CHEMICAL ENGINEERING

Chemical Technology

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Chemical Technology

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CHAPTER

1

Inorganic Chemical Industries

1.1 SULPHUR AND SULPHURIC ACID INDUSTRY

1.1.1 Sulphur Industry

- Sulphur is the basic raw material for manufacture of sulphuric acid (H_2SO_4), which typically occurs as a rhombic crystal.
- 80 - 90% of sulphur is used for manufacture of sulphuric acid.
- 7% to paper and pulp, 3% to CS_2 making.
- And the rest is used in the manufacture of SO_2 , SO_3 , CS_2 , P_2S_5.

Properties:

Chemical formula	:	S
Atomic weight	:	32.07
Melting point	:	Rhombic crystal (112.8° C)
		Monoclinic crystal (119° C)
Boiling point	:	444.6° C

Various process are employed in the manufacture of sulphur.

They are:

1. Frasch process : Elemental sulphur mining from salt domes.
2. By oxidation - reduction of H_2S
3. Finnish process : Elemental sulphur from pyrites

Process:

Recovery of elemental sulphur during the refining of crude petroleum.

1. Frasch Process:

- Treated water at suitable temperature and pressure is pumped into wells of sulphur deposit, water moves upward and the collected discharge is undergone a few more steps to collect sulphur.
- No chemical reaction involved.

Raw materials:

- Sulphur deposits in salt domes.
- Hot water supply

Process description:

- Treated water is sent to domes at 160 - 180° and 25 atm.
- Molten sulphur sinks to the bottom of casing.
- Sump-separation units are used.
- Filtration is sometimes used to remove contaminants.
- Treated water is used to avoid scaling and corrosion.

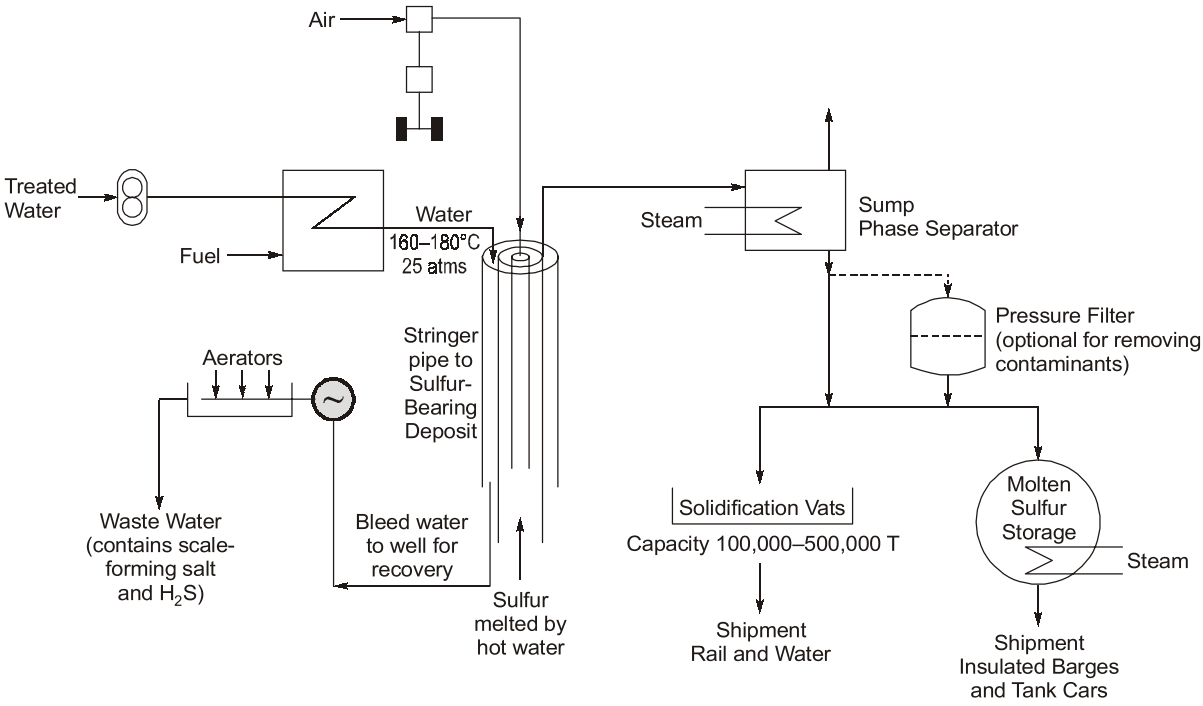


Fig. : *Elemental sulfur mining by Frasch process*

2. Oxidation and Reduction of H_2S:

Raw materials:

- H_2S from natural gas and petroleum refinery.

Reactions:

(i) $2H_2S + 3O_2 \rightleftharpoons 2SO_2 + 2H_2O$ (Exothermic)

(ii) $4H_2S + 2SO_2 \rightarrow S_6\,(g) + 4H_2O$ (Exothermic)

Process:

It consists of two-stage catalytic converter with interstage cooling.

