UNIT 3: INDUSTRIAL CHEMISTRY

Introduction to Industrial Chemistry and Natural Resources

Industrial Revolution and Chemical Industry Development

The 19th-century Industrial Revolution marked the beginning of the rapid development of chemical industries, leading to an increased demand for goods produced through chemical processes. Today, both developed and developing countries benefit from chemical industries that produce a wide array of essential products, including synthetic fibers, plastics, rubber, fertilizers, dyes, and drugs.

Importance of Industrial Chemistry

Chemistry and chemical technology are crucial for economic growth, especially in developing countries like Ethiopia. Ethiopia possesses a wealth of mineral resources, including iron, lead, copper, gold, and tantalum, among others. Additionally, resources like rock salt, gypsum, coal, and crude oil are abundant. For Ethiopia to capitalize on these resources, an industrial revolution in the chemical sector is necessary.

What is Industrial Chemistry?

Industrial chemistry is a branch of chemistry that focuses on applying physical and chemical procedures to transform natural raw materials into products beneficial to humanity. It bridges the gap between academic chemistry and its commercial applications.

The Role of the Chemical Industry

The chemical industry plays a pivotal role in producing a wide variety of products, such as food, medicine, building materials, and plastics. These products often undergo chemical reactions and refining processes to ensure they meet societal needs. Some of these products serve as raw materials for other industries, while others are used directly by consumers.

Natural Resources and Industry

Natural Resources as Raw Materials

Natural resources, the raw materials for the chemical industry, are derived from the environment:

1. **Atmosphere:** The Earth's atmosphere contains gases like nitrogen, oxygen, carbon dioxide, and noble gases, which serve as essential industrial raw materials.
2. **Hydrosphere:** Oceans, with about 3.5% dissolved materials, are a source of sodium chloride, magnesium, and bromine.
3. **Lithosphere:** The Earth's crust provides mineral ores, carbon, hydrocarbons, coal, natural gas, and crude petroleum, which are energy sources and raw materials for thousands of chemicals.
4. **Biosphere:** Vegetation and animals supply raw materials like oils, fats, waxes, resins, and natural fibers for agro-based industries.

Classification of Natural Resources

Natural resources are classified into two categories:

1. **Renewable Resources:** These resources can be replenished through natural cycles, such as plants, animals, water, and solar energy.
2. **Non-Renewable Resources:** These resources cannot be regenerated naturally and are available in limited amounts, like fossil fuels, metals, and minerals.

The Chemical Industry

Classification Based on Raw Materials and Products

1. **Natural Raw Materials:** Industries like sugar manufacturing use natural resources like sugarcane.
2. **Industrial Products:** Industries such as detergent manufacturing use preprocessed products from other industries.

Product-Based Classification

Chemical industries are classified based on the products they produce, including food processing, beverages, textiles, apparel, leather, and paper industries.

Key Concepts in Chemical Manufacturing

General Methods of Manufacturing

The manufacturing process involves several steps designed to produce a desired product from various raw materials using energy through successive physical or chemical treatments.

Example: Ammonia Production Using the Haber-Bosch Process

The Haber-Bosch process, developed in the early 20th century, revolutionized ammonia production by combining nitrogen from the air with hydrogen from methane under high pressure and temperature. This process is vital for producing nitrogen fertilizers, which are essential for increasing crop yields.

Steps in Ammonia Production

1. **Obtaining Raw Materials:** Hydrogen is derived from methane, and nitrogen is obtained from air.
2. **Reaction Conditions:** The gases are introduced into a reactor at high pressure and temperature in the presence of a catalyst.
3. **Condensation and Recycling:** Ammonia is condensed, and unreacted gases are recycled, achieving a high conversion rate.

Nitric Acid: Properties, Uses, and Production

Properties of Nitric Acid:

- **Physical Properties:**
  - Nitric acid (HNO_3) is a colorless liquid with a highly pungent odor, similar in appearance to water.
  - It has a density of 1.51 g/cm^3.
  - When exposed to light, it decomposes slightly into nitrogen dioxide (NO_2), which gives it a brown color:

    $$4HNO_3(l) \rightarrow 4NO_2(g) + O_2(g) + 2H_2O(l)$$

- **Chemical Properties:**
  - Nitric acid is a strong acid that dissociates completely in water to form hydronium ions (H_3O^+) and nitrate ions (NO_3^-).
  - It is a highly corrosive mineral acid and a strong oxidizing agent, especially when concentrated and hot.
  - It reacts violently with metals, releasing hydrogen and heat, and many of its reactions are explosive.
  - Contact with skin can cause severe burns and necrosis.

