UNIT-3
INDUSTRIAL CHEMISTRY



Industrial chemistry:

- Is a branch of chemistry which applies physical and chemical procedures toward the transformation of natural raw materials and their derivatives in to products that have beneficial to humanity.
- Industrial chemistry is the basis of the chemical industry.

The chemical industry:

- involves chemical processes such as chemical reactions and refining methods to produce a wide variety of materials with desirable properties and quality to satisfy social needs.
- Most of these products, in turn, can be used by other chemical industries to manufacture other items or can be used directly by

Generally, chemical industries

- ✓ use naturally or artificially available raw materials to produce the desired products.
- ✓ involve chemical reactions to transform raw materials into finished and semi-finished products.
- ✓ consume relatively large quantities of energy during the manufacturing process.

Cont…

- ✓use safe operation methods in their manufacturing processes, and
- ✓test their products during and after manufacture in their quality control laboratories to ensure that the products meet the required specifications.

Natural Resources and Industry

- Natural resources are the raw materials that are obtained from the different natural environment. These are
- ✓ **From the atmosphere:** The earth's atmosphere has approximately 5×10^{15} tons of gases. It is composed of different gases namely N_2 , O_2, CO_2, Ne, Ar, Kr and Xe. They are important industrial raw materials.

Cont....

- **From the hydrosphere:** Ocean water which amounts to about 1.5×10^{21} liters contains about 3.5 percent by mass dissolved material. Seawater is a good source of sodium chloride, magnesium and bromine.

From the lithosphere: The vast majority of elements are obtained from the earth's crust in the form of mineral ores, carbon and hydrocarbons. Coal, natural gas and crude petroleum besides being energy sources are also converted to thousands of chemicals.

Cont…

- **From the biosphere:** Vegetation and animals contribute raw materials to agro-based industries. Oils, fats, waxes, resins, sugar, natural fibres and leather are examples of thousands of natural products.

Classification of Natural Resources

Natural resources can be classified as renewable and non-renewable resources.

- Renewable resources: The resources that can be replenished through rapid natural cycles. e.g plants (crops and forests), and animals

There are also renewable resources without any life cycle.

- These include wood and wood-products, natural rubber, fibers , pulp products, and leather.
- water, solar energy and soil are also classified as renewable resources.

Non-Renewable Resources:

- The resources that cannot be replenished through natural processes.
- These are available in limited amounts and cannot be increased. These resources include fossil fuels (petrol, coal etc.), minerals and salts.
- Once a non-renewable resource is consumed, it is gone forever.

Exercise 3.1

1. Define “industrial chemistry"?
2. List the characteristics of chemical industries.

Industry

- Industry is a well-organized facility with a high degree of automation and specialization where large-scale manufacturing of goods take place.
- Manufacturing industry: is a compartment of industry which is concerned with the production or making of goods out of raw materials by means of a system of organized labor.

Cont..

- Manufacturing industries use different type of raw materials, skills, and technologies.

As a result, different types of products are manufactured.

Chemical industry is a facility where industrial chemicals are manufactured. The products result from:

- Chemical reaction between organic materials, or inorganic materials, or both
- Extraction, separation, or purification of natural products, with or without the aid of chemical reactions
- The preparation of specifically valuable materials

Classification of the chemical industry based on raw material used for production

For example,

1. Sugar industries, use sugar cane to manufacture sugar.
2. Agro industries, when raw materials are obtained from agricultural products
3. Mineral industries, when raw materials are minerals

Classification based on the product type

Examples are:

1. Food processing industries,
2. Beverages industries
3. Textiles industries,
4. Wearing apparel industries,
5. Leather industries
6. Paper industries
7. Chemical industries etc.

Class work

1. Which of the following is not an example of a renewable resources

A. Water B. Coal C. Fish D. Wind

2. Which is not renewable energy

A. Solar energy C. Wind turbine

B. Natural gas D. Geothermal

3. Choose the correct answer

C. Sun can be taken as an inexhaustible sources of energy

D. There is infinite storage of fossil fuel inside the earth

E. Biomass is non renewable resources

F. none

4. List the types of manufacturing industries based on their products.

5. Give examples of renewable and non-renewable natural resources

Manufacturing of Valuable Products

- Manufacturing of valuable products involve a number of chemical processes.
- The process is designed to produce a desired product from a variety of starting raw materials using energy through a succession of treatment steps.
- The treatment steps could be either physical or chemical in nature

Basic steps in a manufacturing process.



Both organic and inorganic chemicals could be used in the manufacturing process.

Ammonia (NH_3)

Activity 3.4

Discuss in group and present your answer to the class.

- Why ammonia is highly soluble in water?
- List and describe the conditions that are required to get high yield of ammonia using Le Chatelier's principle?

Properties of NH_3

- ✓ lighter than air with a density of 0.769 kg/m3 at STP.
- ✓ The common commercial formulation is 28–30% NH3.
- ✓ often referred to as ammonium hydroxide.
- ✓ It is a weak base.
- ✓ It is colorless and irritating gas at room temperature.
- ✓ Its melting point is -77.7 o_C
- ✓ Its boiling point is -33.35 o_C
- ✓ Its solubility in water at 25 o_C is 34% (w/w).