First stage:

- Catalyst: Bauxite
- Operated at 300° - 400° C
- 70 - 80% conversion achieved
- Exothermic SO_2 oxidation of H_2S

Second stage:

- Operated at 250 - 300° C

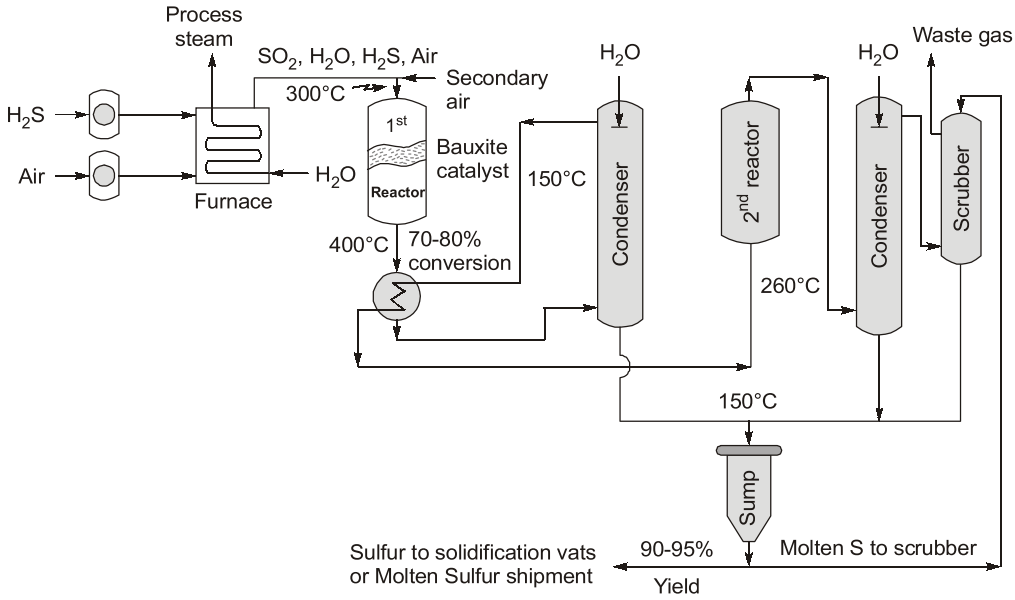


Fig. : *Sulfur production by oxidation-reduction of H_2S*

3. Elemental Sulphur from Pyrites (Finnish Process):

Raw materials:

- Pyrites ore [200 mesh]
- Limestone [To remove Silica]
- Water

Chemical reactions:

Thermal dissociation:

$$Fes_2 \rightarrow Fes(l) + \frac{1}{2}S_2(g)$$

- General combustion reaction :

  $C + H + S + O_2 \rightarrow SO_2, H_2S, CO, H_2O, H_2CO_2$

- Hot stage (sulphur recovery)

  $2\,COS + CS_2 + 2SO_2 \xrightarrow{600°C} S_6 + 3CO_2$

- Cold stage (sulphur recovery):

  $4\,H_2S + 2SO_2 \xrightarrow{280°C} 4H_2O + S_6$

- Roasting of Fes

  $2\,Fes + \frac{7}{2}O_2 \rightarrow Fe_2O_3 + 2SO_2$

Co-products:

- SO_2 [From Fes roasting]
- Fe_2O_3 [From Fes rotating]

1.2 SULPHURIC ACID

Sulphuric acid is a highly corrosive strong dibasic mineral acid with the molecular formula (H_2SO_4). It is a pungent, colorless to slightly yellow viscous liquid which is soluble in water at all concentrations.

Physical Properties:

- Molecular formula : H_2SO_4
- Molecular Weight : 98.08 gram/mole
- Melting point : 10°C
- Boiling point : 290°
- Density : 1840 kg/m^3
- Solubility : Miscible with water in all proportions

1.2.1 Chemical Properties

- Dehydrating agent:
  - It is hygroscopic, readily absorbing water vapour from air.
  - Has great affinity for water and the reaction is extremely exothermic.
  - It forms mono and dihydrate with water, $H_2SO_4 . H_2O$, $H_2SO_4 . 2 H_2O$.
- Oxidising agent:
  - Gives O_2 on strong heating.
  - Hot con H_2SO_4 also acts as an oxidising agent.
- Acidic nature:
  - Strong basic acid
  - Forms two types of salts with alkalis

    Bisulphates [HSO_4^-] ... $NaHSO_4$

    Sulphates [SO_4^{2-}] ... Na_2SO_4
- Manufacturing process:

  The industrial manufacture of sulphuric acid is done mainly by two processes.
  - The lead chamber process
  - The contact process

1.2.2 The Lead Chamber Process

1. This is an old process and uses Nitrogen oxides as oxygen carrying catalysts for the conversion of sulphur dioxide (SO_2) to sulphur trioxide (SO_3).
2. The production of sulphur trioxide and sulphuric acid takes place in the huge lead chambers and that's why the name lead chamber process.
3. Produces acid of concentration less than 80%.
4. All new plants use contact process, although.
5. Gives an yield of 98%.