Uses of Nitric Acid:

- **Agriculture:**
  - Neutralization of nitric acid with ammonia produces ammonium nitrate, a key component of mineral fertilizers.
  - It can also be used for soil acidification in horticulture.

- **Chemical Industry:**
  - Nitric acid is used as a precursor to organic nitrogen compounds, such as nitrobenzenes, and in the production of explosives like TNT and nitroglycerine.
  - It is also used in the production of rocket fuel, organic dyes, lacquers, pharmaceuticals, fungicides, and household cleaning products.
- **Metalworking and Jewelry:**
  - It is employed for cleaning and etching metal surfaces and refining precious metals.
- **Miscellaneous Uses:**
  - Artificial aging of wood to achieve specific shades.
  - Detection of trace metals in laboratory test substances.

Preparation of Nitric Acid:

1. **Laboratory Method:**
   - Nitric acid can be prepared by reacting potassium nitrate (KNO_3) with concentrated sulfuric acid (H_2SO_4):

     $2KNO_3+H_2SO_4 \rightarrow K_2SO_4+2HNO_3$

2. **Industrial Production (Ostwald Process):**
   - **Step 1:** Ammonia (NH_3) is oxidized to nitric oxide (NO) over a platinum catalyst at high temperatures:

     $4NH_3(g)+5O_2(g) \rightarrow 4NO(g)+6H_2O(g)$

   - **Step 2:** The nitric oxide (NO) is further oxidized to nitrogen dioxide (NO_2):

     $2NO(g)+O_2(g) \rightarrow 2NO_2(g)$

   - **Step 3:** The nitrogen dioxide (NO_2) is absorbed in water to produce nitric acid and nitric oxide (NO):

     $3NO_2(g)+H_2O(l) \rightarrow 2HNO_3(aq)+NO(g)$

   - The nitric oxide (NO) produced in the third step is recycled back into the process.

The Ostwald process is highly efficient for producing nitric acid at concentrations of 65-68%, which is most desirable for commercial use.

Common Pesticides and Herbicides

Pesticides

Pesticides are chemicals used to control pests, diseases, weeds, and other plant pathogens. They help prevent yield losses and maintain high product quality. Pesticides are classified based on their chemical composition, which allows for a scientific grouping that correlates their structure with their activity, toxicity, and degradation mechanisms. Here are some common types of pesticides:

1. **Organochlorines**:
    - **Characteristics**: Soluble in lipids, accumulate in the fatty tissues of animals, toxic to a variety of animals, and have long-term persistence.
    - **Main Composition**: Comprised of carbon, hydrogen, chlorine, and oxygen atoms. They are nonpolar and lipophilic (fat-loving).

2. **Organophosphates**:
    - **Characteristics**: Soluble in organic solvents and water, less persistent than organochlorines, some affect the central nervous system, and are absorbed by plants, transferring to leaves and stems.
    - **Main Composition**: Contain a central phosphorus atom. These compounds are more stable and less toxic than organochlorines. They can be aliphatic, cyclic, or heterocyclic.
3. **Carbamates**:
    - **Characteristics**: Derivatives of carbamic acid, kill a limited spectrum of insects, highly toxic to vertebrates, and have relatively low persistence.
    - **Main Composition**: Based on a plant alkaloid, *Physostigma venenosum*.
4. **Pyrethroids**:
    - **Characteristics**: Affect the nervous system but are safer than other pesticides; commonly used as household insecticides.
    - **Main Composition**: Similar to synthetic pyrethrins, alkaloids obtained from the petals of *Chrysanthemum cinerariifolium*.
5. **Biological Pesticides**:
    - **Characteristics**: Derived from natural sources like bacteria, viruses, or microorganisms, and are commonly used against forest pests and crop pests.
    - **Main Composition**: The most common biological pesticide is *Bacillus thuringiensis* (Bt), used to target specific insects like caterpillars and butterflies.

Traditional Pesticides in Ethiopia

In Ethiopia, farmers also produce botanical pesticides from plant origins. These pesticides are extracted from various plant parts like stems, seeds, roots, leaves, and flowers. They are popular due to their broad spectrum of activity, ease of use, short residual activity, and lack of accumulation in the environment or in animal tissues.

Neem Leaf: A common traditional pesticide in Ethiopia, Neem leaf is known for its medicinal properties and pest-deterring capabilities. It is non-toxic to animals, birds, plants, and humans. Neem oil, extracted from the leaves, is effective for about 22 days when sprayed on plants.

Herbicides (Chemical Weed Killers)

Herbicides are chemicals used to control unwanted plants (weeds). They are classified into selective herbicides, which target specific weeds, and non-selective herbicides, which kill all plants they come into contact with.

