High Pressure Chemistry

Contents: Reading and questions about the work of Carl Bosch and the commercial development of the Haber process.

Time: 1 period or homework.

Intended use: GCSE Chemistry and Integrated Science

Aims:

- To complement prior work on the Haber process and on the uses of metals
- To illustrate some of the problems faced by chemical engineers when they scale up a process for use in industry
- To provide opportunitites to practise skills in reading and comprehension

Requirements: Students' worksheets No.810

Author: Tony Travis

This unit could be used in conjunction with unit 207, *The Story of Fritz Haber.*

The passage of reading and the associated questions can be used in class or for homework. It is assumed that the students have already studied the Haber process. They may need to refer to their notes, or textbook, for help with some of the answers to the questions. It may be best to delay issuing page 3 until students have attempted their own design of reactor vessel in question 7.

Once Bosch had demonstrated the success of his first design he tried some other variations. In one of his later reactors he did away with the holes in the outer wall. Instead he passed the compresssed mixture of nitrogen through the gap between the two walls before it entered the bed of catalyst. This meant that the pressure on both sides of the inner wall was the same. The flow of compressed gas kept the outer wall cool and prevented any reaction between hydrogen and carbon in the steel.

Finding a cheaper catalyst to replace platinum was a major research undertaking. Over 20 000 experiments were carried out in twenty-four small test reactors over a ten-year period. Bosch and his team finally developed an iron catalyst with added promoters. This type of catalyst is still in use.

Other development work required the design and manufacture of high pressure compressors, new valves, pipe fittings and pipe joints.

Bosch also had to develop new methods of getting cheap nitrogen and hydrogen. Synthesis gas was made from coal, steam and air. Nowadays natural gas or fractions from oil distillation are used instead of coal but the essential chemistry is very similar in principle.

A 35-ton ICI gas compressor used for the Haber process at Billingham from 1923, and a 1917 BASF ammonia convertor can be seen at the Science Museum at the Wroughton airfield outstation near Swindon.

Other resources

Further information about this topic can be found in *The High Pressure Chemists* written by Dr Tony Travis for the Brent Schools and Industry Project. This is available from the ASE Bookselling Department.

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HIGH PRESSURE CHEMISTRY

This unit describes part of the work of Carl Bosch (Figure 1). Bosch worked for the large German manufacturing firm called Badische Anilin and Soda-Fabrik (BASF).

BASF bought the rights to the Haber process in 1909. You may remember that Haber invented this process as a means of solving the 'nitrogen problem' At that time many scientists were trying to discover new methods for 'fixing nitrogen'.

Answer questions 1 to 3.

Bosch and his team of engineers were the first to manufacture chemicals at very high presssures. You can appreciate one of their problems if you look at Figure 2.

The steam inside a pressure cooker is at twice atmospheric pressure while food is cooking. The metal wall of the cooker has to be much thicker than in a normal saucepan. The designers of a pressure cooker have to be sure that it can hold the steam safely.

Bosch faced a much bigger problem. He had to design a reactor vessel which would contain gases at 200 times atmospheric pressure.

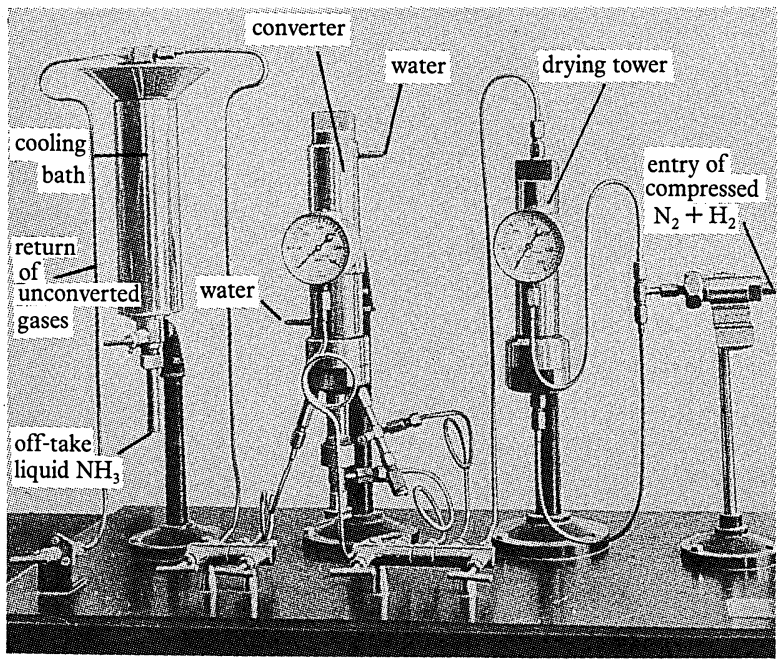

Figure 3 Haber's experimental apparatus for making ammonia

Figure 3 shows the size of apparatus used by Haber in his laboratory trials.