1.3 COMPARISON OF VANADIUM AND PLATINUM CATALYST

	Characteristic	Platinum	V_2O_5
1.	Investment	High investment, Lower life time	Initially less investment 5% replacement is required per year
2.	Catalyst poisoning	Easily poisoned, mainly by arsenic	Relatively immune to poisoning
3.	Handling of SO_2	8 - 10%	7 - 8%
4.	Conversion	Lower	Higher

Example 1.1 Which one of the following oxides is used as oxygen carrying catalyst in lead chamber process?

(a) Carbon oxides
(b) Sulphur oxides
(c) Nitrogen oxides
(d) None

Solution: (c)

Example 1.2 Reason for using only 7–8% SO_2 in the input stream of catalytic converter?

(a) Catalyst (V_2O_5) limitation
(b) Converter limitation because of heat accumulation problem
(c) To increase H_2SO_4 concentration
(d) For better flow patterns inside the converter

Solution: (a)

Example 1.3 What does DCDA mean?

(a) Double Convertor Double Absorption
(b) Double Contact Double Absorption
(c) Diverging Contact Double Absorption
(d) Double Contact Diverging Absorption

Solution: (b)

1.4 CHLOR-ALKALI INDUSTRY

This industry represents production of three major industrial chemicals.

1. Na_2CO_3 [Sodium Carbonate, Soda Ash]
2. NaOH [Caustic Soda, Sodium Hydroxide]
3. Cl_2 [Chlorine]

Soda Ash (Na_2CO_3):

Also known as washing soda is a sodium salt of carbonic acid. Most commonly occurs as a crystalline substance (Na_2CO_3 , $7H_2O$). It is synthetically produced in large quantities from salt and limestone.

Properties:

Molecular weight - 106
MP - 851°C

Student's Assignments

Q.1 Which of the following catalysts is employed for converting SO_2 to SO_3 in the contact process for sulphuric acid manufacture?
(a) P_2O_5 (b) V_2O_5
(c) N_2O_5 (d) PCl_5

Q.2 In the contact process for sulphuric acid manufacture, the feed gas entering the converter (where SO_2 is oxidized to SO_3) contains:
(a) 0.1 – 1% SO_2 (b) 7–10% SO_2
(c) 20–30% SO_2 (d) 60–70% SO_2

Q.3 There are two industrial processes for sulphuric acid manufacture (contact process and lead chamber process). The produced acid of lead chamber process is of concentration :
(a) Less than 10%
(b) Less than 30%
(c) Less than 60%
(d) Less than 80%

Q.4 In the normal contact process of sulphuric acid manufacture, sulphur dioxide to sulphur trioxide conversion efficiency is around
(a) 20% (b) 50%
(c) 90% (d) 98%

Q.5 In the double contact double absorption process for sulphuric acid manufacture, sulphur dioxide to sulphur trioxide conversion is more than that in normal contact process and is equal to
(a) 98.2% (b) 98.5%
(c) 99.5% (d) 100%

Q.6 In contact process, sulphur dioxide required can be produced either by burning elemental sulphur on by roasting iron, copper or zinc pyrites. In India majority of sulphuric acid plants still use
(a) Elemental Sulphur
(b) Iron Pyrites
(c) Zinc Pyrites
(d) Copper Pyrites

Q.7 Commercial catalyst used for sulphuric acid manufacture contains:
(a) 6.2–6.5% vanadium pentoxide supported on silica and 1% potassium sulphate.
(b) 25% vanadium pentoxide supported on silica and 1% potassium sulphate.
(c) 50% vanadium pentoxide and 50% potassium sulphate mixture.
(d) 100% pure vanadium pentoxide.

Q.8 20% oleum is
(a) 20% SO_3 in 80% H_2SO_4
(b) 20% SO_3 in 100% H_2SO_4
(c) 80% SO_3 in 100% H_2SO_4
(d) None of those

Q.9 In the manufacture of sulphuric acid, the absorption of sulphur trioxide is done in
(a) concentrated sulphuric acid
(b) water
(c) Both (a) and (b)
(d) Oleum

Q.10 Advantages of V_2O_5 catalyst are :
(a) Relatively immune to poisons
(b) Low initial investment
(c) Both (a) and (b)
(d) Catalyst is less active

Q.11 Sulphur dioxide is dried by passing it through concentrated sulphuric acid. It is because concentrated sulphuric acid has a very strong affinity for water and reacts with it to form
(a) $H_2SO_4.H_2O$ (b) $H_2SO_4.2H_2O$
(c) $H_2S_2O_7$ (d) $H_2SO_4 \cdot \frac{1}{2}H_2O$

Q.12 Sulphur dioxide is one of the starting compounds of sulphuric acid industry. It can be obtained by
(a) Burning sulphur in air or oxygen
(b) By roasting zinc sulphide in air
(c) By roasting iron pyrites in air
(d) All of the above

Q.13 Which one of the following compounds is called anhydride of sulphuric acid
(a) SO_3 (Sulphur trioxide)
(b) SO_2 (Sulphur dioxide)
(c) $H_2S_2O_7$ (Oleum)
(d) H_2SO_3 (Sulphurous acid)