Uses of NH_3

- ✓It is used as a cleaning agent,
- ✓antimicrobial agent,
- ✓a raw material for the production of nitrogen fertilizers,
- ✓raw material in the manufacturing of explosives such as nitrocellulose and trinitrotoluene (TNT)
- ✓used in the production of soda ash and in the Ostwald process to get nitric acid.

Preparation NH_3

- ✓ in the laboratory by heating an ammonium salt, such as NH4Cl with a strong alkali, such as NaOH or Ca(OH)2

$$2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O + 2NH_3(g)$$

- ✓ Its diverse applicability has caused large demand for its production.
- ✓ The development of the Haber-Bosch process for ammonia production has made it possible to meet this demand.

CONT..

- ✓ The commercial production of ammonia (Haber-Bosch process).
- ✓ The direct combination of nitrogen and hydrogen under high pressure in the presence of a catalyst.
- ✓ Haber involved the practical use of atmospheric hydrogen and nitrogen to produce ammonia
- ✓ Bosch was tasked with scaling up the process to an industrial production.
- ✓ For their efforts both these men awarded Nobel prizes in 1918 and 1931, respectively.
- ✓ Presently, about 454 million tons of nitrogen fertilizers are produced using the Haber-Bosch process.

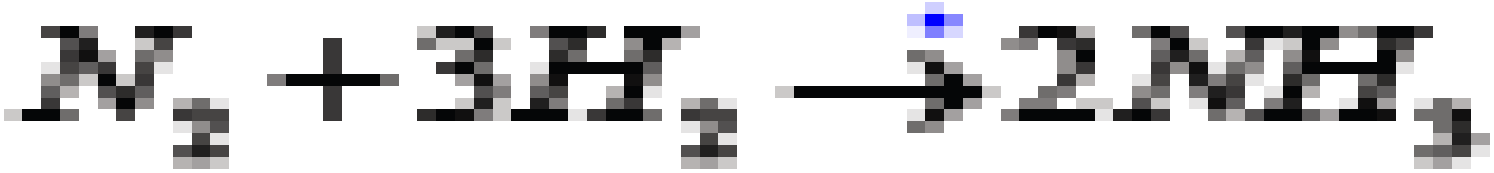
Steps Involved in Ammonia Production

Step 1: The primary requirements for the production of ammonia are H_2 and N_2.

- ✓ H_2 was initially obtained by electrolyzing water,
- ✓ In recent times, use methane as a source of H_2.
- ✓ Methane is easily obtained from natural gas, and requires very less external energy to produce hydrogen.
- ✓ Nitrogen, is obtained by carrying out fractional distillation of air.

Step 2

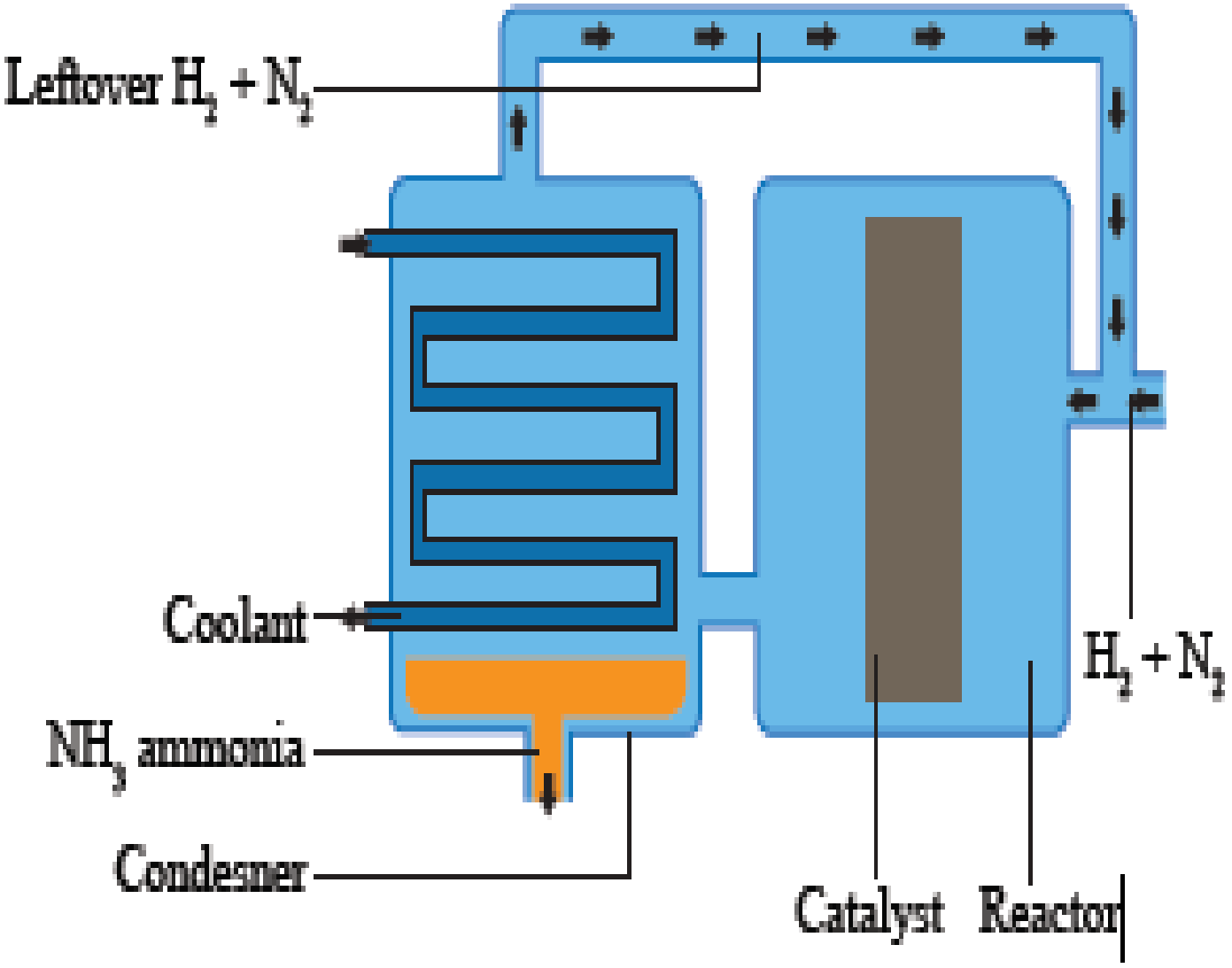
- The hydrogen and nitrogen are then, introduced into a chamber containing iron particles and a pressure of 15 – 25 MPa at a temperature of 300 – 500 °C is applied to the gases.
- These conditions cause the gases to react and produce ammonia



