2. INDUSTRIAL PROCESSES IN CHEMISTRY

Competency: The learner appreciates the principles behind some industrial processes and the importance of the products formed.

Key words

- Ore
- Fertilizer
- Nitrate
- Cement
- Calcination
- Electrolysis
- Crystallization
- Extraction
- Refining
- Casting
- Primary Industry
- Secondary Industry
- Tertiary Industry
- Roasting
- Limestone

The learner should be able to:

- Know about some of the main industries that produce useful chemicals, such as the oil industry for organic chemicals, the production of metals, the acid industry, the alkali industry, the fertilizer industry and the cement industry.
- Understand the processes for obtaining useful chemicals from rocks.
- Understand the processes involved in extracting and purifying metals, with particular reference to processes used in Uganda.
- Understand the importance of nitrates as fertilizers in food production and know how they are produced from the nitrogen in the air.
- Outline four industrial processes that make use of natural resources obtained in Uganda.
- Recognize the importance of industrial processes in utilizing natural resources to make useful chemicals, and appreciate that industrial processes have social benefits and cause problems of pollution and environmental destruction.
- Describe some of the dangers to the community arising from these industrial processes and the steps that may be taken to minimize these dangers.
- Understand the process in the manufacture of lime and cement.
- Understand the production of alkali and chlorine by the electrolysis of salt solution.

Industrial processes are large-scale chemical reactions carried out in factories to produce various products. These processes involve the use of raw materials, energy, and catalysts to convert substances into desired products.

Key Industrial Processes

Haber process

- Produces ammonia from nitrogen and hydrogen gases.
- Used to manufacture fertilizers and explosives.

Contact Process

- Produces sulphuric acid from sulphur, oxygen, and water.
- Used in the production of fertilizers, batteries, and other chemicals.

Chloralkali Process

- Produces chlorine, sodium hydroxide, and hydrogen gas from sodium chloride brine.
- Used in the production of paper, plastics, and disinfectants.

Cracking

- Breaks down large hydrocarbon molecules into smaller ones.
- Used to produce gasoline, diesel fuel, and other petroleum products.

Fermentation

- Converts sugars into ethanol and carbon dioxide using microorganisms.
- Used in the production of alcoholic beverages, biofuels, and pharmaceuticals.

Common Industries, their products and class.

Industry	Products	Use of the products	Class of industry
Sugar Industry (Kakira sugar works)	Sugar	Food, Beverages	Primary Industry
Coffee Industry (Uganda Coffee Development Authority)	Coffee Beans	Beverages	Primary Industry
Cotton Industry (Uganda Cotton Ginners Association)	Cotton Lint, Textiles	Clothing, Bedding	Secondary Industry

Tobacco Industry	Tobacco Products	Smoking	Secondary Industry
Cement Industry (Hima cement Ltd)	Cement	Construction	Secondary Industry
Steel Industry (Mukwano Steel Industry)	Steel Products	Construction, Manufacturing	Secondary Industry
Brewery Industry (Uganda Breweries Ltd)	Beer, Soft Drinks	Beverages	Secondary Industry
Food Processing Industry (British American Tobacco Uganda)	Processed Foods	Food	Secondary Industry
Leather Industry	Leather Products	Footwear, Clothing	Secondary Industry
Timber Industry	Timber Products	Construction, Furniture	Primary Industry
Electricity Generation Industry (Uganda Electricity Generation Company Ltd)	Electricity	Powering Homes, Industries	Tertiary Industry
Oil Refining Industry	Refined Petroleum Products	Transportation, Energy	Secondary Industry
Pharmaceutical Industry	Medicines	Healthcare	Secondary Industry
Textile Industry (Nytil Picfare Ltd)	Textiles, Clothing	Clothing, Bedding	Secondary Industry

Note:

- Primary Industry: Extraction and production of raw materials
- Secondary Industry: Processing and manufacturing of goods
- Tertiary Industry: Provision of services

Major Industries Producing Useful Chemicals

Industry	**Chemicals produced**	**Uses**
Petrochemical Industry	Ethylene, Propylene, Benzene, Toluene, Xylene	Plastics, synthetic fibers, detergents, solvents, pharmaceuticals
Chemical Industry	Sulphuric acid, Nitric acid, Chlorine, Sodium hydroxide	Fertilizers, batteries, paper, textiles, cleaning agents
Pharmaceutical Industry	Aspirin, Paracetamol, Antibiotics, Vaccines	Medicine, healthcare
Fertilizer Industry	Urea, Ammonia, Phosphoric acid, Potassium chloride	Agriculture
Food Processing Industry	Citric acid, Acetic acid, Sodium benzoate	Food preservatives, flavorings, acidity regulators
Cement Industry	Calcium oxide (lime), Calcium silicate	Cement production, construction
Metal Industry	Various metals and alloys	Construction, machinery, electronics

Useful Minerals, Their Chemical Formulas, and Uses

Mineral Name	**Chemical Formula**	**Image**	**Use**
Gold	Au		Jewelry, electronics, dentistry
Silver	Ag		Jewelry, photography, electronics

Copper	Cu		Electrical wiring, plumbing, alloys
Platinum	Pt		Jewelry, catalytic converters, laboratory equipment
Quartz	SiO_2		Glassmaking, electronics, jewelry
Feldspar	$KAlSi_3O_8$, $NaAlSi_3O_8$, $CaAl_2Si_2O_8$		Ceramics, glass, fertilizers
Mica	$KAl_2(AlSi_3O_{10})(OH)_2$		Insulation, lubricants, electronics
Calcite	$CaCO_3$		Cement production, construction materials, agriculture
Gypsum	$CaSO_4{\cdot}2H_2O$		Plaster, drywall, cement

Hematite	Fe_2O_3		Iron ore, pigment
Magnetite	Fe_3O_4		Iron ore, magnetic materials
Bauxite	AlO(OH)		Aluminum production
Halite (Rock Salt)	NaCl		Food seasoning, industrial use
Fluorite	CaF_2		Steelmaking, glassmaking, ceramics

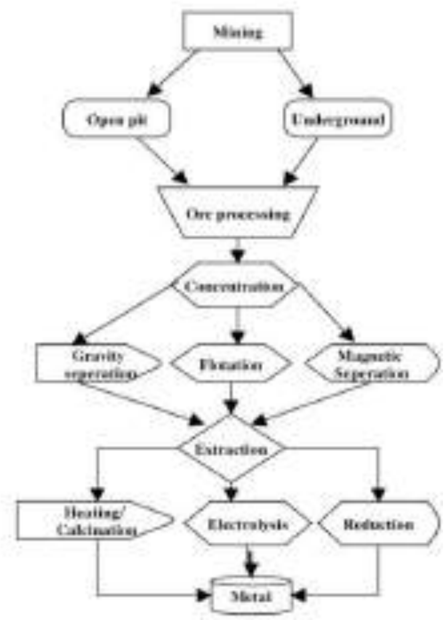
Obtaining Useful Chemicals from Rocks

The process of extracting useful chemicals from rocks involves a series of steps, from mining the raw material to refining it into valuable products.

Mining

Identification of Ore Deposits: Geological surveys and exploration techniques are used to locate mineral-rich deposits.