Q.14 Which one of the following compounds is used as bleaching agent
(a) SO_2 (Sulphur Dioxide)
(b) SO_3 (Sulphur Trioxide)
(c) N_2O (Nitrous Oxide)
(d) CO_2 (Carbon Dioxide)

Q.15 Sulphuric acid is mainly used in
(a) Fertilizer Industry
(b) Polymer Industry
(c) Petroleum Industry
(d) Automobile Industry

Q.16 In the contact process of sulphuric acid manufacture, 98% sulphuric acid is stored in
(a) Hastelloy steel
(b) Stainless steel
(c) Cast iron
(d) Durmet-20

Q.17 Vanadium pentoxide is used as catalyst in sulphuric acid industry for conversion of SO_2 to SO_3, what are the disadvantages of vanadium pentoxide catalyst
(a) Sulphur dioxide content in incoming air mixture should be limited to 7–10%.
(b) Require high O_2 : SO_2 ratio to give economic conversion.
(c) Catalyst is less active initially.
(d) Catalyst is easily poisoned by arsenic.

Q.18 The conversion of Sulphur dioxide (SO_2) to Sulphur trioxide (SO_3) is favoured by : (strictly according to thermodynamics)
(a) Increase in temperature above 500°C
(b) Increase in pressure
(c) Decrease in temperature
(d) Decrease in pressure

Q.19 Which one of the following catalysts is used in conversion of sulphur dioxide to sulphur trioxide in the manufacture of sulphuric acid before vanadium pentoxide
(a) Platinum (Pt)
(b) Nitrogen oxides
(c) Chromium oxide
(d) Nickel

Q.20 Sulphur dioxide is produced by oxidation of Hydrogen sulphide (H_2S). Which one of the following catalysts is used during this process?
(a) Platinum (Pt)
(b) Vanadium Pentoxide (V_2O_5)
(c) Bauxite (Al_2O_3)
(d) Iron Oxide

Q.21 Which of the following methods is correct for diluting sulphuric acid?
(a) Slowly mixing and adding water in sulphuric acid.
(b) Slowly mixing and adding sulphuric acid in water.
(c) Rigorous addition of water and sulphuric acid.
(d) All of the above

Q.22 Sulphur is the primary raw material for the manufacture of sulphuric acid. Which of the following processes is used for the production of sulphur.
(a) Frasch process
(b) Claus process
(c) Finnish process
(d) Oxidation, reduction of H_2S

Q.23 The reason why treated water is used in frasch process (elemental sulphur mining from salt domes using treated water)
(a) To avoid scaling of the equipment
(b) Treated water is lighter than untreated water
(c) Solubility of sulphur is more in treated water
(d) All of the above

Q.24 Finnish process is used for the manufacture of sulphur, which is the raw material of sulphuric acid industry. What are the co-products of this process?

(a) Sulphur dioxide (SO_2)
(b) Fe_2O_3
(c) FeS
(d) SO_3

Q.25 The lead chamber process was initially used for the manufacture of sulphuric acid. Which one of the following catalysts is used in the lead chamber process?
(a) Platinum
(b) Vanadium Pentoxide (V_2O_5)
(c) Nitrogen oxides
(d) Cobalt (Co)

Q.26 Most sea water contains approximately :
(a) 0.5% dissolved Sodium Chloride
(b) 2.6% dissolved Sodium Chloride
(c) 7.5% dissolved Sodium Chloride
(d) 19.7% dissolved Sodium Chloride

Q.27 Solvay is the most important process for the production of Sodium Carbonate (Soda Ash). What are the raw materials used in the solvay process?
(a) Ammonia and Sodium Chloride
(b) Carbon Dioxide and Sodium Chloride
(c) Carbon Dioxide, Ammonia and Sodium Chloride
(d) Carbon Dioxide, Ammonia

Q.28 Carbon Dioxide is one of the raw materials required for the production of Sodium Carbonate (Soda Ash) by solvay process. Carbon Dioxide used in the solvay process is obtained by
(a) Burning 100% pure coke
(b) Burning coal
(c) By heating limestone
(d) By heating carbonic acid

Q.29 Sodium Hydroxide is produced by :
(a) Mercury Cell Process
(b) Membrane Cell Process
(c) Diaphragm Cell Process
(d) Dual Process

Q.30 Sodium Hydroxide is produced by membrane cell, diaphragm cell, mercury cell processes. Which one of the following gives the purest sodium hydroxide?
(a) Mercury cell
(b) Membrane cell
(c) Diaphragm cell
(d) All of the above

Q.31 Solvay process is the most important process used in the production of sodium carbonate (soda ash). Which one of the following compounds is the byproduct of the solvay process?
(a) Sodium Sulphate (Na_2S)
(b) Ammonium Chloride (NH_4Cl)
(c) Gypsum ($CaSO_4.2H_2O$
(d) Calcium Chloride ($CaCl_2$)

Q.32 Diaphragm cell process is one of the processes used for the production of Sodium Hydroxide. Which of the following statement(s) is/are correct about Diaphragm cell process?
(a) NaOH produced is pure, Cl_2 gas is contaminated.
(b) NaOH produced is dilute, Cl_2 gas is contaminated.
(c) NaOH produced is dilute, Cl_2 gas is contaminated by hydrogen gas.
(d) NaOH produced is pure, Cl_2 gas is contaminated by hydrogen gas.