Step 3

- The hot mixture of gases is then passed through a condenser.
- Since NH_3 condenses easily as compared to nitrogen and hydrogen, the liquefied ammonia is collected and removed,
- the leftover nitrogen and hydrogen gases are re-introduced into the reactor.
- Thus, pressure is maintained, and there is no loss or wastage of reactants.
- This recycling of the raw materials allows a 97% conversion of initial reactants into NH_3.

production of NH_3 using Haber-Bosch



Properties of HNO_3

- ✓ density of 1.51 g/cm3.
- ✓ It is a colorless liquid
- ✓ with a highly pungent odor
- ✓ in appearance similar to water
- ✓ but on exposure to light, it turns brown because of slight decomposition into NO_2 (brown) and O_2.

$$4HNO_3(l) \rightarrow 4NO_2(g) + O_2(g) + 2H_2O(l) \text{ brown}$$

Cont..

- ✓ Nitric acid is a strong acid
- ✓ highly corrosive mineral acid.
- ✓ Nitric acid and its salts are strong oxidizing agents.
- ✓ produces heat when dissolved in water
- ✓ Concentrated nitric acid is highly hazardous to health.
- ✓ Upon contact with the skin, it causes severe burns and even necrosis.

Uses HNO_3

- In the production of fertilizers (NH4NO_3)
- for soil acidification in horticulture
- to make explosives such as TNT and nitroglycerine.
- As a rocket fuel.
- a mixture of HNO_3, dinitrogen tetroxide and hydrogen peroxide, also known as red fuming nitric acid, is prepared.
- in the production of plastic

less popular uses of HNO_3

- ✓ production of organic dyes and lacquers;
- ✓ pharmaceutical industry;
- ✓ production of fungicides;
- ✓ cleaning and etching of metal surfaces;
- ✓ refining of precious metals for the jewellery industry (in preparation of aqua regia);
- ✓ the artificial ageing of wood to obtain the desired shade;
- ✓ production of household cleaning products;
- ✓ detection of traces of metals in laboratory test substances.

Preparation HNO_3

- In the laboratory prepared by reacting nitrogen dioxide with water or by the reaction of potassium

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

By principle that a more volatile acid can be displaced from its salt by a less volatile acid.

Industrial production of HNO_3 (Ostwald process.)

- Nitric acid is produced industrially from ammonia by the three-step
- **Step 1:** Ammonia is burned in excess oxygen over a platinum catalyst to form nitric oxide (NO):

