Multigas: Air Cycle and Air Separation (3 hrs)

Syllabus: Air Separation Unit (ASU) cycle schematic and Temperature versus Entropy (Ts) diagram / compressors/, expanders / isothermal compression/ isentropic expansion / isentropic compression/ isenthalpic expansion

The history and general descriptions of the Air Cycle can be read in
13_chapter2.pdf
78_6_080.pdf
AIR LIQUEFACTION - DISTILLATION.pdf

From McConkey Thermodynamics for Engineering Technicians

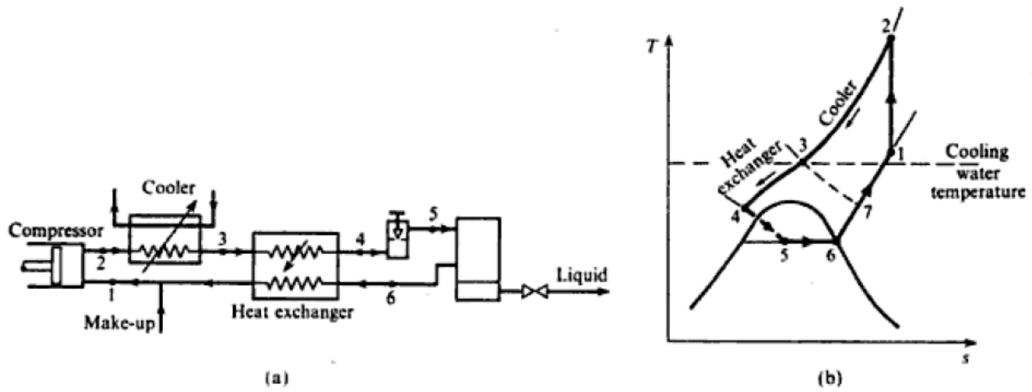

Fig. 14.27 The Linde system for gas liquefaction (a) with the processes on a *T–s* diagram (b)

corresponding *T–s* diagram is shown in Fig. 14.27(b). This is called the ***Linde process.*** The corresponding state points are indicated on both diagrams.

Substances which solidify at a temperature above that of the required liquid temperature must be removed from the gas before admission to the plant. The gas is compressed to a pressure of 100–200 atm before delivery to the cooler. The gas is cooled in the cooler to a temperature which depends on the temperature of the cooling water available. The gas passes through a heat exchanger where heat is transferred from it to the returning low-temperature vapour. It is cooled at 3 to a temperature which is in the region of its critical value and is then throttled to atmospheric pressure, at which pressure it exists as a wet vapour. The liquid is drawn off and the vapour is returned to the compressor. The quantity is made up from an external supply before induction into the compressor.

Lower temperatures could be obtained by replacing the throttling operation with an expansion machine of the turbine type.

From what has been said previously about the throttling of a gas it would appear that the process described in this section is impossible, as there would be no change in the temperature of the gas in throttling and therefore no cooling effect. With real gases there is a small change in temperature on throttling and this may be either an increase or a decrease. At any particular pressure there is a temperature above which the gas will not be reduced in temperature by a throttling process. This temperature is called the *temperature of inversion.*

At the commencement of the Linde process there is no cold gas returning through the heat exchanger and so there will be no cooling effect from 3 to 4. If, however, the temperature at 3 is below the temperature of inversion there will be some cooling as the gas is throttled from 3 to 7. As the process continues the amount of cooling due to returning cold vapour will increase and the line 3–7 will gradually move down to position 4–5. If conventional cooling is not able to cool the gas to below the temperature of inversion then a refrigeration process must first take place to do so.

From Rogers and Mayhew textbook, Engineering Thermodynamics Work and Heat Transfer

The simplest liquification process was first developed by Linde for liquefying

air, and it is illustrated in Fig. 13.12. Air at atmospheric pressure, state 1, is compressed to state 2, and is then cooled at constant pressure back to atmospheric temperature, state 3, in a water cooler. The air is cooled further to state 4 in a heat exchanger before being throttled to state 5. In this state the liquid portion 5_f is drained off and the vapour portion 5_g is taken to the heat exchanger and back to the compressor. To keep the mass of air in the system constant, make-up air, equal in mass to the liquid air drained off, is introduced into the system in state 1.