Q.33 Diaphragm cell, mercury cell, membrane cell processes are the important methods/processes used for the production of Sodium Hydroxide. Arrange these processes in the order of their purity of Sodium Hydroxide produced.
(a) Diaphragm cell > Membrane cell > Mercury cell
(b) Diaphragm cell < Membrane cell < Mercury cell
(c) Diaphragm cell < Membrane cell > Mercury cell
(d) Membrane cell < Diaphragm cell > Mercury cell

CHAPTER

2

Fertilizer Industry

2.1 INTRODUCTION

Fertilizers are the mixture of chemical compounds (organic or inorganic) which provides the soil or plants directly with the primary nutrients (N, P, K), secondary nutrients (Ca, Mg, S) and micro-nutrients (Zn, Boron, Cu, Manganese, Chlorine, Iron and Molybdenum) for the better growth of the plants and to increase the yield.

2.2 PRIMARY NUTRIENTS AND THEIR FUNCTIONS

Nitrogen

- It is one of the important constituent for synthesis of amino acids which are essential for the production of proteins and enzymes in the plant.
- It is also a special constituent of chlorophyll, which is the key to photosynthesis.
- Required during early stages of plant growth to develop stems and leaves.

Phosphorous

- Required in lesser amounts than nitrogen.
- Most soils contain phosphate in the form of complex, insoluble compounds which are of no use for the plant.
- Involved in the respiratory and photosynthetic processes and also in the formation of reproductive parts in the early stages of plant life.
- Stimulates early growth and accelerates seeding or fruit formation in later stages of growth.

Potassium

- Necessary for the healthy growth of plants.
- Helps in the formation and movement of carbohydrates in plant.
- Deficiency of potassium quickly reduces the carbohydrate content.
- Ample supply of potassium, sometimes helps to prevent disease and to lessen the effects of excessive nitrogen application.

  The important chemicals or compounds of fertilizer industry are:

  (i) Ammonia; (ii) Urea; (iii) Nitric acid; (iv) Super phosphate; (v) Triple super phosphate

2.3 AMMONIA

Properties

Molecular weight	:	17.03	M.P.	:	–77.7°C
B.P.	:	–33.4°C	Solubility	:	Highly soluble in water

- Ammonia can be directly applied as fertilizer or used in the production of typical fertilizers and chemicals like urea, ammonium phosphate, nitric acid, etc.
- All processes for NH_3 production are based on pressure catalytic reaction of N_2 and H_2. The variation is the operating temperature.

Reaction

$$N_2 + 3H_2 \overset{Fe}{\rightleftharpoons} 2NH_3 \text{ (Exothermic)}$$

Reactants (Raw Materials)

(i) Nitrogen (N_2) (from air)
(ii) Hydrogen (H_2) (from synthesis gas)
(iii) Cooling water

Hydrogen Production

- Produced from natural gas.
- But first the sulphur present in the natural gas is removed because sulphur is poisonous for the catalyst.

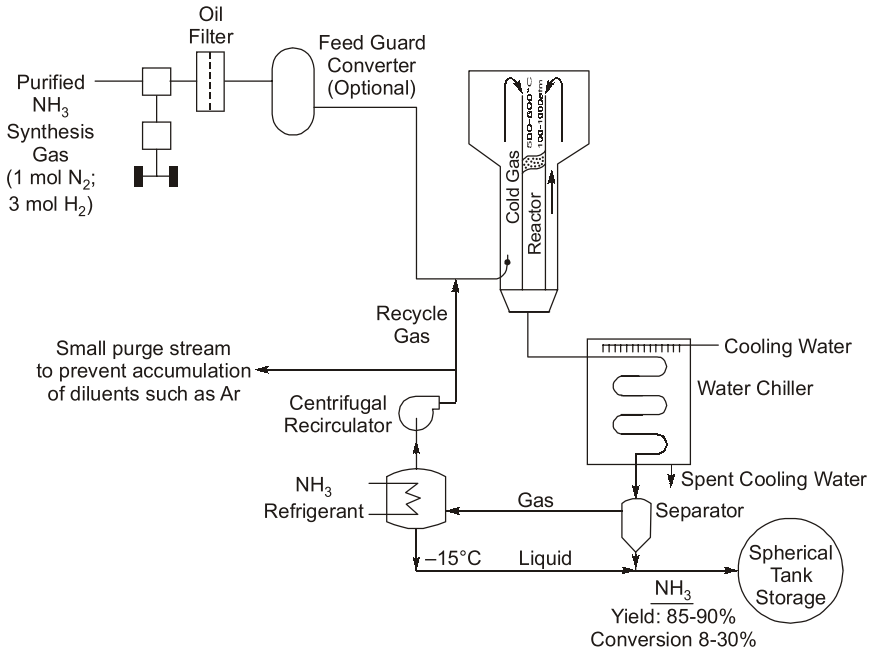
$$ZnO + H_2S \rightarrow ZnS + H_2O$$

- Now methane in natural gas is reacted with water to give hydrogen according to the following reactions:

$$CH_4 + H_2O \rightarrow 3H_2 + CO$$
$$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$$
$$CO + H_2O \rightarrow O_2 + H_2$$

- Nitrogen is obtained from the air.