$$4NH_3(g) + 5O_2(g) \xrightarrow[5atm,\ Pt]{850\ 0c} 4NO(g) + 6H_2O(g)$$

Step 2

- Additional air is added to cool the mixture and oxidize *NO* to NO_2

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

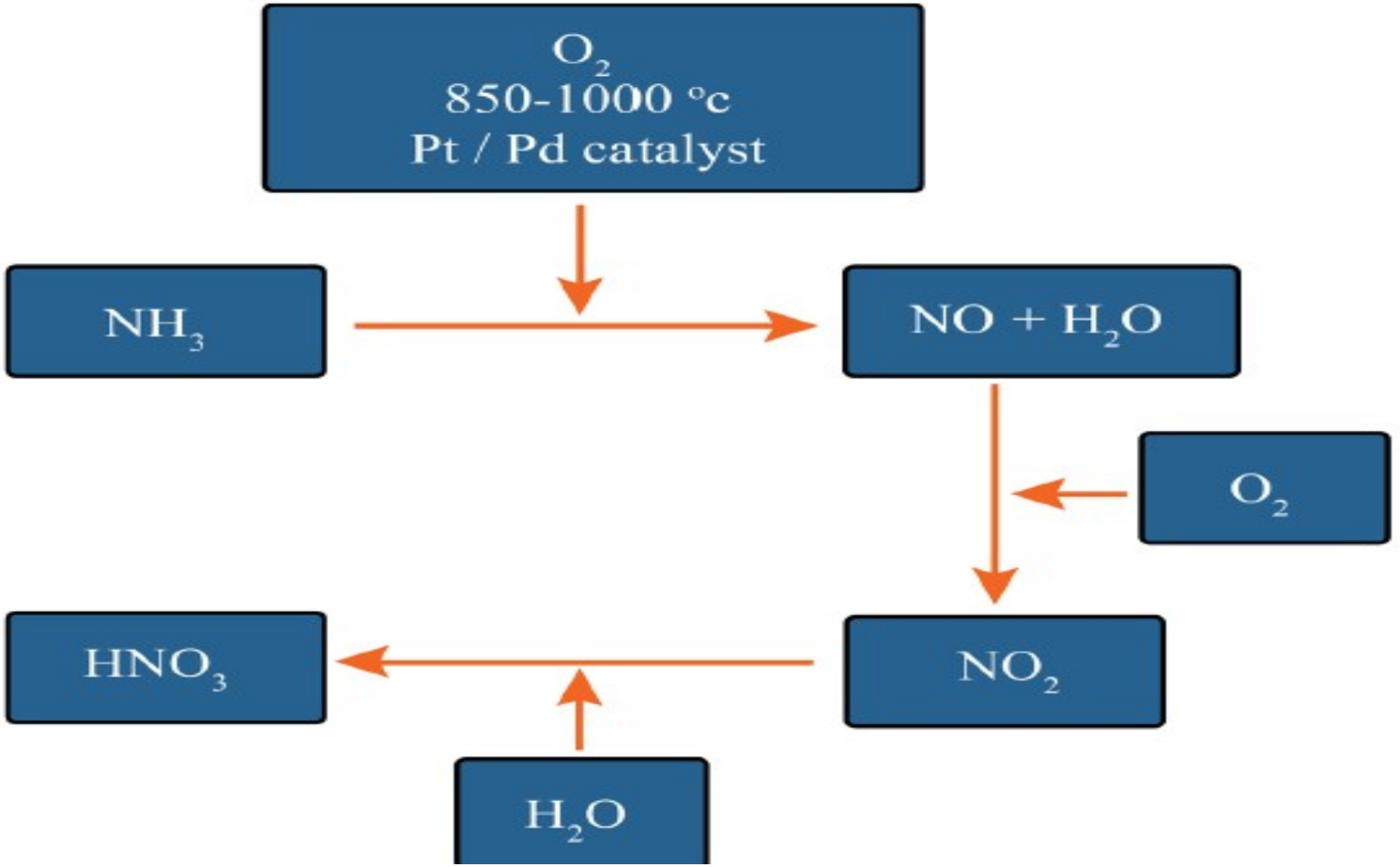
Step 3:

The NO2 gas is bubbled into the warm water, where it reacts to give nitric acid and nitric oxide:

$$3NO_2(g) + H_2O(l) \rightarrow 2NHO_3(aq) + NO(g)$$

The nitric oxide (NO) is recycled in Step 2.

Diagrams representation of Ostwald process



Activity 3.6

- Discuss in a group and present your opinion to your classmates.

1. Describe why a large-scale use of synthetic fertilizers can be harmful to the environment
2. What is the purpose of adding nitrogen stabilizers in the soil after the addition of nitrogen-based fertilizers?
3. What is the role of nitrifying bacteria in the reaction of nitrogen-based fertilizers?

A. Anhydrous Ammonia(NH_3)

- ✓ the most basic form of nitrogen fertilizer
- ✓ It must be compressed into a liquid for transport, storage and application.
- ✓ it must be injected into the soil to prevent its escape into the air.
- ✓ 80% of atmospheric nitrogen, is unusable for plants.
- ✓ nitrogen combined with a hydrogen converted into (NH3) a form that can be used by growing plants.

Application of NH_3

- applied by injection 6 to 8 inches below the soil surface to minimize escape of gaseous.
- *NH3* is a very hygroscopic compound and once in the soil, reacts quickly with water form ($NH4^+$)
- ($NH4^+$) reacts and binds with negatively charged soil constituents including clay and organic matter.
- it is held on the soil exchange complex and is not subject to movement with water.

Soil reactions

- $NH4^{+}$ ions are converted to the $NO3^{-}$ form by the action of specific soil bacteria in a process known as nitrification.
- Nitrification generally occurs at soil temperatures above 50 °F, and increases as temperatures rise above this level. However, some limited activity occurs below 50 °F.





