# AMMONIA

Concept and application

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# 8 Refrigeration

## 8.1 Introduction

The synthesis unit of the ammonia plant is designed to produce a $NH_3$ content of about 16% by volume in the recycle gas downstream of the converter. In order to avoid $N_2$ and $H_2$ losses, the unconverted gas must be fed back to the converter. Before returning the gas to the converter, the $NH_3$ previously formed must be removed from the recycle gas. This is done by cooling the hot reaction gas to a temperature below the dew point of ammonia, as a result of which liquid ammonia is obtained. A separator serves to separate the liquid phase from the gaseous phase. Total ammonia condensation is not possible for equilibrium reasons. The residual ammonia content depends on the temperature, as can be seen from the following graph.

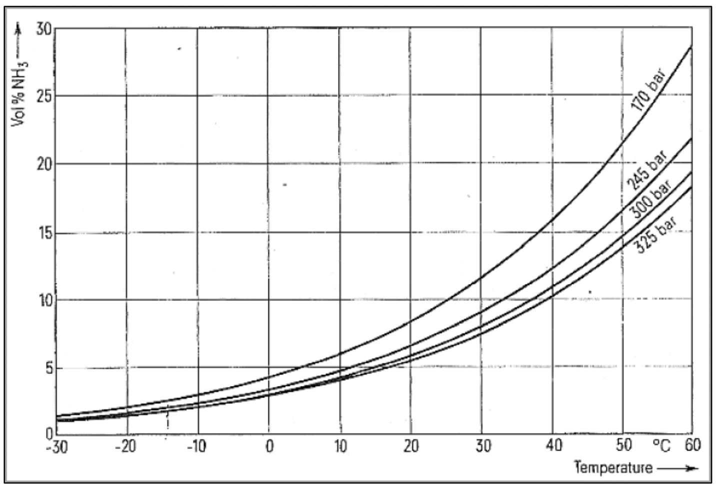


Figure 94. Ammonia in synthesis gas ($3H_2 + N_2$) in the presence of liquid ammonia

It is always desirable to condense the ammonia as completely as possible, since the $NH_3$ yield will be the greater, the lower the $NH_3$ content in the recycle gas is at the converter inlet.

The recycle gas leaves the ammonia converter at a temperature of 380 °C. The gas is first sent through a boiler feed water preheater or waste heat boiler and then through heat exchangers, where the gas temperature is reduced to about 45 °C. Part of the ammonia will condense at this temperature. The remainder condenses in the ammonia chillers. The condensed ammonia is separated from the non-converted gas in the ammonia separator and then sent to a flash vessel.

The cold required for cooling the recycle gas and for condensing the ammonia is generated in a refrigeration unit. The cold is transferred to the gas in a low-temperature cooler with the aid of a suitable refrigerant. It was found that maximum cold duty could be obtained per unit of process fluid is by utilizing the latent heat used for the transition from the liquid to the vapor phase.

The quality of a refrigerant is primarily characterized by its physical and thermal properties which determine its field of application. It is also important to know whether the refrigerant is toxic and to what extent it is not inflammable and not explosive. The refrigerants commonly used are fluorinated and chlorinated hydrocarbons (freons), propylene and ammonia. It is only natural to use the product of an ammonia plant as refrigerant.

## 8.2 The refrigeration unit using the compressor principle

The boiling point of $NH_3$ at atmospheric pressure is -33 °C. Figure 95 illustrates the relationship of ammonia vapor tension and temperature within a range of -33 °C to +20 °C.

