless steel bomb (containing the fuel sample, a fuse wire, and oxygen at 25 atm) submerged in a known quantity of water in a calorimeter vessel. The water in the calorimeter is stirred by a stirrer, and its temperature is measured by a thermometer. The bomb has electrodes connected to a power supply to ignite the fuel.
- **Procedure:**
  1. Accurately weigh about 1g of the solid fuel sample and convert it into a pellet.
  2. Place the pellet in a crucible inside the bomb, stretching a fuse wire (of known weight) in close contact with the fuel.
  3. Supply pure oxygen to the bomb at 25 atmospheres through a valve.
  4. Place the bomb into a weighed quantity of water in the calorimeter.
  5. Measure the initial temperature of the water.
  6. Ignite the fuel using an electric current through the fuse wire.
  7. The heat released by combustion raises the temperature of the water and calorimeter. Record the final temperature.



8. **Calculations:** Use the formula:  $GCV = [(W + w) \times (T_2 - T_1) \times S] / m$  to determine the Gross Calorific Value. (Variables defined above).  
Corrections for heat released by the fuse wire and acid formation may also be applied in advanced calculations.

#### 4. Analysis of Coal

Coal analysis helps in assessing its quality and suitability for various applications.

- **a) Proximate Analysis:**

- **Concept Overview:** This analysis determines the percentage of moisture, volatile matter, ash, and fixed carbon in a coal sample. It's a quick and relatively simple method.
- **Determination (not detailed in provided sources):** Typically involves heating the coal under controlled conditions and measuring weight loss at different stages.

- **b) Ultimate Analysis:**

- **Concept Overview:** This analysis determines the elemental composition of coal, i.e., the percentage of carbon, hydrogen, nitrogen, sulfur, and oxygen. It provides more precise information about the coal's quality.
- **Determination Methods:**
  - **Carbon and Hydrogen:** A known amount of coal is combusted in oxygen.  $CO_2$  and  $H_2O$  formed are absorbed by weighed tubes of KOH and anhydrous  $CaCl_2$  respectively. The increase in weight of the tubes gives the mass of  $CO_2$  and  $H_2O$ , from which %C and %H are calculated.
    - **Chemical Reactions:**  $C + O_2 \rightarrow CO_2$ ;  $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ .
    - **Calculations:**
      - % of Carbon = (Increase in weight of KOH tube / Weight of coal sample)  $\times$  (12/44)  $\times$  100.
      - % of Hydrogen = (Increase in weight of  $CaCl_2$  tube / Weight of coal sample)  $\times$  (2/18)  $\times$  100.
  - **Nitrogen (Kjeldahl's Method):**
    - A known amount of powdered coal is heated with concentrated  $H_2SO_4$  (in presence of  $K_2SO_4$  and  $CuSO_4$ ) to convert nitrogen into ammonium sulfate  $[(NH_4)_2SO_4]$ .
    - The ammonium sulfate solution is then heated with 50% NaOH solution to liberate ammonia ( $NH_3$ ).
    - $NH_3$  is distilled over and absorbed in a known quantity of standard HCl solution.
    - The unreacted HCl is titrated against standard NaOH to determine the amount of acid neutralized by  $NH_3$ .
    - **Calculation:** % of Nitrogen = (1.4  $\times$  Volume of acid used  $\times$  Normality) / Weight of coal sample.

- **Sulfur:** Determined by oxidizing sulfur in coal to sulfates (e.g.,  $\text{BaSO}_4$ ).
  - **Calculation:** % of Sulfur = (Weight of  $\text{BaSO}_4$  formed / Weight of coal sample)  $\times$  (32/233)  $\times$  100.
- **Ash Content:** Determined by heating a known weight of coal without a lid at  $700 \pm 50^\circ\text{C}$  for 30 minutes in an electric furnace. The residual weight is ash.
  - **Calculation:** % of Ash = (Weight of ash formed / Weight of air-dried coal)  $\times$  100.
- **Oxygen:** Calculated by difference: %O = 100 - (%C + %H + %N + %S + %Ash).
- **Numerical Problem (Example from source):**
  - **Query:** Calculate the quantity of air required for complete combustion of 1 Kg of fuel having composition C=70%, H=6%, O=4%, N=3%, S=3%, Ash=6%, Moisture=8%.
  - *(Note: The source provides the problem but not the step-by-step solution. This involves calculating the oxygen required for each combustible element and then determining the corresponding volume of air based on air composition (e.g., 21%  $\text{O}_2$  by volume in air).)*