Urea

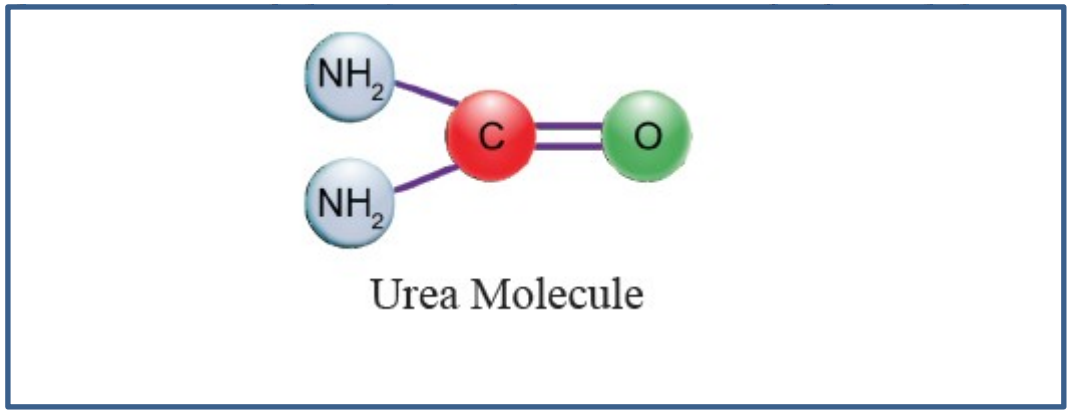
- Urea is a solid fertilizer with high N content (46%) that can be easily applied to many types of crops and turf.
- Its ease of handling, storage and transport, convenience of application by many types of equipment, and ability to blend with other solid fertilizers has made it the most widely used source of N fertilizer in the world.

Production Urea

- Urea is manufactured by reacting CO_2 with NH_3 in the following two step reactions:

$$2NH_3 + CO_2 \rightarrow NH_2COONH_4 \quad (\text{ammonium carbamate})$$

$$NH_2COONH_4 \xrightarrow[\text{high T}]{\text{high P}} (NH_2)_2CO + H_2O \quad (urea + water)$$



Urea Molecule

Soil Reactions

- If urea is applied to the soil surface and not incorporated by water or tillage, it is subject to volatilization losses of nitrogen.
- This occurs as urea undergoes hydrolysis to carbon dioxide and

$$(NH_2)_2CO + H_2O \rightarrow CO_2 + 2NH_3$$

Urea-ammonium nitrate (UAN) Solutions

- These solutions are made by dissolving urea and a NH_4NO_3 in water.
- Urea-ammonium nitrate (UAN) solutions are mixtures of urea, NH_4NO_3, and water in various proportions.
- All common UAN solutions (28%, 30% and 32%) are formulated to contain 50% of actual N as amide, (from urea), 25% as ammonium (from ammonium nitrate), and 25% as nitrate (from ammonium nitrate).

Production UAN

- Liquid urea-ammonium nitrate (UAN) fertilizer is relatively simple to produce.
- A heated solution containing dissolved urea is mixed with a heated solution of ammonium nitrate to make a clear liquid fertilizer.
- Half of the total nitrogen comes from the urea solution and half from the ammonium nitrate solution.

Soil Reactions

- The urea portion of UAN solutions reacts just as dry urea.
- If applied on the surface, the amide-N in the solution may incur losses due to volatilization when urease hydrolysis releases NH3.
- But if UAN is incorporated by tillage or sufficient water, the NH3, quickly reacts with soil water to form $NH4^{+}$ ions.
- nitrogen will be taken up by plants in the ammonium form, or if not, eventually converted to nitrate by soil bacteria.

Diammonium Monohydrogen Phosphate(DAP),

- Diammonium monohydrogen phosphate (DAP) is a white crystalline compound

Production

- Diammonium monohydrogen phosphate (DAP) is formed by the reactic $3NH_3(g) + 2H_3PO_4(l) \rightarrow NH_4H_2PO_4(s) + (NH_4)_2HPO_4(s)$ phospl
- **Step 1** $NH_4H_2PO_4(s) + NH_3(g) \rightarrow (NH_4)_2HPO_4(s)$
- **Step 2:**

Uses of DAP

- ✓ used as a fertilizer.
- ✓ DAP has the advantage of having both nitrogen and phosphorus, which are essential for plant growth.
- ✓ DAP can be used as fire retardant.
- ✓ It lowers the combustion temperature of the material, decreases weight-loss rates, and causes an increase in the production of residue.
- DAP is also used as a yeast nutrient in wine making and beer brewing.
- ✓ Disadvantage It temporarily increases soil acidity, but over the long term, the soil becomes more acidic than before upon nitrification of the ammonium.

Sulphuric Acid

Properties

- ✓The most widely produced chemical in the world

Anhydrous, 100% sulphuric acid is a colorless, odorless, heavy, oily liquid.

- ✓It is heavier than water
- ✓It melts at 10.5 °C and boils at 338 °C.
- ✓ It is soluble in all ratios with water.
- ✓highly corrosive, reactive and soluble in water.

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- It can oxidize both metals as well as non-metals. Example





- 33.5 % sulphuric acid commonly called battery acid while 62.18 sulphuric acid is known as chamber acid used for production of fertlizers

