10.4 The Haber process and NPK fertilisers

Name: _____ Class: _____ Date: _____ **Total: 34 marks**

KEY WORDS Haber process • compromise conditions • NPK fertiliser

Objective

Explain the Haber process conditions and NPK fertiliser production. Chemistry only. Original questions for spec statement 4.10.4.

1 Key knowledge and worked examples

Haber: N_2 (from **air**) + 3 H_2 (from **natural gas + steam**) $\rightleftharpoons$ 2 NH_3 (exothermic forward). Conditions: **iron catalyst, ~450 °C, ~200 atm**; cool – **ammonia liquefies out**; unreacted gases **recycled**.

(HT) The compromise: higher pressure → more NH_3 (fewer gas molecules) but costly and unsafe; lower temperature → more NH_3 (exothermic) but slow – so 450 °C gives an acceptable rate at an acceptable yield; the catalyst speeds the approach to equilibrium without shifting it.

NPK fertilisers – compounds of nitrogen, phosphorus, potassium for growth: ammonia → **nitric acid**; NH_3 + HNO_3 → **ammonium nitrate**; **potassium chloride/sulfate** mined; phosphate rock treatment: nitric acid → calcium nitrate/phosphoric acid; sulfuric acid → single superphosphate (phosphate + sulfate); phosphoric acid → triple superphosphate (phosphate).

Worked example (4 marks, HT). Explain why 200 atm rather than 1000 atm is used.

Higher pressure favours the forward reaction – fewer gas molecules – so yield would rise; but very high pressures need expensive, strong plant and add safety risk; ~200 atm balances yield against cost and safety; with recycling of unreacted gases, the overall conversion stays economic.

2 Practice

2.1 Give the source of the nitrogen and the hydrogen for the process. [2]

2.2 Name the catalyst. [1]

2.3 What happens to unreacted nitrogen and hydrogen? [1]

3 Exam-style questions

3.1 Describe how ammonia is separated and the process made economic. [4]

3.2 *(HT)* The forward reaction is exothermic. Explain the effect of raising the temperature on yield and rate, and the chosen compromise. [5]

3.3 Ammonium nitrate is made from ammonia. Outline the acid-making and neutralisation stages, then give two criteria for comparing industrial production with a laboratory preparation. [4]

3.4 Name the products from treating phosphate rock with nitric acid, sulfuric acid and phosphoric acid. Distinguish single and triple superphosphate. [4]

3.5 A feed contains 2 mol nitrogen and 6 mol hydrogen. On one Haber pass, 1 mol nitrogen reacts. Use the balanced equation to calculate ammonia made and both unreacted amounts. Explain why recycling is not proof of zero resource use. [5]

3.6 *(HT)* An operator claims an iron catalyst raises the equilibrium percentage of ammonia, and a much higher temperature must improve both yield and rate. Correct both claims for the exothermic forward reaction. [4]

3.7 A laboratory makes a pure ammonium salt by controlled neutralisation followed by crystallisation. A factory uses integrated continuous processes to make the same salt. Give two useful comparison criteria and explain why "laboratory titration always produces an impure solution" is not a valid verdict. [4]

Solutions

Authored marking guidance for these original questions.

2.1 Nitrogen from the air; hydrogen from natural gas/methane reacted with steam.

2.2 Iron.

2.3 They are recycled back into the reactor.

3.1 The mixture is cooled; ammonia's boiling point is higher, so it liquefies and is tapped off; the unreacted nitrogen and hydrogen are recycled to improve feedstock use; continuous operation with cheap raw materials (air, methane) keeps the process economic.

3.2 Raising temperature shifts equilibrium in the endothermic direction – the reverse – so the ammonia yield falls; but the rate rises – more collisions exceed activation energy; a low temperature would give high yield but impractically slow production; ~450 °C is the compromise giving acceptable rate at acceptable yield; the iron catalyst raises the rate further without changing the yield.

3.3 Ammonia is used to manufacture nitric acid; ammonia + nitric acid → ammonium nitrate – a neutralisation. Industrially: raw materials are cheap and abundant, and continuous large-scale output; compare energy per unit product, purity, equipment or waste using supplied data; careful laboratory neutralisation and crystallisation can give a pure solid.

3.4 Nitric acid gives calcium nitrate and phosphoric acid; sulfuric acid gives single superphosphate containing calcium dihydrogen phosphate and calcium sulfate; phosphoric acid gives triple superphosphate containing calcium dihydrogen phosphate. Single contains the sulfate component whereas triple does not. Do not call all three treatments simply "superphosphate".

3.5 $N_2 + 3H_2 \rightleftharpoons 2NH_3$ gives ratios 1:3:2. Reaction of 1 mol nitrogen uses 3 mol hydrogen and forms 2 mol ammonia; nitrogen left $= 2 - 1 = 1$ mol, hydrogen left $= 6 - 3 = 3$ mol. Recycling still needs feedstock/energy for compression, heating/cooling and replacement; it does not imply zero emissions or waste.

3.6 Iron speeds both directions/approach to equilibrium, without changing equilibrium composition. Higher temperature increases reaction rate but favours the endothermic reverse direction, lowering equilibrium ammonia yield. Rate and equilibrium yield are different quantities.

3.7 Two criteria such as output scale, energy per unit product, raw-material source/cost, purity, equipment, heat recovery or waste handling, compared for the same product and quality. Accurate laboratory neutralisation and suitable evaporation/crystallisation can produce a pure solid, so inherent impurity is false. Industrial advantage needs actual data and context.