Types of Herbicides:

1. **Chlorophenoxy Acids**: Examples include 2,4-D and 2,4,5-T.
2. **Triazines**: Examples include Atrazine, Hexazinone, and Simazine.
3. **Organic Phosphorus Chemicals**: Glyphosate is a well-known example.
4. **Amides**: Examples include Alachlor and Metolachlor.
5. **Thiocarbamates**: An example is Butylate.
6. **Dinitroanilines**: Trifluralin is a common example.
7. **Chloroaliphatics**: Examples include Dalapon and Trichloroacetate.
8. **Inorganic Chemicals**: Various arsenicals, cyanates, and chlorates are used as herbicides.

Herbicides have largely replaced mechanical weed control methods in highly mechanized agricultural systems.

Some Manufacturing Industries in Ethiopia

Overview of the Chemical Industry: The chemical industry in Ethiopia is still in its early stages of development. The growing economy demands the expansion of this sector, as currently, much of the country's chemical products are imported. As of 2022, Ethiopia has over 2,228 manufacturing industries, as reported by ADDISBIZ.com.

Key Manufacturing Industries:

1. **Glass Manufacturing**:
    - **Overview**: Glass is a non-crystalline solid known for its versatility, heat resistance, and recyclability. The primary component of glass is silica.
    - **Types of Glass**:
        - **Quartz Glass**: Made from pure silica at around 2300°C, it is known for its strength and transparency.
        - **Soda-Lime Glass**: The most common type, made from silica sand, sodium carbonate, and limestone. It is used in windows, bottles, and dishes.
        - **Borosilicate Glass (Pyrex)**: Made with boron oxide, it resists chemical corrosion and temperature changes, making it ideal for laboratory equipment and ovenware.
    - **Production Process**:
        i. **Batch Preparation**: Mixing raw materials like sand, sodium carbonate, and limestone.
        ii. **Glass Melting**: Heating the mixture to 1600°C to form molten glass.
        iii. **Glass Forming**: Shaping the molten glass.
        iv. **Annealing**: Removing internal stresses by reheating and slowly cooling the glass.
        v. **Inspection**: Ensuring the glass meets quality standards.
        vi. **Packing and Dispatching**: Preparing the final product for distribution.
2. **Ceramic Manufacturing**:
    a. **Overview**: Ceramics are inorganic, non-metallic solids made by heating and cooling. They are used in various applications due to their hardness, wear resistance, and thermal stability.
    b. **Manufacturing Process**:
        i. **Moulding**: Shaping ceramic powder into objects using wax or plastic additives.
        ii. **Densification**: Heating the shaped object in a furnace to achieve a dense, strong structure.
    c. **Applications**: Ceramics are used in art, kitchenware, electrical insulators, engine parts, and even in medical implants and space shuttles.
3. **Cement Production**:
    a. **Overview**: Cement production in Ethiopia has increased due to new and upgraded factories. The primary raw material is limestone, which is abundant in the country.
    b. **Manufacturing Process**:

i. **Calcination**: Heating limestone, alumina, and silica to 1450°C to form clinker.
ii. **Grinding**: Mixing clinker with gypsum to produce Ordinary Portland Cement (OPC).

c. **Setting of Cement**: When mixed with water, cement forms a plastic mass that hardens into a solid due to the formation of chemical bonds. Initial setting occurs within 24 hours, with full hardening taking about two weeks.

4. **Sugar Manufacturing**:
   a. **Overview**: Sugar is primarily produced from sugarcane, a tall grass grown in tropical and subtropical regions.
   b. **Production Steps**:
      i. **Harvesting**: Gathering mature sugarcane.
      ii. **Cleansing and Grinding**: Cleaning and shredding the cane.
      iii. **Juicing**: Extracting juice from the shredded cane.
      iv. **Clarifying**: Removing impurities from the juice.
      v. **Evaporation**: Concentrating the juice into syrup.
      vi. **Crystallization**: Forming sugar crystals from the syrup.
      vii. **Refinery**: Purifying the raw sugar to produce refined sugar.
      viii. **Separation and Packaging**: Finalizing and packaging the refined sugar.
5. **Paper Manufacturing**:
   a. **Overview**: Paper is made from wood pulp, a mixture derived from rags and wood chips. Wood pulp is mainly sourced from softwood trees.
   b. **Manufacturing Process**:
      i. **Harvesting**: Cutting down trees and transporting them to the mill.
      ii. **Preparation**: Removing bark and chipping wood into uniform pieces.
      iii. **Pulping**: Converting wood chips into pulp through mechanical or chemical means.
      iv. **Bleaching**: Removing color and increasing brightness using chemicals like chlorine or hydrogen peroxide.
      v. **Paper Making**: Converting pulp into paper sheets through a series of compression and drying steps.