Rocks containing the desired minerals are extracted from the earth through mining or quarrying. Different mining methods are employed based on the type of deposit and its depth. Open-pit Mining for deposits near the surface and Underground Mining for deeper deposits.



Ore Processing

Crushing and Grinding: The mined ore is crushed and ground into smaller particles to increase the surface area for further processing.

Concentration

The crushed rocks are then separated into different minerals using various techniques such as:

- Gravity Separation: Separates minerals based on density differences.
- Froth Flotation: Uses surfactants to selectively attach to mineral particles, separating them from the gangue.
- Magnetic Separation: Separates magnetic minerals from non-magnetic ones.

Extraction of Useful Chemicals

The separated minerals are then processed to extract the useful chemicals. This can involve:

- Heating (calcination)
- Reaction with acids or bases
- Electrolysis

Purification

The extracted chemicals are then purified to remove impurities. This can involve:

- Crystallization
- Distillation

- Chromatography

The purified chemicals are then packaged and distributed to various industries for use.

Properties of Ore Considered Before Concentration

Before selecting a suitable concentration method, several properties of the ore are considered:

- Density: The difference in density between the ore mineral and the gangue minerals determines the suitability of methods like gravity separation.
- Magnetic Properties: Magnetic ores, like magnetite, can be separated from non-magnetic gangue using magnetic separation.
- Particle Size: The size of the ore particles influences the choice of crushing and grinding techniques.
- Reactivity: The chemical reactivity of the ore minerals determines the choice of leaching agents and other chemical treatments.
- Solubility: The solubility of the ore mineral in specific solvents can be exploited in hydrometallurgical processes.

Metallurgical Processes

Metallurgy: The science and technology of extracting metals from their ores and refining them.

Pyrometallurgy: Involves heating the ore to high temperatures to extract the metal.

- Roasting: Oxidizing the ore to remove impurities.
- Smelting: Reducing the metal oxide to the pure metal using a reducing agent like carbon.

Hydrometallurgy: Involves leaching the metal from the ore using chemical solvents.

Electrometallurgy: Uses electrolysis to extract pure metals from solutions.

Chemical Processing

Chemical Reactions: Various chemical reactions are used to extract and purify chemicals from minerals.

- Precipitation: Solutes are separated from a solution by forming a solid precipitate.
- Crystallization: Pure substances are obtained from solutions by forming crystals.
- Distillation: Separates liquids based on their boiling points.

Refining and Purification

Further Processing: The extracted chemicals are often further refined and purified to achieve the desired purity and quality.

Physical and Chemical Methods: Techniques like distillation, crystallization, and chemical reactions are used to remove impurities.

Extraction and purification of Metals

Food for thoughts

What is Metal Extraction?

Why is Metal Extraction Necessary?

Metal extraction is the process of separating metals from their **ores** and other impurities. This process involves various physical and chemical methods to isolate the metal in its pure form.

Metal extraction is necessary because metals are not found in their pure form in nature. They are often mixed with other elements and compounds, and extracting the metal from its ore is essential for its use in various industries.

Metal extraction and purification are crucial for the **production** of **high-quality metals**, which are used in various industries such as construction, transportation, electronics, and more.

Common methods used for extraction and purification of metals and examples of metals extracted by each method

Method of Extraction	Description	Examples of Metals Extracted
Electrolysis (Pr)	Uses electric current to extract metal from ore	Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg)
Reduction with Carbon	Uses carbon to reduce metal oxide to pure metal	Iron (Fe), Zinc (Zn), Tin (Sn)
Reduction with Hydrogen	Uses hydrogen to reduce metal oxide to pure metal	Tungsten (W), Molybdenum (Mo)
Flotation	Separates metal-bearing minerals from impurities based on differences in surface properties	Copper (Cu), Lead (Pb), Zinc (Zn)
Magnetic Separation	Separates metal-bearing minerals from impurities based on differences in magnetic properties	Iron (Fe), Titanium (Ti)
Hydrometallurgy	Uses aqueous solutions to extract metal from ore	Copper (Cu), Nickel (Ni), Gold (Au)
Distillation (Pr)	Separates metal from impurities based on differences in boiling points	Mercury (Hg), Zinc (Zn)
Crystallization (Pr)	Separates metal from impurities based on differences in solubility	Copper (Cu), Silver (Ag)

Extraction of Aluminum: The Hall-Héroult Process

Aluminum is a lightweight, durable, and versatile metal widely used in various industries. Its primary ore is bauxite, which contains aluminum oxide (Al_2O_3). However, due to the high melting point of aluminum oxide, it's not feasible to directly electrolyze it.

Aluminum is primarily extracted from bauxite, which is the main ore of aluminum. Bauxite contains aluminum oxides along with impurities like iron oxides, silica, and titanium dioxide.

Bauxite is crushed and then treated with a concentrated solution of sodium hydroxide ($NaOH$) under high pressure and temperature. This dissolves the aluminum oxides, forming sodium aluminate.

The impurities, being insoluble, remain as a solid residue called "red mud." The sodium aluminate solution is then cooled and seeded with crystals of aluminum hydroxide ($Al(OH)_3$). This causes the aluminum hydroxide to precipitate out of the solution.

The precipitated aluminum hydroxide is then filtered, washed, and dried. The dried aluminum hydroxide is heated strongly to drive off water, converting it into pure aluminum oxide (Al_2O_3).

$2Al(OH)_3(s) \rightarrow Al_2O_3(s) + 3H_2O(g)$

2. Electrolysis of Alumina:

* Hall-Héroult Process: This process is used to extract aluminum from pure aluminum oxide (alumina).
  * Electrolyte: Alumina has a very high melting point, making it difficult to electrolyze directly. Therefore, it is dissolved in molten cryolite (Na_3AlF_6), which significantly lowers the melting point.
  * Electrolysis Cell: The electrolysis cell consists of a steel tank lined with carbon, which acts as the cathode. Carbon anodes are immersed in the molten electrolyte.
  * Electrolysis: When a direct current is passed through the electrolyte, the following reactions occur:
    * At the Cathode (Reduction):
      * $Al^{3+} + 3e^- \rightarrow Al(l)$
      * Aluminum ions gain electrons and are reduced to molten aluminum, which collects at the bottom of the cell.
    * At the Anode (Oxidation):
      * $2O^{2-} \rightarrow O_2(g) + 4e^-$
      * Oxide ions lose electrons and are oxidized to oxygen gas. The oxygen reacts with the carbon anodes, forming carbon dioxide.