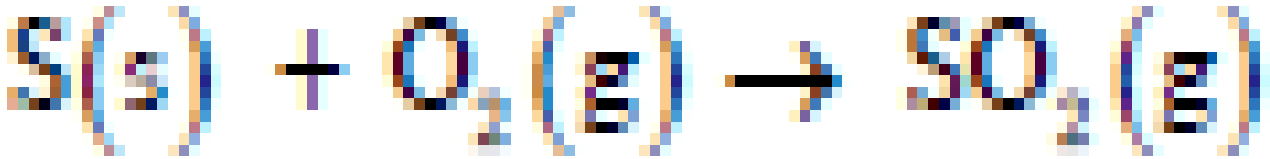
Uses

- In the production of fertilizer, detergent plastic and etc

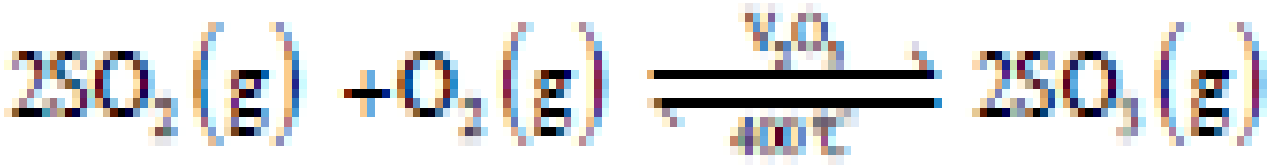
Preparation

- Sulphuric acid is manufactured industrially by the contact Process which involves the following four major steps:

Step 1: Burning sulphur in air (preparation of sulphur dioxide):

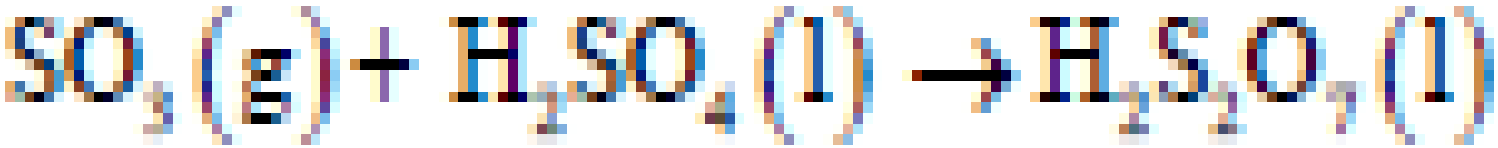


Step 2: Converting SO2 to SO3 (Oxidation of sulphur dioxide to prepare sulphur tri oxide)



step3

addition reaction of sulphur trioxide and sulphuric acid to give oleum:



Step-4 Dilution of oleum to produce concentrated sulphuric acid

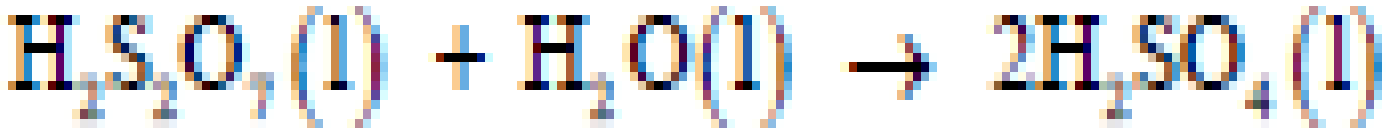
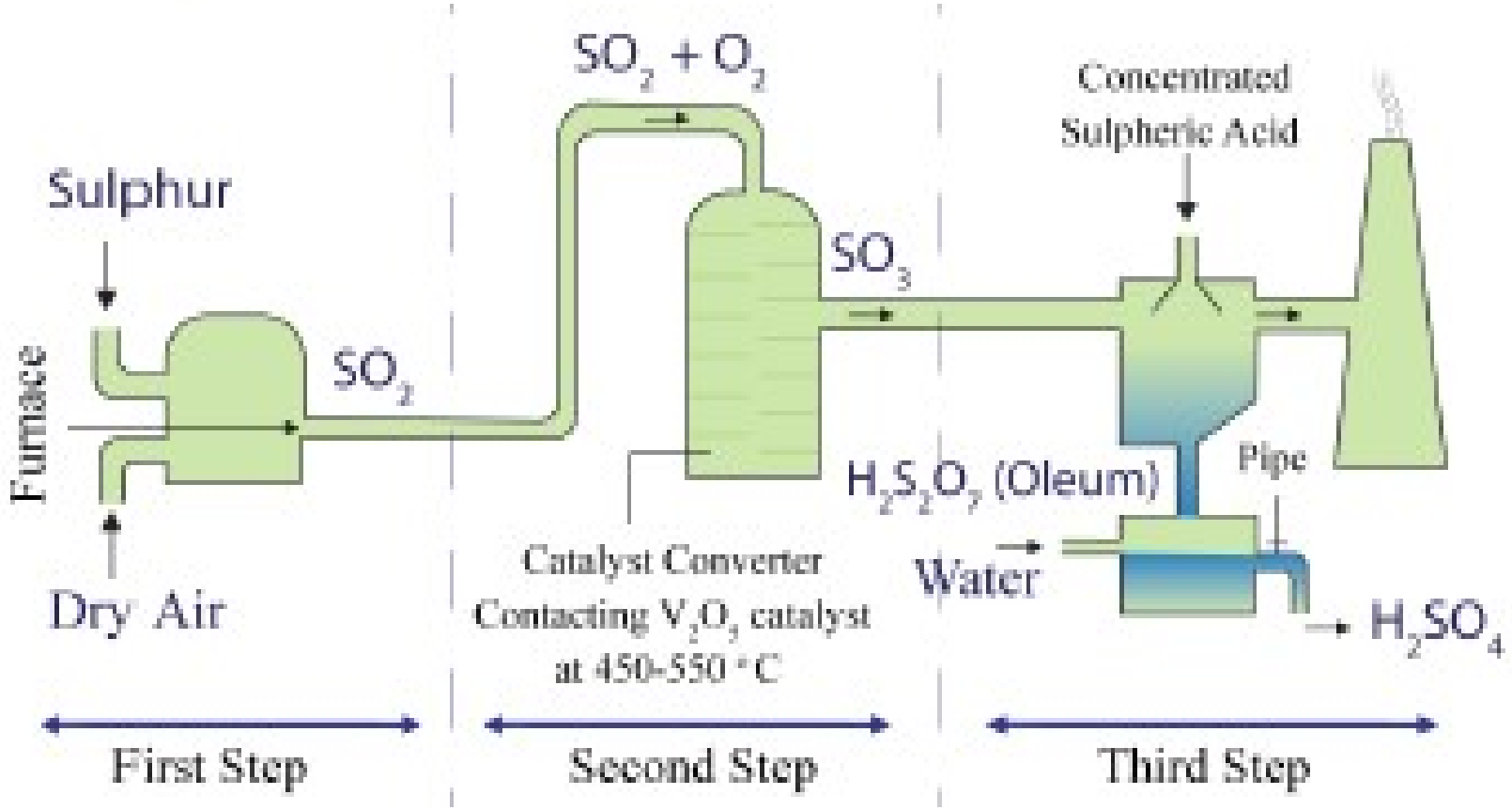