## 5. Chemistry of Biogas Production and Environmental Impact

- **Concept Overview:** Biogas is a gaseous fuel produced by the anaerobic decomposition of organic waste materials (like agricultural waste, animal manure, sewage) by microorganisms.
- **Detailed Explanation:** The process occurs in a biogas digester, where organic matter is broken down in the absence of oxygen to produce a mixture of gases, primarily methane ( $\text{CH}_4$ ) and carbon dioxide ( $\text{CO}_2$ ).
- **Environmental Impact:** Biogas production is an eco-friendly way to manage organic waste and reduce greenhouse gas emissions (by converting methane, a potent GHG, from uncontrolled decomposition into fuel). It provides a renewable energy source and organic fertilizer (digested slurry).

## 6. Combustion and Related Concepts

- **Introduction to Combustion:** Combustion is an exothermic oxidation reaction in which a fuel burns in the presence of oxygen, releasing heat and light.
- **Ignition Temperature:** The lowest temperature at which a fuel vaporizes and produces a mixture with air that can ignite and continue to burn.
- **Spontaneous Ignition Temperature:** The minimum temperature at which a substance will spontaneously ignite in a normal atmosphere without an external source of ignition, such as a flame or spark.
- **Explosive Range:** The range of concentrations of a fuel vapor in air (or oxygen) within which an explosion can occur upon ignition. Below the lower explosive limit (LEL), there isn't enough fuel to burn; above the upper explosive limit (UEL), there isn't enough oxygen.

## 7. Flue Gas Analysis (ORSAT Method)

- **Concept Overview:** **Flue gas** is the gas exiting a combustion furnace or boiler after the combustion process. Its analysis determines the percentage composition of gases like  $\text{CO}_2$ ,  $\text{O}_2$ , and  $\text{CO}$ , which indicates the efficiency of combustion and the amount of excess air supplied. The **ORSAT METHOD** is a common technique for this analysis.
- **Diagram Description:** The Orsat apparatus consists of a horizontal tube with a 3-way stopcock at one end and a water-jacketed measuring burette at the other. This tube is connected to three different absorption bulbs, each containing a specific reagent for absorbing  $\text{CO}_2$ ,  $\text{O}_2$ , and  $\text{CO}$  respectively. A leveling bottle is connected to the lower end of the burette by a rubber tube.
- **Procedure:**
  1. **Preparation:** The burette is filled with water, and air is expelled. Flue gas is drawn into the burette up to 100 cc by adjusting the leveling bottle.
  2. **Absorption of  $\text{CO}_2$ :** The gas from the burette is passed into **Bulb 1**, which contains a **KOH solution**. KOH absorbs  $\text{CO}_2$ . The gas is cycled multiple times to ensure complete absorption. The decrease in volume represents the volume of  $\text{CO}_2$ .
  3. **Absorption of  $\text{O}_2$ :** After closing Bulb 1, the remaining gas is passed into **Bulb 2**, which contains **alkaline pyrogallol**. This reagent absorbs  $\text{O}_2$ . The decrease in volume gives the volume of  $\text{O}_2$ .
  4. **Absorption of  $\text{CO}$ :** After closing Bulb 2, the remaining gas is sent into **Bulb 3**, containing **ammoniacal cuprous chloride**. This absorbs  $\text{CO}$ . The final decrease in volume gives the volume of  $\text{CO}$ .
  5. **Remaining Gas:** The gas remaining in the burette after these absorptions is usually considered to be nitrogen ( $\text{N}_2$ ).
- **Significance:** Orsat analysis provides critical data for optimizing combustion processes, ensuring maximum energy recovery from fuels, and minimizing harmful emissions.

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These notes comprehensively cover the key concepts of Unit 4 as outlined in your provided sources. Remember to integrate these theoretical concepts with practical understanding for a holistic preparation.