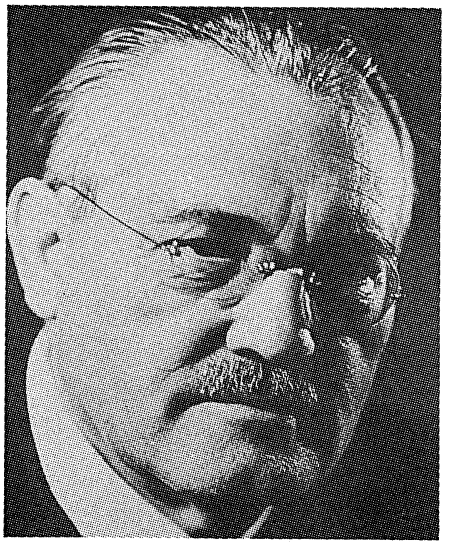

Figure 1 Carl Bosch (1874-1940)

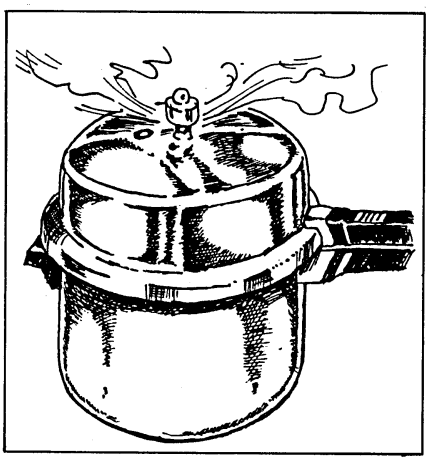

Figure 2 A pressure cooker

Questions

(You will find it helpful to refer to other sources when answering these questions including your notes and your textbook).

1 *Which chemical is manufactured by the Haber process and why is it needed on a large scale?*

2 *Why were large chemical companies such as BASF interested in investing in the development of the Haber process in 1909?*

3 *What is meant by the term 'nitrogen fixation'?*

Bosch's engineers had to 'scale up' Haber's small-scale process. They had to solve three main problems:

- They had to design a large reactor vessel to work at pressures up to 200 times atmospheric pressure at temperatures around 500°C.
- They had to find a cheap catalyst in place of the platinum catalyst used by Haber.
- They had to find large-scale methods of making the nitrogen and hydrogen needed by the plant.

Figure 4 shows what Bosch and his team achieved in the space of five years.

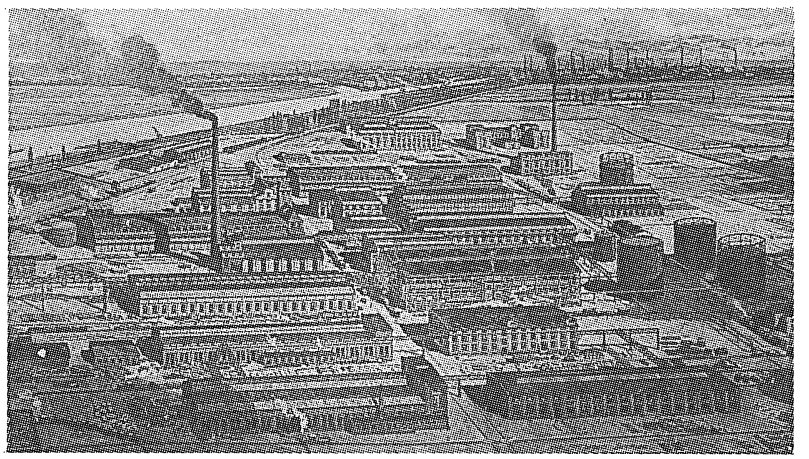

Figure 4 A painting of the first synthetic ammonia plant at Oppau in 1914

Designing the reactor vessel

Designing the reactor vessel involved many problems for Bosch and his team. The first small-scale test plants exploded under pressure. They discovered that this happened because some of the hydrogen used in the process was reacting with carbon in the steel walls of the vessel. This made the metal brittle. The brittle metal could not withstand the pressure.