Diagram that show contact process



Pesticides

- Pesticides are chemicals used to prevent pests, diseases, weeds and other plant pathogens.
- maintain high product quality.
- Chemical pesticides can be classified according to their chemical composition as:

✓ Organochlorines
✓ Organophosphates
✓ Carbamates
✓ Pyrethroids
✓ Biological pesticides

Organochlorines

characteristics

- Composed of Carbon, Hydrogen, Chlorine, and Oxygen atoms
- Soluble in lipids
- They accumulate in the fatty tissue of animals and transferred through the food chain
- toxic to a variety of animals
- long-term persistence

Organophosphates

Characteristics

- Possess central phosphorus atom in the molecule.
- Soluble in organic solvents but also in water
- less persistent than chlorinated hydrocarbons
- some affect the central nervous system
- They are absorbed by plants and then transferred to leaves and stems which are the supply of leaf-eating insects.
- more stable and less toxic than chlorinated

Carbamates

Charactestics

- Carbamate acid derivatives
- Chemical structure based on a plant alkaloid Physostigma venenosum
- kill a limited spectrum of insects
- highly toxic to vertebrates
- Relatively low persistence

Pyrethroids

characteristics

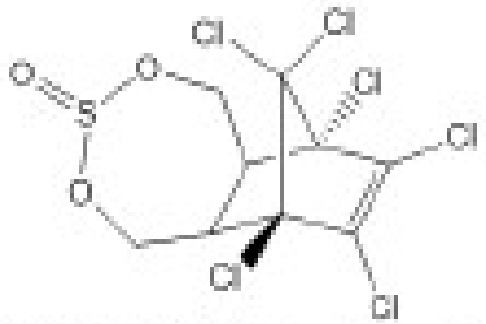
- Compounds similar to the synthetic pyrethrins (alkaloids obtained from petals of Chysanthemun cinerariefolium
- Affect the nervous system but less than compared to the other pesticides
- the safest in terms of their use
- some are used as household insecticides

Biological

Characteristics

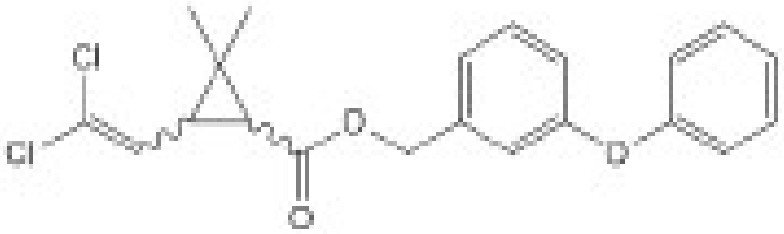
- Viruses, microorganisms or their metabolic product
- Only the Bacillus thuringiensis (Bt) and its subspecies are used with some frequency
- are applied against forest pests and crops
- Particularly against butterflies and also affect other caterpillars

e.g of chemicals structure of pesticides



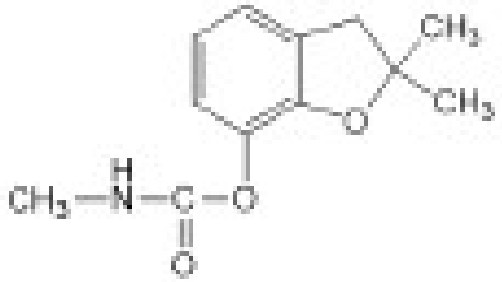
Endosulfan (*6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin 3-oxide*)

A)



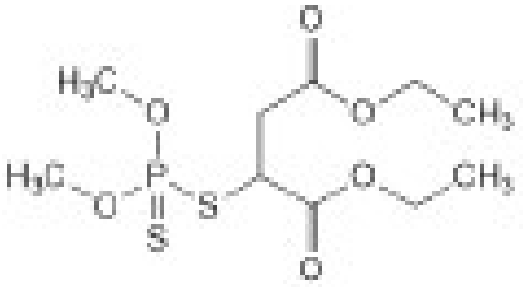
Permethrin (*3-phenoxybenzyl (1RS)-cis-trans-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate*)

B)



Carbofuran (*2,3-Dimethyl-2,2-dihydrobenzofuranyl-7 N-methylcarbamate*)

C)



Malathion (*Diethyl 2-dimethoxyphosphinothioyl sulfanylbutanedioate*)

D)

List natural pesticides commonly used in some areas of Ethiopia?