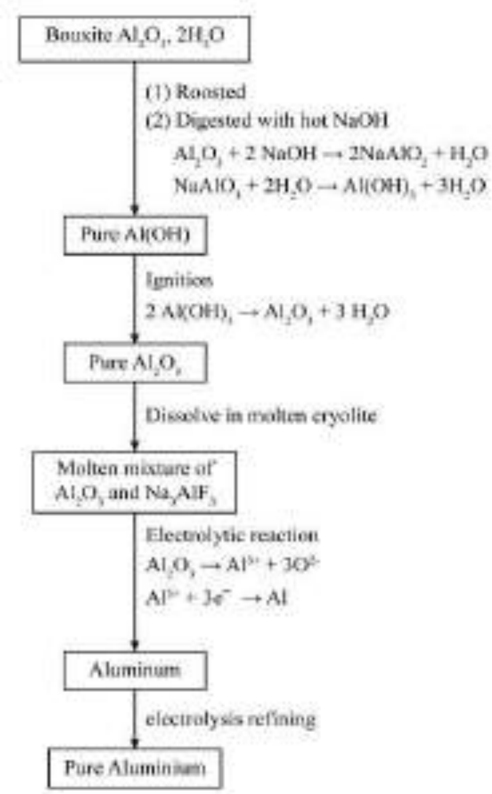
* Molten Aluminum: The molten aluminum is periodically tapped from the bottom of the cell.

Key Points:

* The extraction of aluminum is an energy-intensive process, primarily due to the high temperatures required for the Bayer and Hall-Héroult processes.
* The Bayer process generates a significant amount of red mud, which can be an environmental concern if not properly managed.
* Recycling aluminum is crucial to conserve energy and reduce environmental impact, as it requires significantly less energy than extracting aluminum from bauxite.

I hope this explanation is helpful!

The Hall-Héroult Process is the primary method for extracting aluminum from bauxite.



Bauxite, the primary ore of aluminum, is mined from open-pit or underground mines. The bauxite is crushed into smaller pieces to increase the surface area.

The crushed bauxite is mixed with a hot concentrated solution of sodium hydroxide (NaOH) in a process known as digestion. The NaOH dissolves the aluminum-bearing minerals, leaving behind impurities such as iron oxides and silicates.

Al_2O_3 (s) + 2NaOH (aq) → $2NaAlO_2$ (aq) + H_2O (l)

The resulting mixture is then clarified to remove any remaining impurities. This is done by adding flocculants, which cause the impurities to clump together and settle out of the solution.

The clarified solution is then seeded with small crystals of aluminum hydroxide ($Al(OH)_3$).The $Al(OH)_3$ precipitates out of the solution, leaving behind a solution of sodium aluminate ($NaAlO_2$).

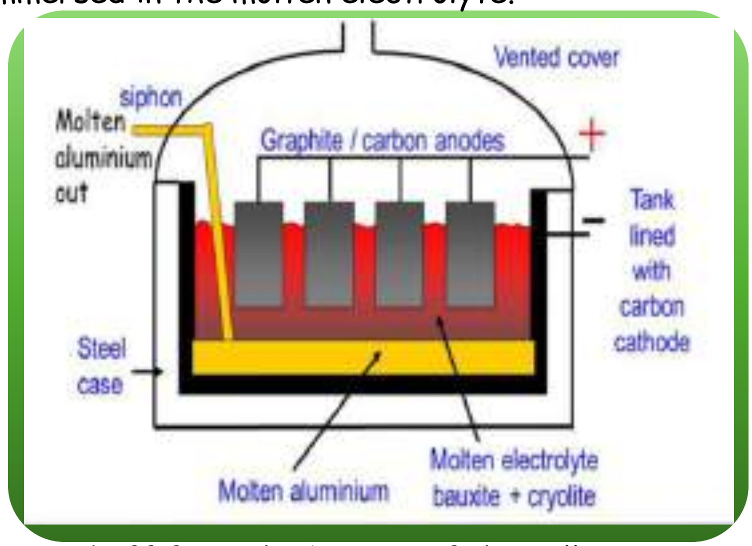
The precipitated $Al(OH)_3$ is then heated in a calciner to produce alumina (Al_2O_3).This process removes water and converts the $Al(OH)_3$ into a more reactive form.

$2Al(OH)_3 (s) \rightarrow Al_2O_3 (s) + 3H_2O (g)$

The alumina is then dissolved in a bath of molten cryolite (Na_3AlF_6) in electrolytic cell at a temperature of around 950°C to lower the melting point and improve conductivity.

$Al_2O_3 (s) + 2Na_3AlF_6 (l) \rightarrow 4NaF (l) + 2AlF_3 (l) + 3O^{2-} (l)$

Electrolysis Cell is designed with a large steel tank lined with graphite which acts as the cathode. Carbon anodes are immersed in the molten electrolyte.



An electric current is then passed through the bath, causing the aluminum to be reduced at the cathode (negative electrode) and deposited as pure aluminum.

At the cathode: Aluminum ions gain electrons and are reduced to molten aluminum, which collects at the bottom of the cell.

$Al^{3+} (aq) + 3e^- \rightarrow Al (s)$

The molten aluminum is periodically tapped off from the bottom of the cell.

The resulting aluminum is then cast into its desired shape using a mold. The casting process involves pouring the molten aluminum into the mold and allowing it to cool and solidify.

At the anode: Oxide ions lose electrons and form oxygen gas, which reacts with the carbon anode to form carbon dioxide.

$2O^{2-} (l) \rightarrow O_2 (g) + 4e^-$

Key Points

The Hall-Héroult process is energy-intensive due to the high temperatures required.
The carbon anodes are gradually consumed during the process and need to be replaced periodically.
The process produces significant amounts of carbon dioxide, contributing to greenhouse gas emissions.

Extraction of Copper

Copper is a widely used metal, essential for various applications such as electrical wiring, plumbing, and construction. Its extraction involves several steps, including mining, concentration, smelting, and refining.

Raw materials

The principle ores in the extraction of copper are;

- Copper pyrites
- Cuprite
- Copper (I) sulphide
- Malachite

Extraction of Copper from copper pyrite

Copper ore (copper pyrite) is extracted from open-pit or underground mines.
The ore is crushed into smaller pieces and then ground into a fine powder to increase the surface area for the next stage.
The powdered ore is mixed with water, oil, and a frothing agent. Air is blown through the mixture, creating a froth. This process of Froth Flotation separates the copper-containing minerals from the gangue (impurities). The copper-containing minerals, being hydrophobic, adhere to the air bubbles and rise to the surface with the froth, while the gangue sinks to the bottom. The froth is skimmed off, and the copper-rich concentrate is recovered.

The copper concentrate is heated strongly in the presence of air in a furnace. This process, called roasting, converts copper sulphides into oxides while removing some of the sulphur as sulphur dioxide gas.

$2CuFeS_2 + O_2 \rightarrow Cu_2S + 2FeS + SO_2$

$2FeS + 3O_2 \rightarrow 2FeO + 2SO_2$

$Cu_2S + O_2 \rightarrow Cu_2O + SO_2$

The roasted ore is mixed with silica (SiO_2) and coke (carbon) and smelted in a blast furnace.

The silica reacts with iron(II) oxide (FeO) to form iron(II) silicate ($FeSiO_3$), which is a slag that floats on top of the molten copper.

$FeO + SiO_2 \rightarrow FeSiO_3$ (slag)

Some of the copper(I) oxide (Cu_2O) is reduced to metallic copper by carbon.

$Cu_2O + C \rightarrow 2Cu + CO$

The molten material from the blast furnace, called matte, contains copper(I) sulphide (Cu_2S) and some iron sulphides. It is transferred to a converter, where air is blown through the molten matte.