Ammonia Production



- Synthesis gas (3 moles pure H_2 : 1 mole pure N_2) is compressed to operating pressure (100-1000 atms)
- A guard converter is used to remove traces of H_2O, H_2S, P and as (operates at high temperature)
- The preheated gas flows through the reactor which contains promoted porous iron catalyst at 500-600°C.
- The Ammonia (8–30%) conversion depending upon the operating conditions, is removed by condensation.
  - Water cooling
  - NH_3 refrigeration
- The unconverted reactants are recycled to give yield of 85-90%.

Catalyst Development

Iron oxide promoted by alkali on non-ferrous metal.

Oxides : K_2O (1–2%), Al_2O_3 (2–5%)

2.4 NITRIC ACID (HNO_3)

Properties

Molecular weight	:	63.03
M.P.	:	–42°C
B.P.	:	86°C
Density (18°C)	:	1502 kg/m^3

- Completely miscible with H_2O.
- Commonly available as 58% HNO_3. (A constant boiling mixture at 110°C and 1 atm)
- Fuming nitric acid ≥ 85%.
- Red fuming nitric acid ≥ 95%.

Uses

For the manufacture of

(i) Ammonium nitrate
(ii) Fertilizers
(iii) Explosives and other nitro-compounds.

The following processes are employed for production of nitric acid:

(i) Ammonia oxidation process
(ii) $NaNO_3 + H_2SO_4$ process
(iii) Wisconsin process
(iv) Nitrogen fixation by nuclear fission process

(i) Ammonia Oxidation Process

Raw Materials

(i) NH_3 from synthetic ammonia process
(ii) Filtered air

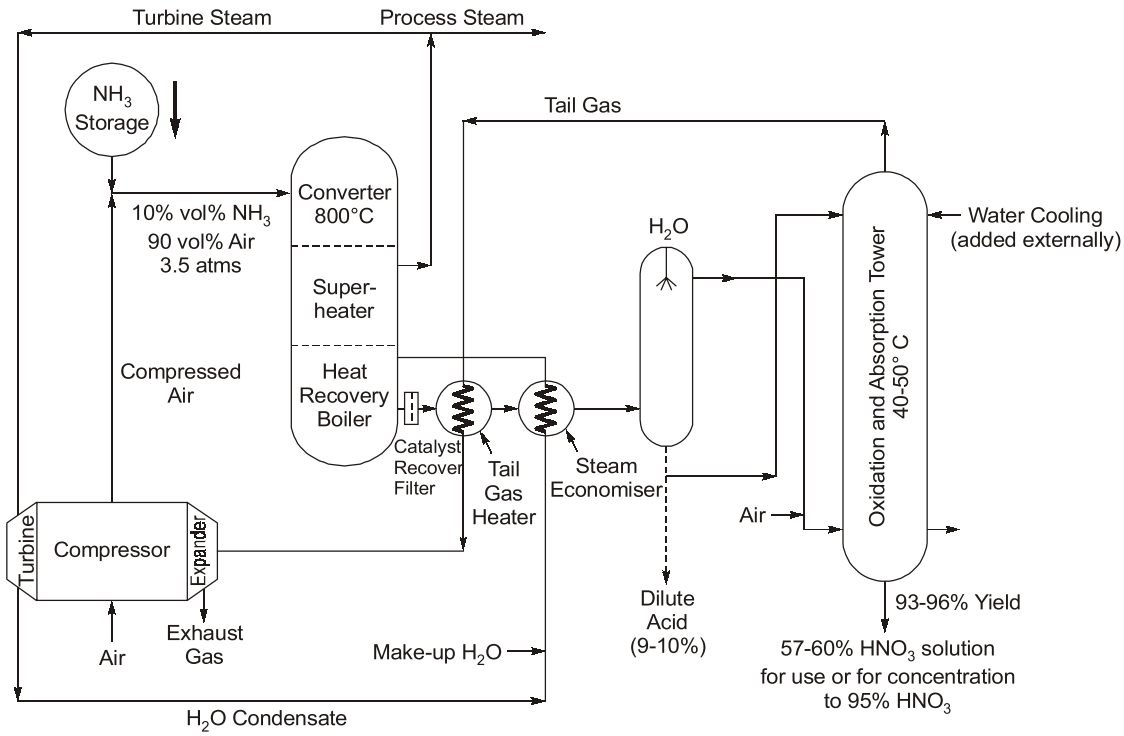
Catalyst

Platinum-Rhodium makeup catalyst (promoted by 2-10% Rh)