Tannery and the Process of Leather Production

Tanning is the process of converting raw animal hides and skins into durable and flexible leather using tannin. Tannin is an acidic chemical that permanently alters the protein structure of the skin, ensuring that it cannot revert to its raw state.

Leather production involves three main stages: preparatory stages, tanning, and crusting.

1. Preparatory Stages

These stages prepare the hide or skin for tanning and include several processes:

- **Curing**: This involves salting or drying the hide after it is removed from the animal to prevent bacterial infection and decay. Curing also removes excess water from the hide, with brine curing being a common method.
- **Soaking**: Cured hides are soaked in water to remove salt, dirt, blood, and excess fat.
- **Flesh Removal**: Machines strip flesh from the hide's surface.
- **Hair Removal**: Hides are immersed in a lime and water mixture (liming) to loosen hair, which is then mechanically removed.
- **Scudding**: Any remaining hair and fat are removed with a dull knife or plastic tool.
- **Deliming**: Lime is removed from the hides by soaking them in an acidic solution, preparing the hides for tanning.

2. Tanning

This stage converts the protein in the hide into stable leather. There are two main types of tanning:

- **Vegetable (Natural) Tanning**: Hides are placed in tannin solutions derived from plant barks and leaves, such as oak or chestnut. This method produces flexible leather used in shoes, luggage, and furniture.
- **Mineral Tanning**: Hides are treated with chromium salts, which speed up the tanning process and produce stretchable leather used in garments and handbags. The leather typically turns greenish-blue due to the chromium.

3. Crusting

The final stage involves several finishing processes:

- **Dyeing**: Leather is dyed to achieve the desired color.
- **Rolling**: The leather is rolled to increase its strength.
- **Stretching**: The leather is stretched in a heat-controlled environment.
- **Surface Treatment**: The grain surface of the leather is treated with chemical compounds like wax or oil to enhance its appearance and make it attractive.

In summary, the tanning process transforms raw animal hides into durable leather through a series of preparatory, tanning, and finishing steps. This complex process ensures that leather remains a versatile material used in various industries.

Soap and Detergents

Soaps:

- **Definition and Composition:** Soaps are organic chemicals synthesized from fats and oils, which are esters of glycerol and fatty acids. They are surface-active agents, meaning they reduce the surface tension of water and help in cleaning by altering surface properties.
- **Types of Soaps:**
  - **Hard Soaps:** Made from sodium salts of long-chain carboxylic acids.
  - **Soft Soaps:** Made from potassium salts, generally softer than hard soaps.
- **Manufacturing Process:**

1. **Saponification:** Fats/oils react with a base (e.g., sodium hydroxide) to form soap.
2. **Glycerine Removal:** Most glycerine is removed due to its higher value. Some remains to soften the soap.
3. **Soap Purification:** Excess sodium hydroxide is neutralized, and water content is reduced.
4. **Finishing:** Additives like color, perfume, and preservatives are added, and the soap is shaped.

Industrial Ingredients: Common ingredients include tallow, lard, and various oils (cottonseed, palm, olive, etc.). The type of lye used (sodium or potassium hydroxide) determines whether the soap is hard or soft.

Detergents:

- **Definition and Composition:** Detergents are synthetic cleaning agents, often called soapless soaps. They are composed of long-chain organic alcohols and sulfonic acids, which make them more effective in hard water.
- **Types and Properties:**
  - **Example:** Sodium lauryl sulfate, made by reacting lauryl alcohol with sulfuric acid and then neutralizing with sodium hydroxide.
  - **Advantages:** Unlike soaps, detergents do not form scum in hard water because their calcium and magnesium salts are soluble.

Experimentation and Observations:

- **Soap Preparation:** Soap can be prepared by heating fats or oils with a base like NaOH. Ethanol is added to help dissolve the fat, and NaCl is used to precipitate the soap.

- **Comparison with Detergent:** In an experiment, soap and detergent are added to hard water to observe which forms better lather. Detergents generally lather better in hard water because they do not react with calcium and magnesium ions to form scum.

Dry Cleaning:

- **Purpose:** Dry cleaning uses chemicals to clean fabrics without water, preserving the quality of delicate materials like silk.
- **Common Chemicals:** Include tetrachloromethane (CCl_4), tetrachloroethylene ($Cl_2C=CCl_2$), benzene, and gasoline.