Unit 4 Cryogenics

1. Explain Joule–Thomson expansion

The Joule–Thomson effect describes the increase or decrease in the temperature of a real gas (as differentiated from an ideal gas) or a liquid when allowed to expand freely through a valve or other throttling device while kept insulated so that no heat is transferred to or from the fluid, and no external mechanical work is extracted from the fluid. The Joule–Thomson effect is an *isenthalpic process*, meaning that the *enthalpy* of the fluid is constant (i.e., does not change) during the process.

Joule–Thomson inversion temperature

Similar to liquids, gases can also be expanded from high pressure to low pressure either by using a turbine (isentropic expansion) or a throttling device (isenthalpic process). Similar to throttling of liquids, the throttling of gases is also an isenthalpic process. Since the enthalpy of an ideal gas is a function of temperature only, during an isenthalpic process, the temperature of the ideal gas remains constant. In case of real gases, whether the temperature decreases or increases during the isenthalpic throttling process depends on a property of the gas called Joule-Thomson coefficient, given by:

$$\mu_{JT} = \left(\frac{\partial T}{dp}\right)_h$$

For all real gases, it will equal zero at some point called the inversion point and, as explained above, the Joule–Thomson inversion temperature is the temperature where the coefficient changes sign (i.e., where the coefficient equals zero). The Joule–Thomson inversion temperature depends on the pressure of the gas before expansion.

In any gas expansion, the gas pressure decreases and thus the sign of ∂P is always negative. With that in mind, the following table explains when the Joule–Thomson effect cools or heats a real gas:

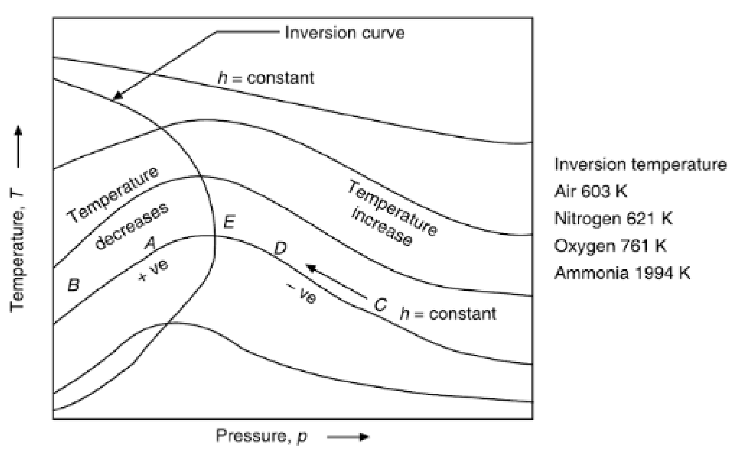
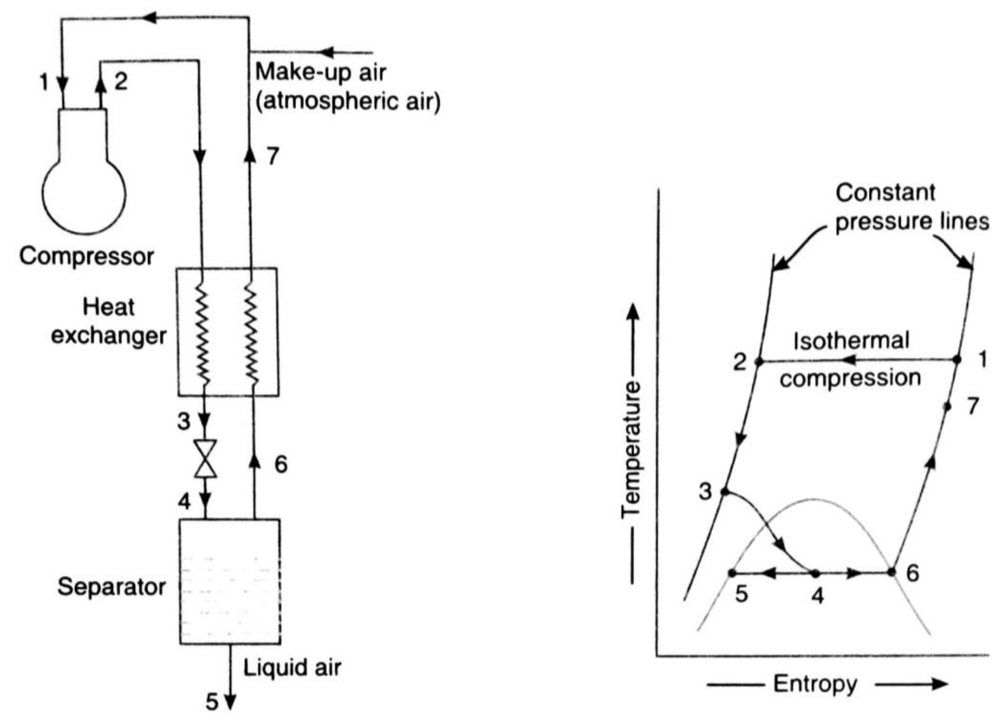


