The Haber Process

While you are not expected to memorise any industrial processes, you may be asked to apply your understanding of equilibrium principles to questions about an industrial process, such as the Haber process.

In the Haber process, nitrogen and hydrogen react to form ammonia gas. The pressure of the mixture of gases is increased to 200 atmospheres. The pressurised gases are heated to a temperature of 450°C and passed over an iron catalyst.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92.4 \text{ kJ mol}^{-1}$$

Due to the Haber process being a reversible reaction, the yield of ammonia can be changed by changing the pressure or temperature of the reaction.

These reaction conditions above are not the best <u>in terms of the yield</u> but are compromise conditions because they balance a <u>decent yield</u> with a <u>decent rate of reaction</u> and a <u>reasonable production cost</u>.

<u>Pressure</u>

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

A high pressure would increase the ammonia gas yield as there are four moles of gas on the reactant side of the equation, and two moles of gas on the product side. Therefore, when there is an increase in pressure, the system would shift towards the products (to minimise the stress / increased pressure on the equilibrium) since there are fewer gas molecules on the product side. This would increase the yield of ammonia, an advantage for the manufacturer.

However if the pressure is made too high, it would significantly increase equipment costs as the equipment (chemical plant) would have to be a lot stronger to contain the higher pressure. A pressure of 200 atmospheres is chosen to give a decent yield and increased rate of reaction.

<u>Temperature</u>

A low temperature would increase the yield of ammonia gas.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H \text{ is negative}$$

As the temperature decreases, the system will act to increase the temperature by favouring the exothermic direction to release some extra heat energy. Since the reaction has a negative Δ_rH, this means that the forward reaction is exothermic and produces heat energy. A decrease in temperature will cause the equilibrium to shift towards the product and therefore the concentration of NH_3 will increase. However, while a bigger % yield of ammonia would be obtained at a lower temperature, if the temperature is too low, the rate of the reaction would be so slow that it would take far too long to make the ammonia. A temperature of 450°C is chosen to give a lower but still decent yield and keep the rate of reaction high.

Catalyst

The use of the hot iron catalyst means that a good yield of ammonia is produced constantly. Catalysts speed up reactions by offering an alternative reaction pathway with a lower activation energy, so more particles have sufficient kinetic energy to overcome the activation energy barrier. While catalysts do not change the equilibrium concentrations of reacting substances in reversible reactions, they reduce the time taken to reach equilibrium. This helps to achieve an acceptable yield in an acceptable time.

Additional Note

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

As part of the process, the ammonia, $NH_3(g)$, is liquified and removed as it is produced, which is an advantage to a manufacturer. As ammonia gas is removed, the concentration of the products decreases. The system opposes the change by favouring the forward reaction to form more ammonia / replace the removed ammonia. In industry, this is an advantage as it maximises the amount of ammonia produced, and therefore the profit.