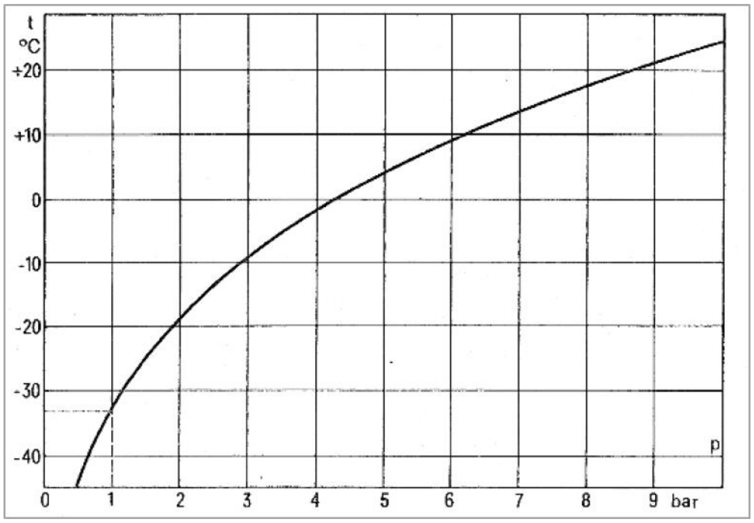


Figure 95. Vapor pressure of ammonia

Basically, every refrigeration unit consists of the evaporator which absorbs ambient heat, thus causing the refrigerant to evaporate at constant temperature and constant pressure. The vaporized refrigerant is withdrawn by a compressor at constant pressure and compressed to liquefaction pressure. The compressed refrigerant vapor is then cooled in a condenser by means of cooling water or air. The refrigerant condenses and is collected in a reservoir, from where it is flashed via a control valve into the evaporator. This completes the circuit and the refrigerant can now be re-evaporated. Figure 96 is a schematic representation of such a refrigeration unit using the compressor principle.

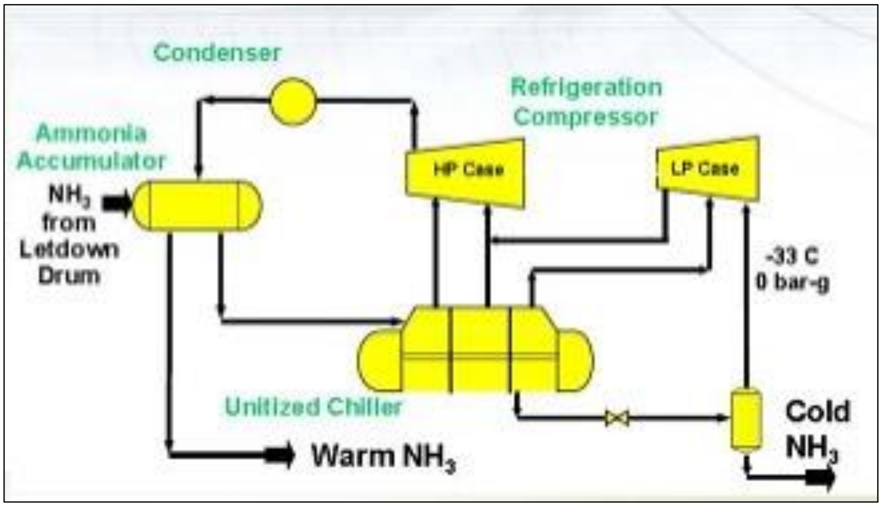


Figure 96. Refrigeration unit

## 8.3 The refrigeration process represented by the i/log p diagram

The refrigeration process described above can be plotted in the form of a graph, in which one axis represents the pressure and the other axis the enthalpy of the refrigerant. Figure 97 shows such a graph.

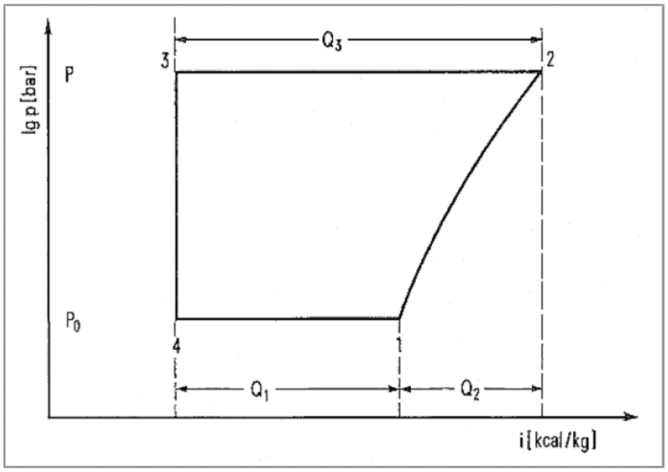


Figure 97. i/log p diagram of the refrigeration process

In the first step, $4 \rightarrow 1$, heat is transferred to the refrigerant at constant pressure. As can be seen from the graph, the enthalpy of the refrigerant increases by $Q_1$. The enthalpy of the fluid to be cooled is reduced by the same amount. In the second step, $1 \rightarrow 2$ , the vaporized refrigerant is compressed. Both pressure and temperature rise. The enthalpy further increases by $Q_2$. The energy required for this purpose is generated by the refrigeration compressor. In the third step, $2 \rightarrow 3$, the vaporized compressed refrigerant is cooled and, consequently, condensed. The enthalpy is reduced by $Q_3$, which is transferred to the cooling water. In the fourth step, $3 \rightarrow 4$, the liquefied refrigerant is flashed to evaporation pressure. On flashing, the enthalpy remains constant.