The remaining iron sulphides are oxidized to iron(II) oxide, which reacts with silica to form slag.

The copper(I) Sulphide is further oxidized to copper(I) oxide.

Finally, copper(I) oxide reacts with the remaining copper(I) sulphide to produce blister copper and sulfur dioxide.

$2Cu_2O + Cu_2S \rightarrow 6Cu + SO_2$

Blister copper contains impurities like sulphur, oxygen, and other metals. It is further refined to produce pure copper.

Electrolytic Refining: In this process, impure copper is made the anode, and a thin sheet of pure copper is made the cathode. The electrolyte is a solution of copper sulphate and Sulphuric acid. On passing an electric current, pure copper dissolves from the anode and deposits on the cathode, while the impurities settle at the bottom as anode mud.

The refined copper is cast into various shapes like sheets, rods, or wires for further use.

Key Points:

- Copper mining and processing can have significant environmental impacts, including water pollution, soil erosion, and deforestation.
- Recycling copper is essential for sustainable resource management and reducing environmental impact.
- Copper is an essential component of many modern technologies, and its demand continues to grow.

Extraction of Iron

Iron is one of the most widely used metals, essential for construction, manufacturing, and transportation. It's primarily extracted from iron ore, which is a rock containing iron oxide minerals.

Uganda's iron ore deposits are primarily located in two main regions:

1. Southwestern Region:

Muko Area: This region, located in Kabale and Kisoro districts, is known for high-grade hematite iron ore deposits.

Kigezi Region: This region also contains significant iron ore reserves.

2. Eastern Region:

Tororo District: This region has deposits of magnetite iron ore in the Sukulu and Bukusu areas.

Principle iron ores

- Hematite - Fe_2O_3
- Magnetite - Fe_3O_4
- Iron Pyrite - FeS_2
- Siderite - $FeCO_3$

Process of iron extraction

Iron ore is mined from deposits using artisanal mining methods, which involves open pit mining.

The extracted ore is then crushed and ground into a fine powder. This increases the surface area of the ore and allows for more efficient extraction.

The ore is then roasted in air to remove moisture and other impurities

The crushed and ground ore is then smelted in a blast furnace at high temperatures (around 1200°C). The blast furnace is a large, vertical furnace that uses a combination of coal and air to smelt the iron.

The smelting process involves the reduction of iron oxides to iron using charcoal as a reducing agent.

Equation: $Fe_2O_3 (s) + 3C (s) \rightarrow 2Fe (l) + 3CO (g)$

The molten iron is then tapped from the bottom of the blast furnace and cast into pig iron.

The pig iron is then further refined through various steelmaking processes, such as "finery forging", to produce pure iron or steel which can be used in a variety of applications, including construction, transportation, and consumer goods.

Key Points

- Iron ore is the primary source of iron, with hematite (Fe_2O_3) and magnetite (Fe_3O_4) being the most common minerals.
- The blast furnace is a crucial step in iron production, converting iron ore into molten iron.
- Steelmaking processes, such as the Basic Oxygen Process, refine pig iron into steel, which is a stronger and more versatile material.

- The iron and steel industry is a major contributor to global economies and infrastructure development.

The major environmental impacts of metal extraction

Air Pollution

Impact: Metal extraction and processing can release pollutants such as particulate matter, sulphur dioxide, and heavy metals into the air, contributing to poor air quality and negative health effects.

Mitigation

- Implementing air pollution control technologies, such as scrubbers and electrostatic precipitators.
- Using cleaner energy sources, such as solar or wind power, to reduce reliance on fossil fuels.
- Implementing dust suppression measures, such as sprinkler systems and dust collection systems.

Water Pollution

Impact: Metal extraction and processing can result in the release of pollutants such as heavy metals, acid mine drainage, and other chemicals into nearby water sources, posing risks to aquatic ecosystems and human health.

Mitigation

- Implementing wastewater treatment systems to remove pollutants and contaminants.
- Using containment systems, such as liners and leachate collection systems, to prevent pollution from tailings and waste rock.
- Implementing water conservation measures, such as water recycling and efficient use of water.

Soil and Land Degradation

Impact: Metal extraction and processing can result in soil and land degradation, including erosion, sedimentation, and loss of biodiversity.

Mitigation

- Implementing reclamation and rehabilitation plans to restore mined land to its original state or to a stable and productive ecosystem.
- Using soil conservation measures, such as mulching and terracing, to prevent erosion.
- Implementing biodiversity conservation measures, such as habitat restoration and species reintroduction.

Energy Consumption and Greenhouse Gas Emissions

Impact: Metal extraction and processing require significant amounts of energy, resulting in greenhouse gas emissions and contributing to climate change.

Mitigation

- Implementing energy-efficient technologies and practices, such as using LED lighting and optimizing processing equipment.
- Using renewable energy sources, such as solar or wind power, to reduce reliance on fossil fuels.
- Implementing carbon capture and storage technologies to reduce greenhouse gas emissions.

Waste Generation and Management

Impact: Metal extraction and processing generate significant amounts of waste, including tailings, waste rock, and hazardous waste.

Mitigation

- Implementing waste reduction and minimization strategies, such as reducing water usage and optimizing processing equipment.
- Using waste management practices, such as containment and disposal in accordance with regulatory requirements.
- Implementing recycling and reprocessing programs to recover valuable materials from waste.

Manufacture of Fertilizers

Fertilizers; are substances added to the soil to provide essential nutrients for plant growth. They are crucial for agriculture and food production.

Types of Fertilizers

- Organic Fertilizers: Derived from natural sources such as animal waste, compost, and green manure. Examples include cow dung, bone meal, and fish emulsion.
- Inorganic Fertilizers: Synthetically manufactured using chemical processes. Examples include ammonium nitrate, urea, and superphosphate.

Components of Fertilizers

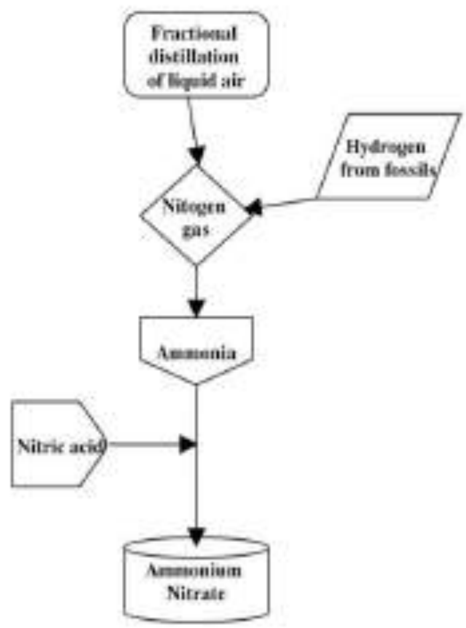
- Nitrogen (N): Essential for plant growth, promotes leaf development and protein synthesis.
- Phosphorus (P): Important for root development, flower and fruit formation.
- Potassium (K): Helps with overall plant health, resistance to disease and water balance.

