Ammonia synthesis

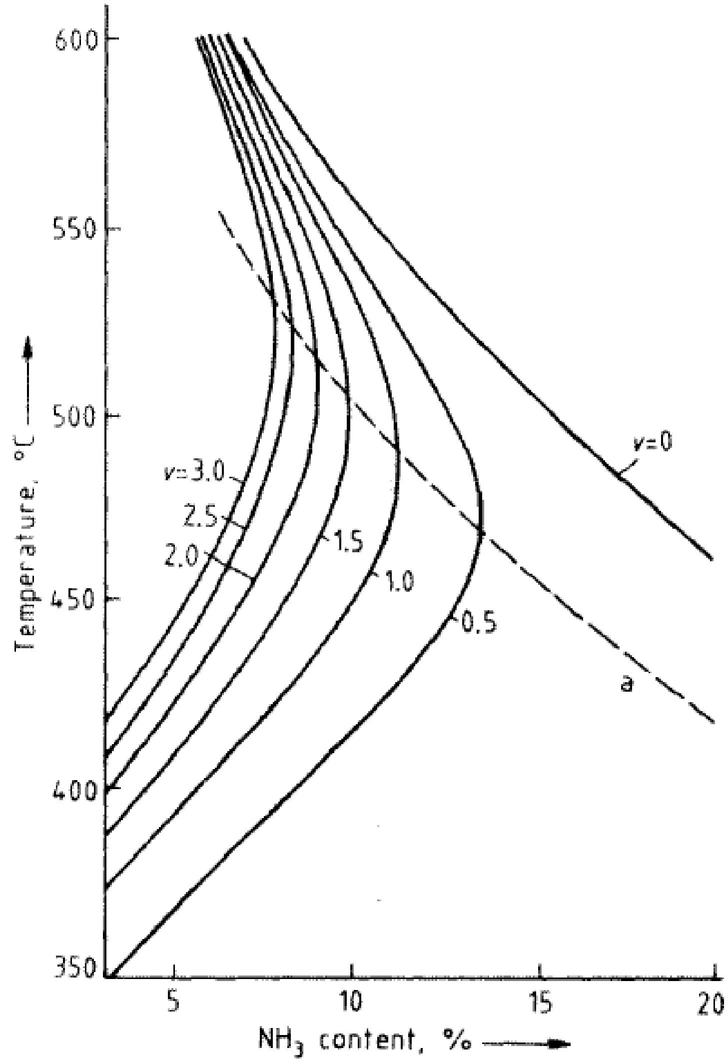
Converter Design

- Catalyst volume
- Dimensions
- No of catalyst beds
- Temperature profile
- Gas composition
- Pressure drop, etc.

Converter Design

Objective in design:
Optimizing catalyst utilization

Curve (a) corresponds to the maximum ammonia production at all rates



Converter Design

- To increase the rate of reaction, **first portion of catalyst bed must react adiabatically** but Service life considerations dictates not to exceed 530^{o}C.
- Following this initial adiabatic temperature rise, it is possible to **minimize the required catalyst volume by cooling the reacting synthesis gas**.

Temperature Control Techniques

Two main groups

- **Tube-cooled converters :** Internally cooled with cooling tubes running through the catalyst bed or with catalyst inside the tubes and the cooling medium on the shell side. The cooling medium is mostly the reactor feed gas, which can flow counter or co-currently to the gas flow in the synthesis catalyst volume.
- **Quench converters or Indirectly cooled multi-bed converter:** The catalyst volume is divided into several beds in which the reaction proceeds adiabatically. Between the individual catalyst beds heat is removed by injection of colder synthesis gas (quench converters) or by indirect cooling with synthesis gas or via boiler feed water heating or raising steam (indirectly cooled multi-bed converter).