Reactions

Main (Desired)	Side Reactions
Ammonia Oxidation $NH_3 + \frac{5}{4}O_2 \rightleftharpoons No + \frac{3}{4}H_2O$ $2No + O_2 \rightarrow 2No_2$	Ammonia Oxidation $NH_3 + \frac{3}{4}O_2 \rightleftharpoons \frac{1}{2}N_2 + \frac{3}{2}H_2O$ $NH_3 \rightleftharpoons \frac{1}{2}N_2 + \frac{3}{2}H_2$ $NH_3 + O_2 \rightleftharpoons \frac{1}{2}N_2O + \frac{3}{2}H_2O$ $NH_3 + \frac{3}{2}No \rightleftharpoons \frac{5}{4}N_2 + \frac{3}{2}H_2O$
Nitrous Oxide Oxidation & Absorption $2No + O_2 \rightleftharpoons 2No_2$ $3No_2 + H_2O \rightleftharpoons 2HNo_3 + No$ $2No_2 + H_2O \rightleftharpoons HNo_3 + HNo_2$	Nitrous Oxide Oxidation & Absorption $2No_2 \rightleftharpoons N_2O_4$ $2HNo_2 \rightleftharpoons H_2O + No + No_2$

Process Description



- Compress air is mixed with anhydrous ammonia (10% NH_3 and 90% air) is fed to a shell and tube converter.
- Converter consists of 10-30 sheets of Pt-Rh catalyst at 800°C.
- Product gases from converter containing 10-12% No is passed through heat recovery units and is sent into oxidizer-absorber system.
- In this NO is converted to NO_2 at a favourable temperature of 40-50°C.

- The product from this absorption system is 57–60% NH_3 which can be concentrated further.
- Concentration of the HNO_3 to 95% can be done by :
  (i) Concentration by H_2SO_4
  (ii) Concentration by $Mg(NO_3)_2$

2.5 UREA

Properties

Molecular weight	:	60.05
M.P.	:	132.7°C
B.P.	:	Decomposes
Density (20°C)	:	1335 kg/m^3
Solubility	:	Fairly soluble in water

- Urea has nitrogen content of about 46% which is the highest in a solid fertilizer.
- It is produced as granules and can be easily transported.
- It does not come with any explosive hazard and is readily dissolved in water.

Uses

- Used in the production of formaldehyde resins, melamine and adhesives.
- Used as fertilizer as it is or as urea-ammonium nitrate solution.

Methods of Production

Ammonium carbamate decomposition

Raw Materials

(i) Ammonia (liquefied)
(ii) Carbon dioxide (compressed)

Reactions

(i) $CO_2 + 2NH_3 \rightarrow \underset{\text{(Ammonium Carbamate)}}{NH_4\text{-}COO\text{-}NH_2}$ (exothermic)

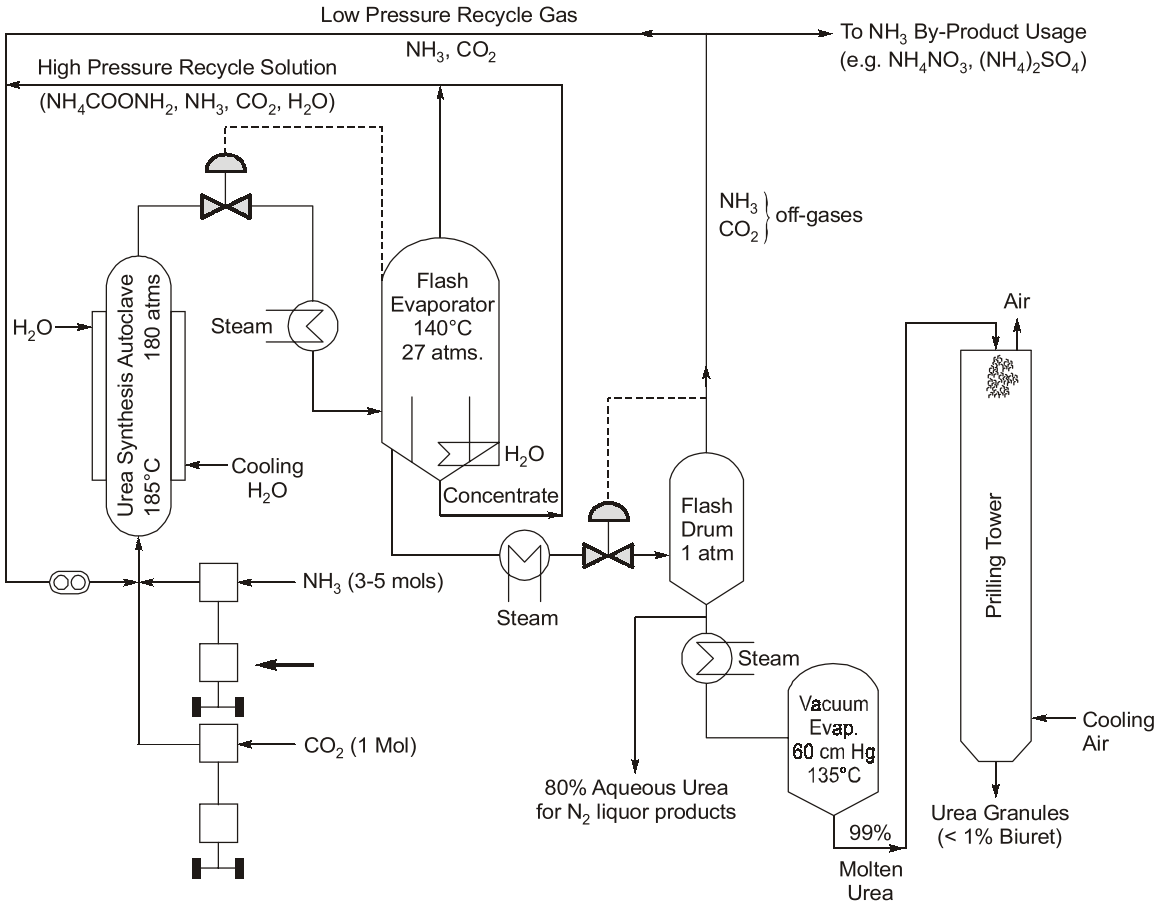
(ii) $NH_4COONH_2 \rightarrow NH_2CONH_2 + H_2O$ (endothermic)