Bosch's solution to the problem is shown on the next page. But before you look at that page try to answer questions 4 to 7.

Questions

4 *Why do you think that Bosch had to find another catalyst to replace the platinum used by Haber?*

5 *Bosch's father owned a plumber's business. Bosch himself worked as a fitter for some time before going to university to read chemistry. How might this background have helped Bosch in his work?*

6 *Why did the first reactors made by Bosch explode?*

7 *Try to think of a way of solving the problem that made the reactor vessel explode.*

Bosch realised that the problem could be solved by using steel with a very low carbon content. But the trouble is that low-carbon steel is relatively soft. It could not stand up to the pressure in the reactor vessel.

Bosch found a solution to the problem in 1911. His design is shown in Figure 5.

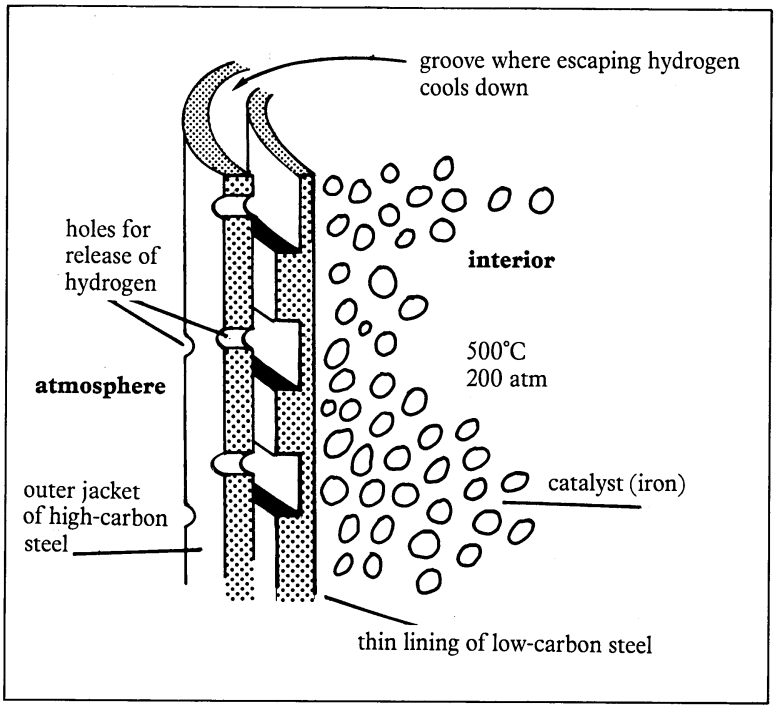

Figure 5 A section of Bosch's double-walled reactor for the Haber process

Bosch's idea was to make a reactor vessel from a double-walled tube. The inner wall was made of soft steel with a very low carbon content. This steel could be exposed safely to the mixture of nitrogen and hydrogen at high temperatures.

The inner wall was not strong enough to contain the gases at high pressure. So it was supported by a strong outer wall made of a higher carbon steel. The outer wall was designed to stand the stresses of the high pressure in the reactor.

A little hydrogen diffused through the inner wall at high pressures. The escaping hydrogen cooled in the grooves cut in the steel wall. Tiny holes drilled in the outer wall allowed the hydrogen to escape. In this way Bosch made sure that there was no danger of the carbon in the steel of the outer wall reacting with hydrogen under pressure.

The basic methods developed by Haber and Bosch are still used today. They are essential for making the huge amounts of ammonia needed in the modern world.

Answer questions 8 to 12.

Questions

8 Why did Bosch use a low-carbon steel for the inner wall of his new reactor vessel?

9 Why could Bosch not make the whole reactor from the low-carbon steel used for the inner wall?

10 Hydrogen is more likely than nitrogen to diffuse through the metal wall of a reactor. Suggest a reason why.

11 What was the purpose of the outer wall and why was it made of high-carbon steel?

12 How did Bosch's design (Figure 5) prevent the strong outer wall from being weakened by the reaction between carbon in the steel and hydrogen from the reaction mixture?

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