Chemical Composition of Common Nitrogen containing Fertilizers

Fertilizer	**Chemical Composition**
Ammonium Nitrate	NH_4NO_3
Urea	$NH_2\text{-}CO\text{-}NH_2$
Ammonium sulphate	$(NH_4)_2SO_4$
Diammonium Phosphate	$(NH_4)_2HPO_4$
Monoammonium Phosphate	$NH_4H_2PO_4$
Potassium Nitrate	KNO_3
Calcium Ammonium Nitrate	$Ca(NH_4)_2(NO_3)_4$

Manufacture of nitrate fertilizers from nitrogen

The atmospheric air is trapped and fed into air filters to remove impurities. Atmospheric air is compressed to a high pressure (around 5-10 atm) using a compressor. This increases the temperature and pressure of the air, making it more suitable for distillation.
The compressed air is then cooled to a low temperature (around -150°C) using a heat exchanger or a refrigeration system. This causes the water vapor and other impurities to condense and separate from the air.
The cooled and purified air is then fed into a distillation column, where it is separated into its component gases based on their boiling points. The distillation column is typically a tall, vertical column with a series of trays or packing materials. The nitrogen is separated based on its boiling point, which is around -196°C.
The separated nitrogen gas is then collected and stored in tanks or cylinders.
Nitrogen and hydrogen (from fossils) gases are mixed in a ratio of 3:1 (hydrogen: nitrogen) and then heated to a high temperature (around 450°C) using a heat exchanger.



The heated gas mixture is then passed over an iron-based catalyst, causing the nitrogen and hydrogen to react and form ammonia. It's then cooled and condensed using a heat exchanger and condenser causing the gas to liquefy, it's later purified by using a series of distillation columns to remove impurities.
Equation: $N_2 (g) + 3H_2 (g) \rightarrow 2NH_3 (g)$
The nitric acid from the Ostwald process is neutralized with ammonia to form ammonium nitrate.
Equation: $HNO_3 (aq) + NH_3 (g) \rightarrow NH_4NO_3 (s)$
The resulting solution is then cooled and allowed to crystallize, forming solid ammonium nitrate.

Production of Calcium Ammonium Nitrate

Calcium ammonium nitrate (CAN) is another common nitrate fertilizer that can be produced using a similar process.

The nitric acid is neutralized with ammonia and calcium carbonate to form calcium ammonium nitrate.

Equation: $2HNO_3 (aq) + (NH_4)_2CO_3 (aq) + CaCO_3 (s) \rightarrow Ca(NO_3)_2 (aq) + (NH_4)_2CO_3 (aq) + H_2O (l)$

The resulting solution is then cooled and allowed to crystallize, forming solid calcium ammonium nitrate.

The nitrate fertilizer is typically packaged in bags or bulk containers and transported to farms and agricultural suppliers. It is then applied to crops as needed, providing essential nutrients for plant growth.

Environmental Impacts of Fertilizer Production

Greenhouse Gas Emissions

Fertilizer production, particularly nitrogen-based fertilizers, requires large amounts of energy majorly derived from fossils, this leads to greenhouse gas emissions resulting into global warming hence seasonal changes, floods and drought.

Mitigation

- Use renewable energy sources, such as solar or wind power, to power fertilizer production.
- Implement carbon capture and storage technologies.

Water Pollution

Fertilizer production can result in water pollution through the release of nutrients, heavy metals, and other pollutants into the water harming aquatic life hence affecting the ecosystem.

Mitigation

- Implement wastewater treatment systems to remove pollutants from fertilizer production effluent.
- Use closed-loop systems to minimize water usage and prevent water pollution.

- Implement best management practices for fertilizer storage and handling.

Air Pollution

Fertilizer production can result in air pollution through the release of particulate matter, nitrogen oxides, and other pollutants, this may result into acid rain lowering soil pH hence affecting crop yields.

Mitigation

- Implement air pollution control technologies, such as scrubbers and electrostatic precipitators
- Use cleaner energy sources, such as natural gas or renewable energy, to power fertilizer production.
- Implement best management practices for fertilizer storage and handling.

Waste Generation

Fertilizer production generates large amounts of waste, including hazardous waste and solid non biodegradable waste, affecting water infiltration into the soil.

Mitigation

- Implement waste reduction and minimization strategies, such as reducing water usage and implementing recycling programs.
- Use environmentally friendly packaging materials and design.
- Implement proper waste disposal practices, including hazardous waste management.

Industrial Processes and Natural Resources

Food for thoughts

1._List some of the natural resources used in the production of materials and give the respective materials.

2._Discuss renewable and non renewable natural resources, giving examples anda comparison between them.

3._List the common chemical products and the industries that produce these chemicals.

Industrial processes play a pivotal role in transforming natural resources into valuable chemicals.

Industrial processes are large-scale operations that involve the transformation of raw materials into valuable products. These processes often rely on complex chemical reactions, physical changes, or a combination of both.

Key Aspects of Industrial Processes

1. Raw Materials:

These are the basic substances used as inputs in the process. They can be natural resources like minerals, plants, or petroleum, or synthetic materials derived from other processes.

2. Process Steps:

Industrial processes involve a series of steps, each designed to transform the raw materials into a desired product. These steps may include:

Physical processes: crushing, grinding, heating, cooling, filtration, distillation

Chemical processes: reactions, catalysis, oxidation, reduction

3. Equipment and Machinery

Industrial processes require specialized equipment and machinery to carry out the various steps efficiently and safely.

4. Energy Input

Energy, often in the form of heat, electricity, or fuel, is essential to drive industrial processes.

5. Product Output

The final products of industrial processes can be diverse, ranging from basic chemicals to complex manufactured goods.

6. By-products and Waste

Industrial processes often generate by-products and waste materials that need to be managed responsibly.

Industrial processes that make use of the natural resources in Uganda

Natural Resource	Industry that uses the resource	Industrial Process	Products

Forests	Forestry and Wood Processing	Logging, Sawmilling, Pulp and Paper	Timber, lumber, plywood, paper products
Water	Hydropower	Hydroelectric Power Generation	Electricity
Minerals (Gold, Copper, Iron Ore)	Mining and Metallurgy	Mining, Smelting, Refining	Gold, copper, iron, steel
Petroleum and Natural Gas	Petroleum and Gas	Exploration, Production, Refining	Petroleum products (petrol, diesel, kerosene), Liquefied Petroleum Gas (LPG)

Benefits of Industrial Processes in Utilizing Natural Resources

Industrial processes offer numerous benefits in the utilization of natural resources:

Economic Benefits

Job Creation: Industrial processes generate employment opportunities in various sectors, contributing to economic growth.

Revenue Generation: The sale of products and services derived from natural resources contributes to national income and foreign exchange earnings.

Value Addition: Raw materials are transformed into high-value products, increasing their economic worth.

Infrastructure Development: Industrial activities stimulate the development of infrastructure like roads, railways, and ports.

Social Benefits

Improved Living Standards: Industrialization leads to better living standards through increased access to goods and services.

Education and Skill Development: Industrial processes require skilled labor, promoting education and training.

Reduced Poverty: Economic growth fueled by industrialization can alleviate poverty and inequality.

Environmental Benefits

Sustainable Resource Utilization: Efficient industrial processes can minimize waste and reduce the depletion of natural resources.