- Traditionally, farmers of different districts produce pesticides from botanical origins and then apply it to fruits, vegetables and other crops.
- These pesticides are called botanical pesticides.
- They have broad spectrum of activity, being easy to process and use, having a short residual activity and for not accumulating in the environment
- some of the common natural pesticides commonly used in some areas of Ethiopia:

Neem Leaf, Salt Spray and Onion and Garlic Spray.

Neem Leaf

- This medicinal herb has a bitter taste and strong odour that may keep the bugs away from your plants, but non-toxic to animals, birds, plants and humans.
- Neem oil serves as pests/insect repellant.
- Neem leaf around your environment and put it simply in your home/table as it serves also as pests/insect repellant.

Neem Leaf (Azadirachta indica)



Figure 3.12: Neem Leaf (Azadirachta indica)

Herbicides (chemical weed killers)

- Herbicides are known as weed killers which are substances used to control unwanted plants.
- Selective herbicides control specific weed species, while leaving the desired crop relatively unharmed.
- Non-selective herbicides (sometimes called total weed killers in commercial products) since they kill all plant material with which they come into contact.
- Herbicides have largely replaced mechanical methods of weed control

Types of Herbicides

Common groups of herbicides

1. Chlorophenoxy acids

-control broad leaf weed

2,4-D and 2,4,5-T

2. Triazines

Atrazine, hexazinone, and simazin

3. Organic phosphorus chemicals

e.g Glyphosate

4. Amides

e.g Alachlor and metolachlor

5. Thiocarbamates

e.g Butylate

Cont...

6. Dinitroanilines

e.g Trifuralin

7. Chloroaliphatics

E.g Dalapon and trichloroacetate

8. Inorganic chemicals

e,g Various arsenicals, cyanates, and chlorates

Exercise 3.7

1. What are insecticides?

2. List the most common groups of herbicides.

Activity 3.10

1. What are the raw materials for glass production?
2. Why does Solvay plant situated near water mass?

Properties

- Sodium carbonate (washing soda) is a white crystalline solid powder.
- It exists as a decahydrate ($Na_2CO_3.10H_2O$) compound.
- It has a density of 2.54 g/cm3,
- It has a high melting point 851°C
- It has high boiling point 1,600 °C.
- ` It has hygroscopic properties in nature.

cont...

- ✓There are two forms of sodium carbonate this are light soda and dense soda.
- ✓Light soda and Dense soda are both chemically identical compounds, with the only difference being their densities.
- ✓it dissolved in acids by liberating CO_2.
- ✓Anhydrous Sodium Carbonate is unaffected by heat.
- ✓ it release $OH^-(aq)$ ions during hydrolysis makes aqueous solutions alkaline.

$$Na_2CO_3(s) + 2H_2O(l) \rightarrow H_2CO_3(aq) + 2Na^+(aq) + 2OH^-(aq)$$

Na_2CO_3(aq) absorb carbon dioxide from air and form NaHCO3(aq)

$$Na_2CO_3(aq) + H_2O + CO_2(g) \rightarrow 2NaHCO_3(aq)$$

Uses of Na_2CO_3

- half of the total production of Na_2CO_3 , used for glass manufacturing .
- It is used in production of detergents and soaps.
- it is used in the manufacturing of pulp and paper, textiles, drinking water.
- In addition, it can also be used for tissue digestion, dissolving amphoteric metals and compounds,
- food preparation as well as acting as a cleaning agent.
- It is also used in the brick industry.

Production Method (Solvay process)

- Sodium carbonate at present is mostly mined from its natural deposits.
- It also is manufactured synthetically by **Solvay (or ammonia-soda) process**.

- The natural production of sodium carbonate currently has surpassed its synthetic production.

The Solvay process involves a series of partial reactions

$$CaCO_3 \rightarrow CaO + CO_2$$

$$CaO + H_2O \rightarrow Ca(OH)_2$$

$$2NaCl + 2CO_2 + 2NH_3 + 2H_2O \rightarrow 2NaHCO_3 + 2NH_4Cl$$

$$2NaHCO_3 \rightarrow \mathbf{Na_2CO_3} + H_2O + CO_2$$

$$Ca(OH)_2 + 2NH_4Cl \rightarrow CaCl_2 + 2NH_3 + 2H_2O$$

The overall reacı $CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$

Exercise 3.8

1. List the four major raw materials that are used to manufacture Na_2CO_3 in the Solvay process.
2. What is the main byproduct in manufacturing of Na_2CO_3 in the Solvay Process?
3. What is the purpose of burning coke in the Solvay process?
4. Write the chemical formula of the following compounds:

a) Washing soda b) soda ash c) baking soda