Undesirable Reaction

$2NH_2CONH_2 \rightarrow NH_2CONHCONH_2 + NH_3$

- The first reaction produces ammonium carbamate under pressure by highly exothermic reaction and can reach completion.
- The decomposition of carbamate is endothermic and cannot reach completion.
- Unconverted ammonia, carbon dioxide, undecomposed carbamate should be recycled.

Process Description



- NH_3 and CO_2 are compressed separately and fed to the autoclave (reactor).
- Autoclave is maintained at a temperature around 185°C and a pressure of around 180 atm.
- The flow rate of reactants is adjusted in such a way that average residence time is 1.5–2 hours.
- Continuous cooling water is supplied to the reactor as the reaction is highly exothermic.
- The exit stream of autoclave which contains a mixture of urea, carbamate, unreacted NH_3, CO_2 is sent into a flash-evaporation at 27 atms.
- The unconverted NH_3, CO_2 undecomposed carbamate are recycled.
- The exit stream of flash-evaporation is sent into an atmospheric flash drum where further decomposition of carbamate takes place.
- The 80% aqueous urea can be used directly, on sent into a vacuum evaporator to obtain urea of more than 99%, which is then sent into prilling (granular solidification) tower.
- The residence time in a prilling tower is 1–2 s and the temperature is maintained just above the melting temperature of urea to avoid formation of biuret.

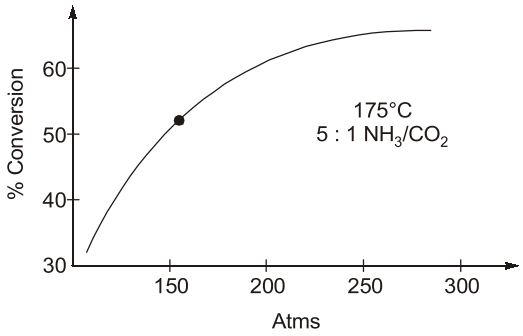
Important Points

- For urea to be used as a fertilizer biuret content should be maintained less than 1%.
- Biuret decomposes urea into CO_2, N_2 and H_2O.
- To avoid corrosion of equipment, excess NH_3 is to be fed.

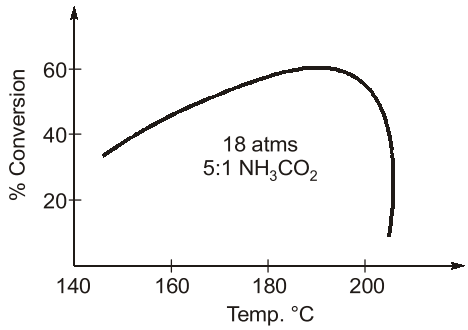
$$NH_3 : CO_2 \rightarrow 5 : 1$$

Kinetics of Thermodynamics

- The urea production rate increases with increase in pressure. The pressure should always be higher than the dissociation pressure at that temperature.



- Increases with increase in temperature upto a temperature range 175-180°C and then decreases sharply after that.



2.6 PHOSPHOROUS

Properties of Yellow Phosphorous (P_4):

Molecular weight	:	123.9
M.P.	:	44.1°C
B.P.	:	280°C

Extremely toxic, ignites spontaneously in air.

Properties of Red Phosphorous (P_4):

Molecular weight	:	123.9
M.P.	:	593°C

Formed by heating yellow phosphorous and exists in atleast six different crystal structures.

Methods of Production:

Chemical Reaction

$$2Ca_3(PO_4)_2 + 10C + 6SiO_2 \rightarrow P_4\,(\text{Yellow}) + 6CaSiO_3 + 10CO$$

$$P_4\,(\text{Yellow}) \xrightarrow[250\text{–}450^\circ C]{\Delta} P_4\ (\text{Red})$$