Technological Advancements: Innovation in industrial processes can lead to cleaner and more sustainable technologies.

Waste Reduction and Recycling: Industrial processes can incorporate recycling and waste reduction practices to minimize environmental impact.

However, it's crucial to balance these benefits with potential negative impacts on the environment and society. Sustainable industrial practices are essential to ensure the long-term viability of natural resources and the well-being of future generations.

Environmental Impacts of Industrial Processes

Industrial processes, while essential for economic growth, can have significant environmental and social impacts.

1. Pollution

Air Pollution: Emission of pollutants like greenhouse gases, particulate matter, and toxic gases contribute to global warming affecting climate hence seasonal changes, drought and floods.

Mitigation

Install pollution control technologies like scrubbers, filters, and catalytic converters.

Promote cleaner energy sources like solar, wind, and hydro power.

Implement strict emission standards and regulations.

Water Pollution: Discharge of wastewater containing pollutants like heavy metals, organic matter, and chemicals can leach into water bodies harming the aquatic organisms.

Mitigation

Treat wastewater before discharge to remove pollutants.

Land Pollution: Generation of solid waste and land degradation from mining and industrial activities can deplete soil fertility affecting crop yields.

Mitigation

Implement waste management practices like recycling, composting, and landfill disposal.

Restore degraded land through reforestation and reclamation.

2. Resource Depletion

Overexploitation of natural resources like minerals, forests, and water, affecting the future generations

Mitigation

Promote sustainable resource management practices.

Develop alternative materials and technologies.

Implement efficient resource extraction and utilization techniques.

3. Health Issues

Exposure to pollutants can lead to respiratory diseases, cancer, and other health problems.

Mitigation

Implement strict occupational health and safety standards.

Provide regular health check-ups for workers.

Ensure safe working conditions and use of personal protective gears.

4. Social Disruption

Industrial activities can displace communities and disrupt social fabric.

Mitigation

Conduct proper environmental impact assessments.

Implement fair compensation and resettlement programs.

Engage with local communities to minimize social disruption.

Manufacture of Cement

Cement is a hydraulic material used as a binder in construction. It is produced by heating limestone (calcium carbonate) and clay in a kiln to form clinker, which is then ground with gypsum to produce cement.

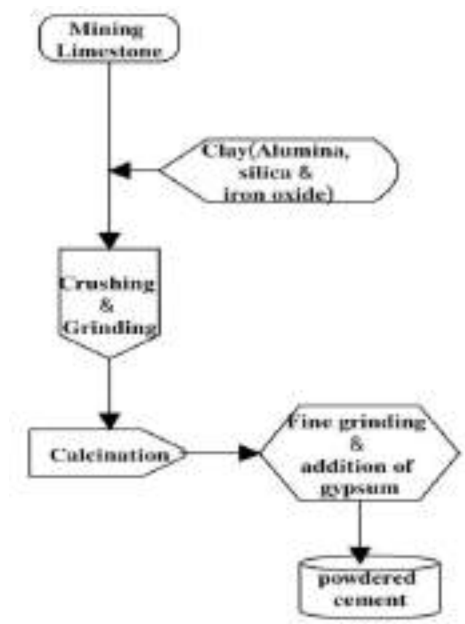
Manufacturing Process

The raw materials used to manufacture cement are:

- Limestone ($CaCO_3$)
- Clay (SiO_2, Al_2O_3, Fe_2O_3)

Cement production in Uganda involves a series of processes, from raw material extraction to the final product.

Extraction: Limestone: The primary raw material, limestone, is extracted from quarries.



Clay: Clay, rich in alumina and silica, is also sourced from mines or quarries.

Crushing and Grinding: The extracted materials are crushed and ground into a fine powder known as raw meal.

Calcination: The raw meal is heated to a high temperature (around 1450°C) in a rotary kiln. At this high temperature, limestone decomposes to form **CaO**.

$$CaCO_3 \rightarrow CaO + CO_2$$

The CaO reacts with alumina and silica forming clinker, the primary ingredient of cement.

$$CaO + Al_2O_3 \cdot 2SiO_2 \rightarrow Ca_2Al_2SiO_7 \text{(Clinker)}$$

Fine Grinding: The clinker is ground into a very fine powder. Gypsum is added to control the setting time of the cement.

$$Ca_2Al_2SiO_7 + CaSO_4 \cdot 2H_2O \rightarrow \text{Cement.}$$

Packaging and Storage: The finely ground cement is packaged into bags or bulk containers for storage and transportation.

Social benefits of the process of production of cement

Economic Benefits:

Job Creation: Cement production generates employment opportunities in various sectors, including mining, manufacturing, transportation, and construction.

Economic Growth: The industry contributes to the overall economic growth of a nation by stimulating related industries and boosting GDP.

Tax Revenue: Cement companies contribute to government revenue through taxes, royalties, and other levies.

Infrastructure Development:

Housing and Shelter: Cement is a crucial component in the construction of homes, schools, hospitals, and other infrastructure.

Urbanization: Cement enables the expansion of cities and towns, accommodating population growth.

Transportation: It's used in the construction of roads, bridges, and other transportation infrastructure, facilitating connectivity and trade.

Improved Quality of Life:

Better Living Conditions: Cement-based construction improves living standards by providing durable and affordable housing.

Public Health: It contributes to the construction of hospitals, clinics, and sanitation facilities, improving public health.

Education: Cement is used in the construction of schools, enabling access to education for many.

Environmental Impacts of Cement Production

Cement production, while essential for infrastructure development, can pose certain risks to communities.

Environmental Dangers and Mitigation

Air Pollution:

Danger: Emission of particulate matter, nitrogen oxides (NOx), and sulphur dioxide (SO_2) from burning of fossil fuels, clinker production can lead to respiratory problems and acid rain.

Mitigation

Electrostatic Precipitators: Capture particulate matter.

Selective Catalytic Reduction (SCR) Systems: Installing SCR systems can reduce NOx and sulphur dioxide emissions.

Wearing of personal protective equipments (PPEs)

Water Pollution:

Danger: Discharge of wastewater containing pollutants like suspended solids, heavy metals, and organic matter can contaminate water bodies, endangering the life of aquatic organisms.

Mitigation

Wastewater Treatment Plants: Treat wastewater before discharge.

Effluent Monitoring: Regularly monitor water quality.

Water Recycling: Reuse treated wastewater.

Noise Pollution:

Danger: Noise from machinery can disturb nearby communities, leading to sleep disturbances and hearing loss.

Mitigation

Noise Barriers: Construct barriers to reduce noise propagation.

Noise-Reducing Equipment: Use quieter machinery and equipment.

Regular Maintenance: Ensure proper maintenance of equipment to reduce noise levels.

Social and Health Risks

Occupational Health Risks:

Danger: Exposure to dust, noise, and hazardous chemicals can lead to respiratory diseases, hearing loss, and other health problems for workers.

Mitigation

Personal Protective Equipment (PPE): Provide workers with appropriate PPE, such as masks, earplugs, and safety goggles.

Regular Health Checkups: Conduct regular health checkups for workers.

