The Chemical Industry

Fertilisers

- Plants need nutrients such as nitrogen, potassium and phosphorus to sustain their growth
- A fertiliser is a substance added to the soil to replace elements harvested or taken up by plants
- Fertilisers containing nitrogen, phosphorus and potassium are known as NPK fertilisers.
- A typical compound fertiliser may contain ammonium nitrate, ammonium phosphate and potassium chloride
- A single fertiliser does not contain potassium and phosphorus
- Fertilisers are often mixtures of salts containing ammonium, potassium, nitrate and phosphate ions

Making fertilisers

- Many fertilisers contain ammonium salts. These are made by neutralising ammonia with acids

$$NH_3 + HNO_3 \rightarrow NH_4NO_3$$

Ammonia + nitric acid → ammonium nitrate

$$3NH_3 + H_3PO_4 \rightarrow (NH_4)_3PO_4$$

Ammonia + phosphoric acid → ammonium phosphate

Displacement of ammonia from ammonium salts

- Many fertilisers are slightly acidic
- Crops do not grow well in acidic conditions so farmers add lime $Ca(OH)_2$ to the soil to neutralise the acidity
- Lime reacts with water in soil to form slaked lime, calcium hydroxide
- This is alkaline, if too much lime is put on the soil it reacts with ammonium slats in fertilisers to release ammonia

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

Ammonium chloride + calcium hydroxide → ammonia + calcium chloride +water

- The stronger alkali displaces ammonia from the ammonium salts. The ammonia escapes as a gas into the air and is lost from the soil

Making ammonia

- The Haber process is the process by which ammonia is made

Raw Materials

- The hydrogen for the Haber process is made from natural gas or by cracking ethane. The ethane is obtained from the fractional distillation of petroleum

$$C_2H_6 \rightarrow C_2H_4 + H_2$$

Ethane → ethene + hydrogen

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

Methane + steam → carbon monoxide and hydrogen

- The carbon monoxide is then reacted with steam to form carbon dioxide and hydrogen

$$CO + H_2O \rightarrow CO_2 + H_2$$

The Haber process

- A mixture of nitrogen (1 volume) and hydrogen (3 volumes) is compressed
- The compressed gases pass into a large tank called a convertor. This contains trays of iron catalyst. The temperature is 450°C and the pressure is 200atm. Nitrogen and oxygen combine

$$N_2 + 3H_2 \leftrightarrow 2NH_3$$

- Understand these conditions about 15% of the nitrogen and hydrogen are converted to ammonia
- The mixture is passed to a cooling chamber. The ammonia condenses here and is removed
- The unreacted nitrogen and hydrogen are returned to the convertor. In this way they are not wasted

What are the best reaction conditions?

- The reaction to make ammonia is an equilibrium reaction
- This means it strives to be balanced (equal number of products and reactants)
- The yield is ammonia
- To increase the yield we can increase the pressure because there are more reactant molecules than product molecules
- High pressure conditions are expensive so 200atm is used and not higher
- If the ammonia is taken away, more ammonia is produced
- The forward reaction is exothermic so increased the temperature would favour the backward reaction
- If we lower the temperature, there is not enough energy to activate the molecules
- Therefore a moderate temperature of 450°C is used
- A catalyst has no effect on the equilibrium as it speeds up both the forward and the backward reactions equally
- The iron catalyst lowers the activation energy which is cost effective

Sulfur and Sulfuric acid

Sources

- Mined in the United States, Mexico, Poland and Sicily
- Found combined with metals ores: zinc blende (ZnS), galena (PbS)
- Natural gas and petroleum also contain sulfur

Uses

- Manufacture of sulfuric acid
- Vulcanising tyres (making them more flexible)
- Making dyes

Sulfur dioxide

- Colourless, poisonous gas
- Added to the atmosphere by volcanoes and burning of fossil fuels
- Highly acidic when touching wet surfaces

$$S + O_2 \rightarrow SO_2$$

$$2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$$

- These two reactions provide sulfur dioxide for the production of sulfuric acid
- It is used as a bleach during the manufacture of paper from wood pulp
- Useful for bleaching silk, wool and straw as they are destroyed by stronger bleaches such as chlorine
- Used to preserve food and drink by killing bacteria

Sulfuric acid

- It is a dibasic acid i.e. it produces two hydrogen ions per molecule that can react

Uses

- Paint and dyes
- Cleaning metals
- Soap and detergents
- Fibres
- Fertilisers
- Plastics

Properties

- It reacts with metals above hydrogen to form a salt and hydrogen
- It reacts with metal oxides to form a salt and water
- It reacts with hydroxides to form a salt and water
- It reacts with carbonates to form a salt, water and carbon dioxide
- Sulfuric acid can also form hydrogensulfates by the replacement of one of the hydrogen ions in the sulfuric acid

Manufacturing sulfuric acid

The Contact Process

Raw materials: sulfur, air and water

Sources of sulfur: sulfur from beneath, sulphide ores, hydrogen sulphide from petroleum or natural gas

Stages

- A spray of molten sulfur is burned in a furnace in a current of dry air, sulfur dioxide is formed
- Sulfur dioxide is cooled and reacted with the excess air in the convertor, which has four layers of vanadium (v) oxide catalyst. The temperature is 450°C and the pressure is 1 atm. In the convertor sulfur dioxide is converted to sulfur trioxide
$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$
- This reaction is exothermic, the heat is removed between each catalyst layer to keep the temperature quite low. The mixture leaving the tower contains between 96% and 99.5% sulfur trioxide
- The sulfur trioxide is then absorbed into a 98% solution of sulfuric acid in the absorber.
- We do not dissolve sulfuric acid directly into water as it forms a fine mist of sulfuric acid
- The sulfur trioxide dissolves un 98% sulfuric acid to form a thick liquid called oleum

$$SO_3 + H_2SO_4 \longrightarrow H_2S_2O_7$$

- The oleum is mixed with a little water to make 98% sulfuric acid

$$H_2S_2O_7 + H_2O \longrightarrow 2H_2SO_4$$

- Some of the sulfuric acid is returned to the absorber and the rest is run off to be used as concentrated sulfuric acid

The limestone industry

Quick lime

- When we hear limestone strongly it breaks down into calcium oxide and carbon dioxide. The common names for calcium oxide are quicklime or lime.

$$CaCO_3 \longrightarrow CaO + CO_2$$

Calcium carbonate → calcium oxide + carbon dioxide (Endothermic)

- Quicklime is usually made in a furnace called a lime kiln
- The limestone is strongly heated by a current of hot air
- The rotation of the kiln helps the limestone mix with hot ait
- The limestone decomposes to calcium oxide (quicklime)
- This is removed at the bottom of the kiln

Slaked lime

- Slaked lime is calcium hydroxide
- This is made from quicklime by adding water
- The water is added slowly because the reaction is very exothermic

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

- A solution of calcium hydroxide in water is limewater. This is used as a test for carbon dioxide

<u>Uses of limestone products</u>

- Limestone is used for building
- Extraction of iron
- Construction of roads
- In powdered form we use it to neutralise excess acidity in soils and lakes and to make glass
- Limestone + gypsum + clay + heat → cement
- Cement + water + sand → mortar
- Mortar hardens when it reacts with CO_2
- Quicklime and slaked lime are used to treat acidity is soils and lakes because it is alkaline
- Scrubbers are fitted into flues (chimneys) for desulfurization