It can be seen clearly from figure 95 that the evaporation temperature of the refrigerant depends on the pressure prevailing in the evaporator. This pressure can be adjusted by controlling the suction pressure of the refrigeration compressor.

Reciprocating compressors, rotary compressors (helical compressors, Roots blowers) or turbo-compressors may be used as refrigeration compressors. Broadly speaking, it can be said that reciprocating and rotary compressors are best for small and medium sized refrigeration units and turbo-compressors for large units. Further criteria for selecting the compressors are the refrigerant employed and the delivery head. The conditions in the ammonia plant are such that a turbo-compressor can be used for the refrigeration unit. The advantages of a turbo-compressor are: small floor space requirements, no valves, and no other parts subject to wear, low noise, no oil in the refrigerant.

## 8.4 Process description

Cold is required at several points of the ammonia plant. A typical refrigeration unit for a 1000 t/day ammonia plant has the following data for normal operation.

- $NH_3$ chiller I. The chiller works at a pressure of approximately 6 bar and a temperature of +10 °C. It serves to cool the recycle gas from approximately +45 °C to a temperature of +17 °C. By lowering the temperature, a part of the ammonia contained in the gas is condensed. The cold duty of $NH_3$ chiller I is approximately $13.6 \times 10^6$ kcal/h.
- $NH_3$ chiller II. The chiller works at an evaporation pressure of approx. 2.6 bar and a temperature of - 12 °C. It serves to cool the recycle gas from +17 °C to -5 °C and for condensing the ammonia contained in the gas until equilibrium conditions are reached. The cold duty of $NH_3$ chiller II is approx. $7.5 \times 10^6$ kcal/h.

- Furthermore, the $NH_3$ vapors set free in the separator of the tail gas scrubbing unit must be liquefied. The separator operates at a pressure of 6 bar. The cold duty is 0.26 x $10^6$ kcal/h.
- The ammonia condensed in $NH_3$ chillers I and II has a temperature of - 4.5 °C.
- However, the requirement is that the ammonia fed to $NH_3$ storage should have a temperature of -34 °C. The cold duty required for this purpose (1.7 x $10^6$ kcal/h) must likewise be generated in the refrigeration unit.
- Heat losses. All heat losses must be made up by the refrigeration unit. It is therefore designed for a total duty of 23.1 x $10^6$ kcal/h.

The energy required for generating the cold is produced in the refrigeration compressor. The compressor is driven by a steam condensing turbine.

The ammonia vapors are compressed in the refrigeration compressor in three steps:

- The medium-pressure stage raises the pressure of the gaseous ammonia from ammonia chiller I and the flash vessel from 2.6 bar to 6.1 bar.
- The high-pressure stage then compresses the gases to the desired final pressure. Gaseous ammonia from ammonia chiller II and from the flash vessel of the tail gas scrubbing unit is also fed to the third compressor stage and is likewise compressed.

The temperature of the gaseous $NH_3$ is lowered in condensers by means of cooling water sufficiently for condensation to set in. The condensed ammonia flows to the $NH_3$ collecting tank. From here, most of the ammonia (84 t/h) flows to ammonia chillers I and II of the synthesis unit, while a minor amount (8 t/h) is flashed in the $NH_3$ intercooler to 6.1 bar. This causes part of the ammonia to evaporate. As can be seen in figure 2, the resulting temperature is - 12 °C. The gas phase is withdrawn by the medium-pressure stage of the $NH_3$ compressor. The entire quantity of $NH_3$ liquid obtained in the flash vessel of the synthesis unit is likewise fed to the $NH_3$ inter- cooler where some of this ammonia also evaporates by means of flashing from 40 to 6.1 bar.

The liquid obtained in the $NH_3$ inter-cooler is sent via a control valve (LIC) to a flash vessel, where the pressure is further reduced to 0.9 bar and, consequently, the temperature is lowered to - 33 °C. The gas phase is withdrawn by the low pressure stage of the refrigeration compressor and compressed to 2.8 bar. The compressed gas is injected into the sump of the $NH_3$ intercooler, where it is cooled down to saturation state. A proportionate part of liquid is vaporized. The liquid ammonia remaining in the flash vessel is pumped at a temperature of - 33 °C to the ammonia storage facilities.