Ventilation Systems: Improve ventilation in workplaces to reduce exposure to dust and fumes.

Land Degradation

Danger: Cement production requires large amounts of limestone, which is often quarried from natural habitats, leading to land degradation and loss of biodiversity.

Mitigation

Revegetation: Rehabilitate quarried land by revegetating with native plant species.

Waste Generation

Danger: Cement Kiln Dust, Cement production generates cement kiln dust, which can be hazardous if not disposed of properly and contaminate soil and water

Mitigation

2. Waste reduction and recycling: Implement waste reduction and recycling programs to minimize waste generation.

3. Proper disposal: Ensure proper disposal of hazardous waste, including cement kiln dust and other chemical waste.

Production of sodium hydroxide and chlorine by electrolysis of brine.

Food for thoughts

1._Discuss the raw materials used in the production of sodium hydroxide and chlorine.

2._Where are these raw materials obtained from in Uganda?

The production of sodium hydroxide (NaOH) and chlorine (Cl_2) by electrolysis is a widely used industrial process. The process involves the electrolysis of sodium chloride (NaCl) solution, also known as brine, to produce NaOH and Cl_2.

Principle behind the Process

The process is based on the principle of electrolysis, where an electric current is used to drive a chemical reaction. In this case, the reaction is the decomposition of NaCl into NaOH and Cl_2.

Experiment: Electrolysis of Sodium Chloride to Produce Sodium Hydroxide

Aim: To demonstrate the electrolysis of sodium chloride (NaCl) to produce sodium hydroxide (NaOH) and chlorine gas (Cl_2), and to test the properties of the products.

Hypothesis: Electrolysis of sodium chloride will produce sodium hydroxide at the cathode (negative electrode) and chlorine gas at the anode (positive electrode). The litmus paper will turn blue in the presence of sodium hydroxide, indicating its production.

Variables:

Independent Variable

- Electric current applied to the sodium chloride solution.

Dependent Variable

- Production of sodium hydroxide and chlorine gas.

Controlled Variables

- Concentration of sodium chloride solution

- Temperature of the solution
- Surface area of the electrodes
- Voltage and current of the power supply

Risks and Mitigation

Risks

- Electric shock: The experiment involves working with an electric current, which can cause electric shock if not handled properly.
- Chemical burns: The experiment involves working with sodium hydroxide, which can cause chemical burns if not handled properly.
- Chlorine gas exposure: The experiment involves the production of chlorine gas, which can be toxic if inhaled.

Mitigation

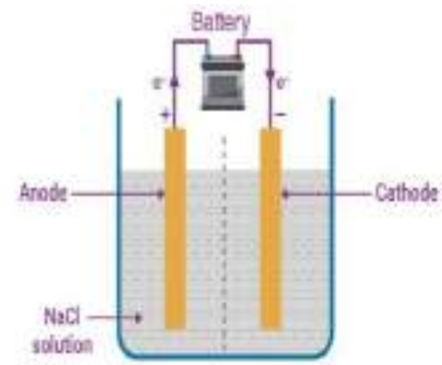
- Wear protective gloves, goggles, and a lab coat to prevent electric shock and chemical burns.
- Perform the experiment in a fume cupboard to prevent inhalation of chlorine gas.
- Ensure that the power supply is turned off before handling the electrodes or the solution.
- Neutralize the solution with acid after the experiment to prevent any further reactions.

Materials

- U-shaped glass tube
- Graphite electrodes(pencils)
- Concentrated sodium chloride solution
- DC power supply
- Litmus paper
- Test tubes

Procedure

- Fill the U-shaped tube with concentrated sodium chloride solution. Insert the graphite electrodes into the solution, ensuring they are submerged.
- Connect the positive terminal of the DC power supply to one electrode and the negative terminal to the other.
- Turn on the power supply and observe the reaction at the electrodes.
- Test the products



At the cathode: Collect the gas produced at the negative electrode in a test tube and test it with a lighted splint.
At the anode: Collect the gas produced at the positive electrode in a test tube and test it with moist litmus paper.
In the solution; Test the solution in the U-tube with litmus paper to determine its pH.

Expected Observations
At the cathode; Hydrogen gas will be produced. It will ignite with a pop sound when a lighted splint is brought near it.
At the anode; Chlorine gas will be produced. It will turn moist blue litmus paper red.
In the solution: The solution will become alkaline, turning red litmus paper blue.
Conclusion
The electrolysis of sodium chloride solution produces sodium hydroxide, hydrogen gas, and chlorine gas.
The sodium hydroxide is formed at the cathode, while the hydrogen gas and chlorine gas are formed at the anode.

At the Cathode (Negative Electrode):
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

At the Anode (Positive Electrode):

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$

Overall Reaction: $2NaCl(aq) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g) + Cl_2(g)$

Industrial Manufacture of Sodium hydroxide and Chlorine Gas

The electrolysis of brine (a concentrated solution of sodium chloride) is a crucial industrial process for the production of sodium hydroxide (NaOH) and chlorine gas (Cl_2).

The production of sodium hydroxide (NaOH) and chlorine (Cl_2) through electrolysis is known as the **chlor-alkali** process.

Electrolysis Cell

The electrolysis cell used for the production of NaOH and Cl_2 is typically a diaphragm cell or a membrane cell. The cell consists of two electrodes, an anode and a cathode, separated by a diaphragm or membrane.

The electrolyte is concentrated sodium chloride which contains the following ions: Na^+, H^+, Cl^- and OH^-

Electrolytic Cell Setup:

Electrolyte: Concentrated brine solution (NaCl)

Anode: Typically made of graphite or titanium

Cathode: Usually made of steel or mercury

Electrolysis Process:

A sodium chloride (NaCl) solution, also known as brine, is prepared by dissolving in water and purified to remove impurities.

The purified brine solution is then fed into an electrolytic cell. The cell consists of a mercury cathode (negative electrode) and a graphite anode (positive electrode). Electricity is then passed through the cell.

At the cathode, sodium ions (Na^+) are reduced to form sodium metal, which dissolves in mercury to form a sodium amalgam (Na-Hg).

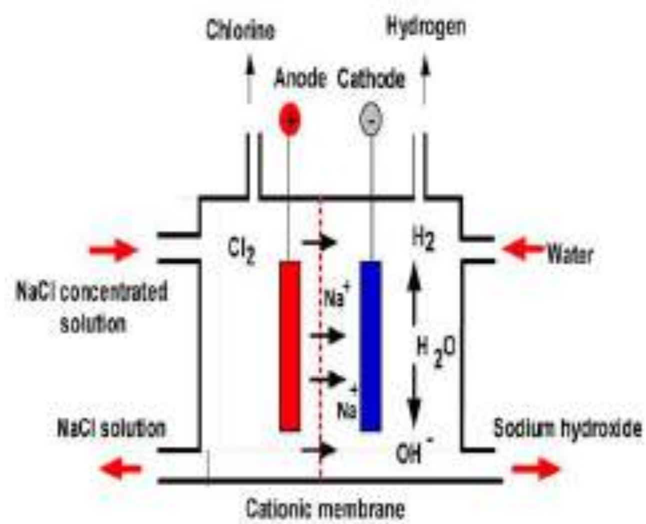
$2Na^+ (aq) + 2e^- \rightarrow 2Na (s)$

$Na (s) + Hg (l) \rightarrow Na\text{-}Hg$ (amalgam)

The sodium amalgam is then reacted with water to produce sodium hydroxide (NaOH) and hydrogen gas (H_2).