Temperature Control Techniques

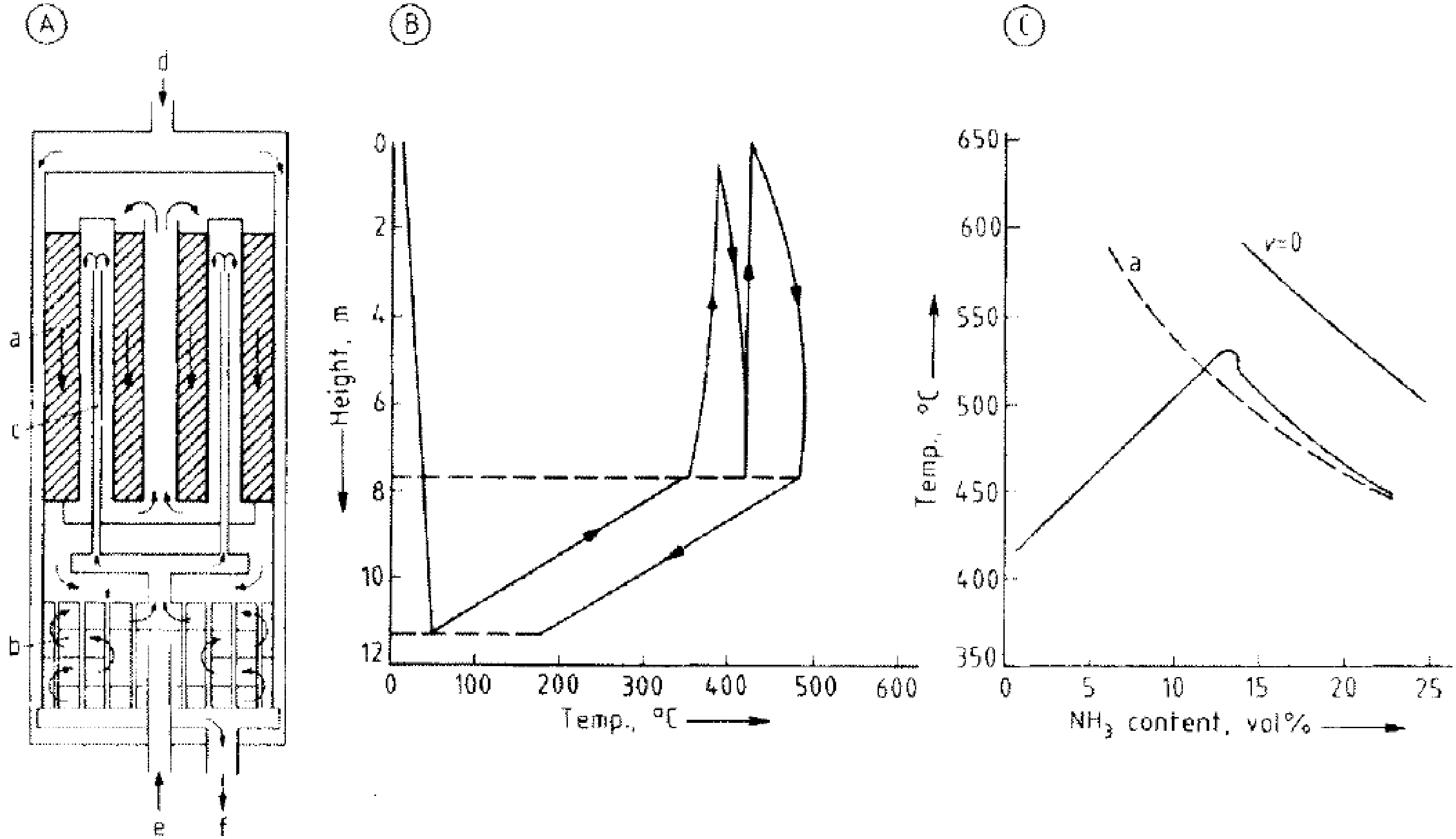


Figure: Co-current exchange type

Temperature Control Techniques

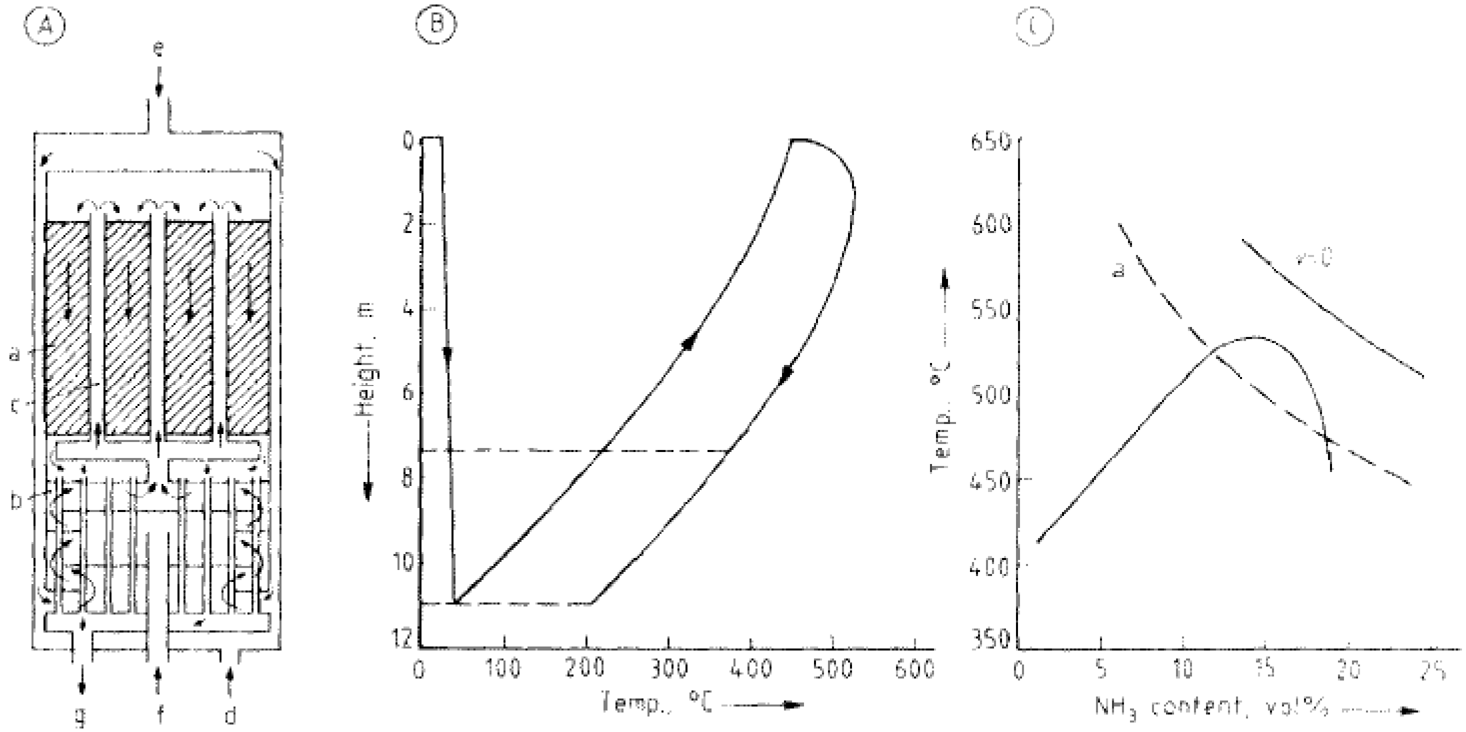


Figure: Counter-current exchange type

Temperature Control Techniques

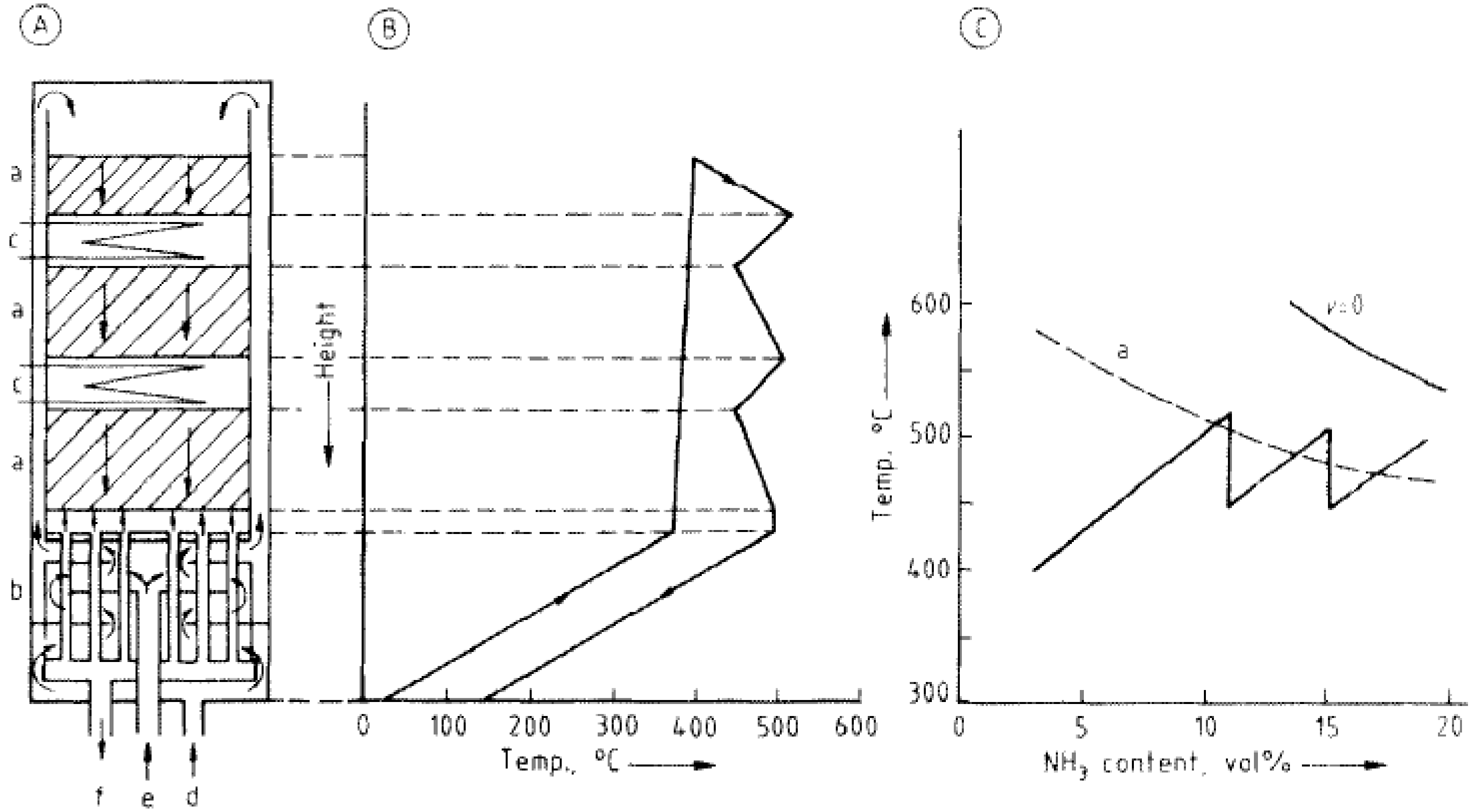


Figure: Multi-bed reactor with indirect cooling

Temperature Control Techniques

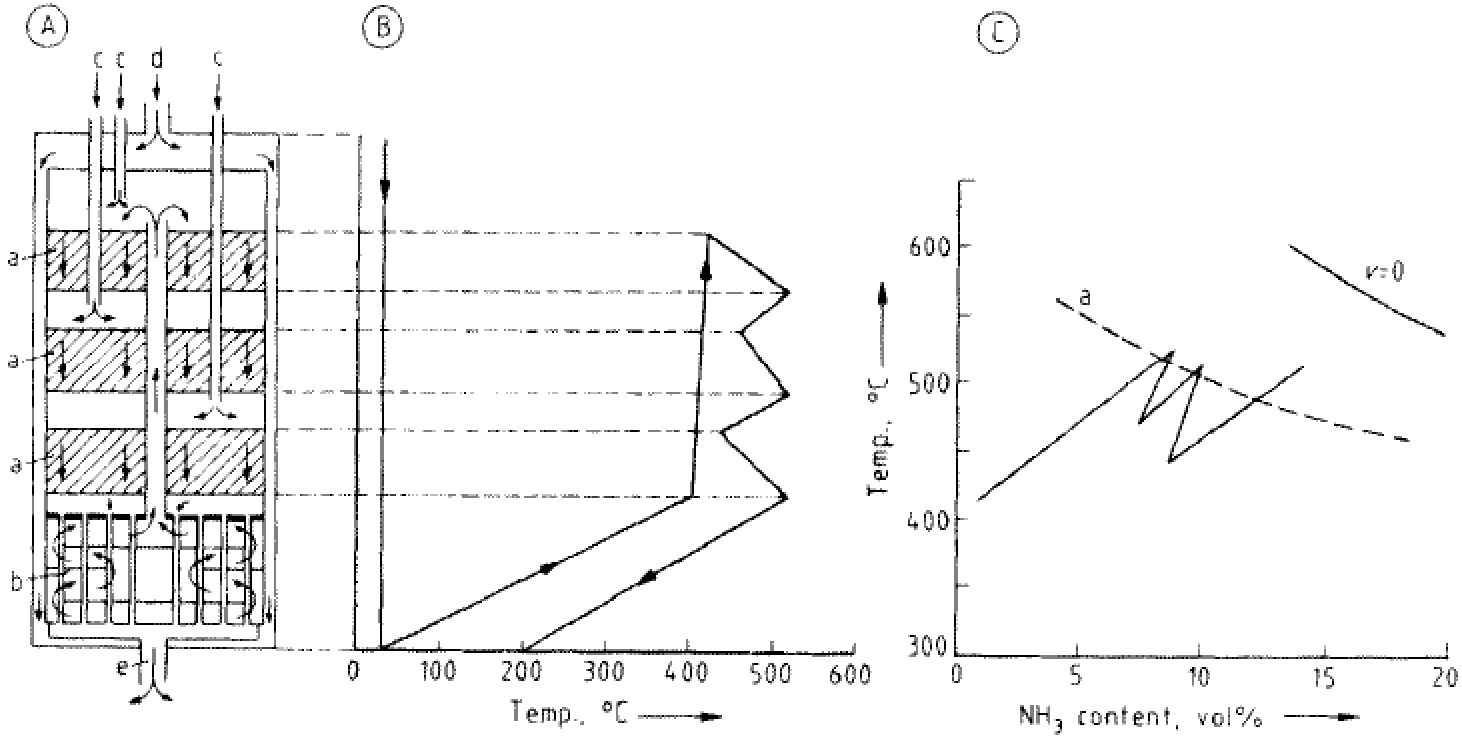


Figure: Multi-bed reactor with quench cooling

Synthesis Over Beds of Catalyst