It is evident that when starting such a plant there is no cold gas in the system, and the throttling process will follow path 3–6. But provided that the gas is below its inversion temperature [see section 7.4 (iv)], a little cooling will occur. This cooling

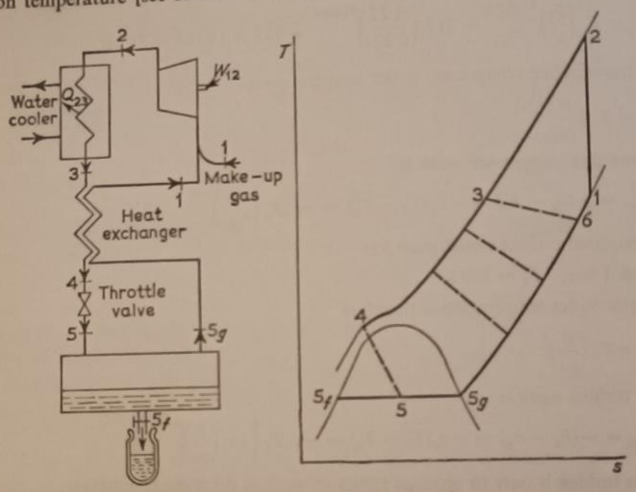

Fig. 13.12 A simple gas liquefaction plant

effect is cumulative, as it is utilised in the heat exchanger, and the throttling curve 3–6 will shift towards path 4–5. The ultimate steady position of state 4 depends on the rate at which liquid is drained off, and on the rate at which heat leaks into the system.

When the gas to be liquefied has an inversion temperature below atmospheric, it is necessary to precool the gas below its inversion temperature with a conventional refrigerator, or to replace the throttle valve with an expansion machine. The reason why a throttle valve has been preferred to an expansion machine is that it is difficult to construct a machine which will work satisfactorily at very low temperatures. Using new materials, suitable expanders have been built in recent years, and much better plant efficiencies can now be obtained. The subject of low-temperature engineering—called *cryogenics*—is of increasing importance but it is outside the scope of this book. A survey of recent work in this field can be found in Ref. (13).

From AIR LIQUEFACTION - DISTILLATION.pdf

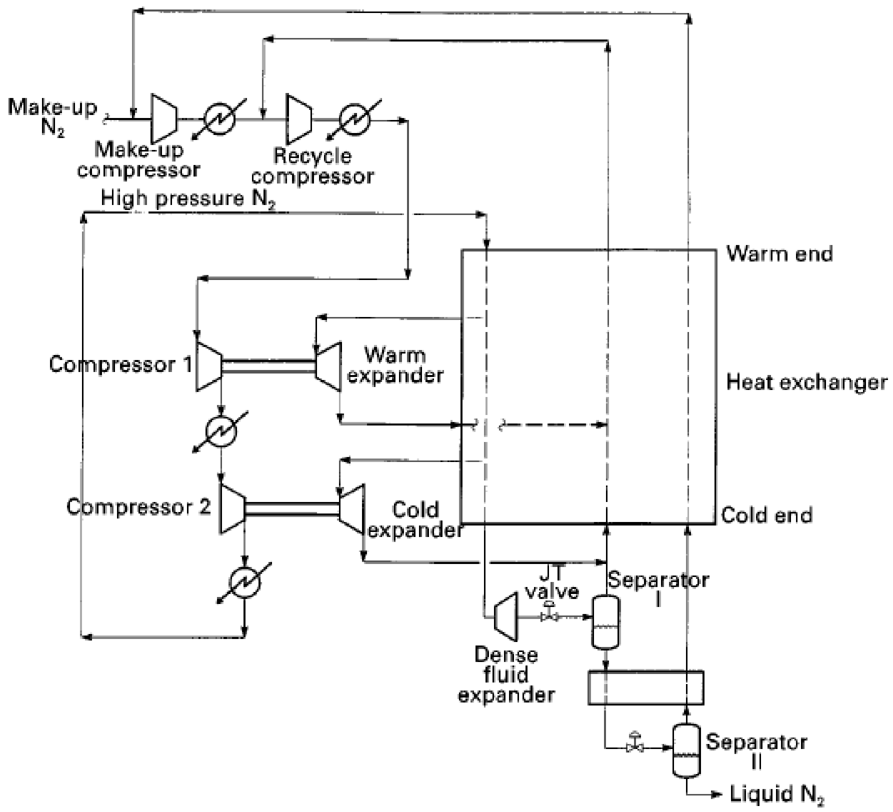

Figure 11 A nitrogen liquefier.

In Figure 11, if none of the expanders are used then the liquefaction process reduces to the one proposed by Carl von Linde. On the other hand, if the warm expander and the dense fluid expander are removed, then the resulting process is similar to the one used by Georges Claude.