$2Na\text{-}Hg \text{ (amalgam)} + 2H_2O (l) \rightarrow 2NaOH (aq) + H_2 (g) + Hg (l)$

The resulting sodium hydroxide solution is then separated and purified through a series of steps, including filtration and evaporation to produce a solid or liquid product.



At the anode, The Cl^- ions are discharged. Chloride ions (Cl^-) lose electrons and are oxidized to form chlorine gas (Cl_2).

$2Cl^- (aq) \rightarrow Cl_2 (g) + 2e^-$

The chlorine gas (Cl_2) produced at the anode is collected and purified by liquefying under pressure for use in various industrial applications.

Note:

To extract sodium metal, the sodium amalgam is separated from the brine solution. The amalgam is heated to distill off the mercury, leaving behind sodium. The sodium metal is collected and cast into desired shapes. The metal is stored under oil or paraffin since its very reactive.

Applications of Sodium Hydroxide and Chlorine

Sodium hydroxide (NaOH) is used in a variety of applications, including:

- Production of paper and pulp
- Production of detergents and soaps
- Water treatment
- Textile industry

Chlorine (Cl_2) is used in a variety of applications, including:

- Water treatment
- Disinfection and sanitation
- Production of plastics and polymers (PVC)
- Production of pharmaceuticals and chemicals

Hydrogen; Used as a fuel, in the production of ammonia, and in the refining of metals.

Benefits of the process of electrolysis of brine

Job creation: The electrolysis of sodium chloride creates jobs in the chemical industry, both directly and indirectly, this generates income for individuals and communities improving standards of living of the people.

Economic growth: The electrolysis of sodium chloride contributes to the overall economic growth of a country by providing essential chemicals for various industries.

Quality life: The sodium hydroxide and chlorine produced are used in water treatment plants to produce clean drinking water, improving the quality of life for communities.

Social development: Companies involved in the electrolysis of sodium chloride often engage with local communities through corporate social responsibility initiatives, this leads to development of communities.

Side effects of the process of production of sodium hydroxide and chlorine

Side effects of sodium hydroxide (NaOH) production:

Caustic burns and eye damage: NaOH is highly corrosive and can cause severe burns and eye damage.

Mitigation: Use personal protective equipment (PPE) such as gloves, goggles, and face shields when handling NaOH. Ensure proper ventilation and emergency showers are available.

Environmental contamination: NaOH can contaminate soil and water if not disposed of properly.

Mitigation: Implement proper waste disposal and storage procedures. Use containment systems to prevent spills and leaks.

Air pollution: The production of NaOH can release air pollutants such as particulate matter, nitrogen oxides, and sulfur dioxide.

Mitigation: Implement air pollution control measures such as scrubbers, electrostatic precipitators, and fabric filters.

Side effects of chlorine (Cl_2) production:

Toxic gas release: Cl_2 is a toxic gas that can cause respiratory problems and other health issues.

Mitigation: Implement proper ventilation systems and use gas detectors to monitor Cl_2 levels. Ensure proper storage and handling procedures.

Chlorine gas explosions: Cl_2 is highly reactive and can explode if not handled properly.

Mitigation: Implement proper safety protocols when handling Cl_2, such as using explosion-proof equipment and following proper storage and handling procedures.

Environmental contamination: Cl_2 can contaminate soil and water if not disposed of properly.

Mitigation: Implement proper waste disposal and storage procedures. Use containment systems to prevent spills and leaks.

Shared side effects and mitigation strategies:

Energy consumption and greenhouse gas emissions: The production of NaOH and Cl_2 requires significant amounts of energy, which can lead to greenhouse gas emissions.

Mitigation: Implement energy-efficient technologies and processes. Consider using renewable energy sources or purchasing carbon offsets.

Water pollution: The production of NaOH and Cl_2 can result in water pollution if not properly managed.

Mitigation: Implement proper wastewater treatment and management procedures. Use containment systems to prevent spills and leaks.

Community impacts: The production of NaOH and Cl_2 can have negative impacts on local communities, such as noise pollution and odors.

Mitigation: Implement community engagement and outreach programs. Use noise-reducing and odor-control technologies to minimize impacts.

End of chapter summary

- Ore: a naturally occurring mineral from which a metal or other valuable substance can be extracted.
- Fertilizer: a substance added to soil to promote plant growth and fertility. Nitrate Fertilizers are fertilizers that contain nitrogen in the form of nitrate, such as ammonium nitrate and calcium nitrate. Processes used to produce nitrate fertilizers may include fractional distillation of liquid air to produce Nitrogen, the Haber process and the Ostwald process.
- Cement: a binding agent used in construction, made from a mixture of limestone, clay, and other minerals. Process involved in production of cement, include calcination and hydration.

Metals: elements that are typically hard, shiny, and conductive, such as copper, iron, and aluminum. Metals are extracted from their ores, which may include mining, crushing, and refining.

- Extraction of Copper: process used to extract copper from its ore (Malachite or Cuprite). It includes mining, crushing, and refining. It's then later refined by electrolysis.

- Iron is extracted from its primary ore(Hematite) mixed with limestone, coke in a blast furnace.
- Electrolysis of sodium chloride (brine) is used in production of sodium hydroxide and chlorine gas.
- Sodium Hydroxide: a strong base used in a variety of industrial processes, including the production of paper and soap. Chlorine: a yellow-green gas used in a variety of industrial processes, including the production of plastics and disinfectants.

End of chapter Scenarios

Item 1:

The government has licensed a new company to mine limestone in the Mbarara district where a new cement factory is to be built. The factory will use limestone as the main raw material.

However, the locals are concerned about the potential environmental impacts of the mining activities.

Task;

Prepare a presentation to educate the locals on the cement production process, and how the factory will contribute to the local economy.

Item 2:

The government has planned to revive the Kilembe Mines in the Kasese district. The mines will extract copper ore, which will then be processed into pure copper. The LC1 of one of the villages in Kasese wants you to educate his community members on how the process of production of pure copper will be done.

Task;

Design a presentation to educate the locals on the copper extraction process, and how the revived mines will benefit the local community.

Item 3:

A group of students from a local secondary school have visited a soap manufacturing factory in the Kampala district. They were then told that soap is produced by mixing vegetable oil with sodium hydroxide. They are curious to know how sodium hydroxide is produced. You are one of the student chosen to move with these students as one with good knowledge on production of sodium hydroxide.

Task;

Explain the sodium hydroxide production process in a way that is easy for the students to understand.

Item 4:

A new fertilizer manufacturing plant is being set up in the Mbarara district. The plant will produce ammonium nitrate fertilizer nitrogen in the air and hydrogen obtained from fossils as the raw materials. The locals are interested in knowing more about the fertilizer manufacturing process.

Task;

Design a chart that will explain to the locals the processes involved in manufacturing fertilizers.