- Iron catalyst is obtained by reducing its oxides (Fe_2O_3, Fe_3O_4)

- Promoters such as Al_2O_3, K_2O, CaO and SiO_2 are added to the Iron catalyst in their manufacture.

FeO	**32.6**
Al_2O_3	**4.1**
K_2O	**0.9**
CaO	**1.4**
SiO_2	**0.7**
MgO	**-**
TiO_2	**0.7**

Typical composition of ammonia synthesis catalyst

Catalyst Poisons and Catalyst Life

- Two classes of poisons are recognized – Permanent and Temporary
- Permanent poisons contain S, P, As, Cl compounds such as H_2S and HCl
- Presence of Oxygenated compounds such as CO, CO_2, H_2O causes temporary poison. If exposure don’t last more than 3 to 6 days catalyst can be restored back to normal simply by exposing it to pure synthesis gas

Catalyst Reduction

- Active sites of synthesis catalyst are on iron crystals, so crystals must be reduced from magnetite to iron before use
- Two way of catalyst reduction – as a part of startup or use of pre-reduced catalyst

Converter Design Equation

$$W = K_2 \left\{ K_P P_{N_2} \left(\frac{P_{H_2}{}^3}{P_{NH_3}{}^2} \right)^{\alpha} - \left(\frac{P_{NH_3}{}^2}{P_{H_2}{}^3} \right)^{1-\alpha} \right\}$$

W= rate of reaction

K_P= equilibrium constant

α = constant, 0 to 1

$$K_2 = K_2(0) \exp^{-\frac{\Delta E_{K_2}}{R}\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

ΔE_{K_2} = 38.0 Kcal/mol

- The above equations are valid for the range 500-1300 °C
- It is also assumed that the rate controlling step in the overall reaction is the adsorption of nitrogen on a non-uniform surface of catalyst.
- Temkin and Pyzher, 1940