The liquid ammonia from the ammonia plant always contains a certain quantity of dissolved gases such as $H_2$, $N_2$, Ar and $CH_4$. On being flashed from 40 bar to 6.1 bar, these gases are set free and must be removed from the cycle since they would otherwise become enriched. An increase of the inert gas content would result in an undesirable pressure increase in the cycle. A part stream is therefore continuously withdrawn from the gas phase of the NH3 condensers. The ammonia contained in this gas is condensed in coolers. The residual gases are blown off into the atmosphere. The pressure is controlled by a PIC. The cold is recovered in a gas-gas heat exchanger.

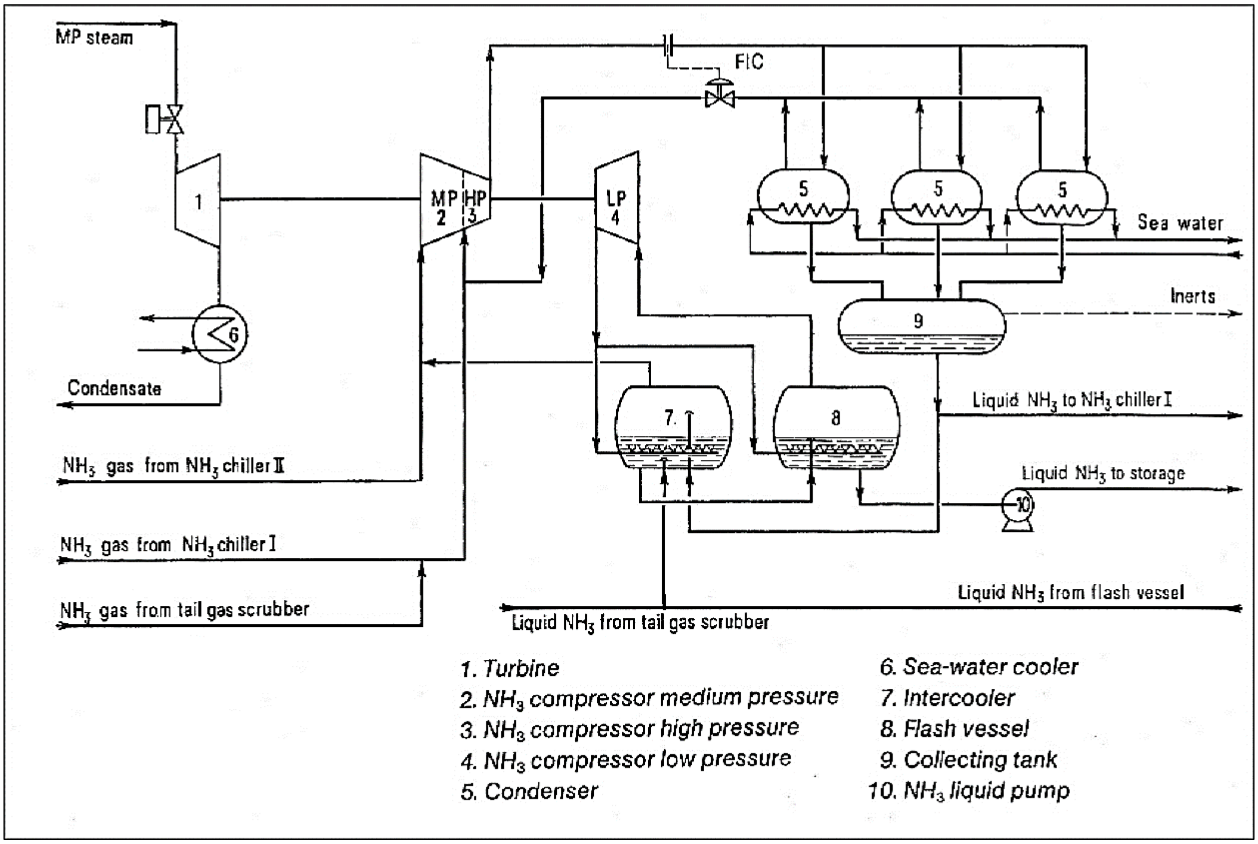


Figure 98. Flow sheet of a refrigeration plant