Figure 16.2 Isenthalpic expansion of a real gas.

If the gas temperature is	then μ_{JT} is	since ∂P is	thus ∂T must be	so the gas
below the inversion temperature	positive	always negative	negative	cools
above the inversion temperature	negative	always negative	positive	heats

2. Explain with neat sketch Linde liquification system

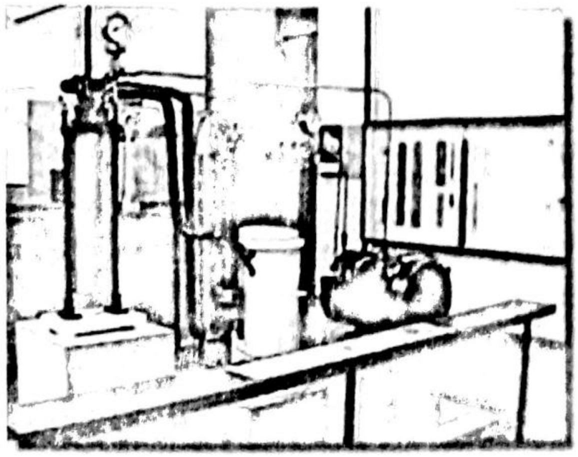
The liquefaction of air is an important industrial process not only for the production of liquid air but also in the separation of oxygen, nitrogen, hydrogen, helium and many other gases from the atmosphere by fractional distillation.



(*a*) Linde system. (*b*) *T-s* diagram.

Fig. 14.11

The simplest method of air liquefaction is the *Linde* or *Hampson system*, as shown in Fig. 14.11 (*a*). The equipment includes a compressor, a heat exchanger and a separator. In this system, the atmospheric air is compressed isothermally in a compressor between points 1 and 2 to pressure of 100 to 200 atmosphere. This high pressure air is cooled to about –106.7°C in the heat exchanger between points 2 and 3. The cooled air from the heat exchanger is throttled between points 3 and 4 to atmospheric pressure and a temperature of –190°C. A portion of the air is liquefied and removed from the separator at point 5. The remainder of the cold air leaves the separator at point 6 and returns to the compressor through the heat exchanger where it cools the incoming high pressure air. The make-up air from the atmosphere (equal to the amount of air liquefied) is also supplied to the compressor along with the air removed from the heat exchanger at point 7. The Linde process is represented on temperature-entropy diagram as shown in Fig. 14.11 (*b*).



Liquefaction of air.

Let m_2 = Mass of air compressed in the compressor or mass of high pressure air passing through the heat exchanger between points 2 and 3,

m_5 = Mass of air liquefied in the separator, and

m_6 = Mass of low pressure air in passing through the heat exchanger between points 6 and 1 = $m_2 - m_5$

Now for the heat balance of the heat exchanger,

$$m_2(h_2 - h_3) = m_6(h_1 - h_6)$$

$$= (m_2 - m_5)(h_1 - h_6) \quad \ldots (\because m_6 = m_2 - m_5) \qquad \ldots (i)$$

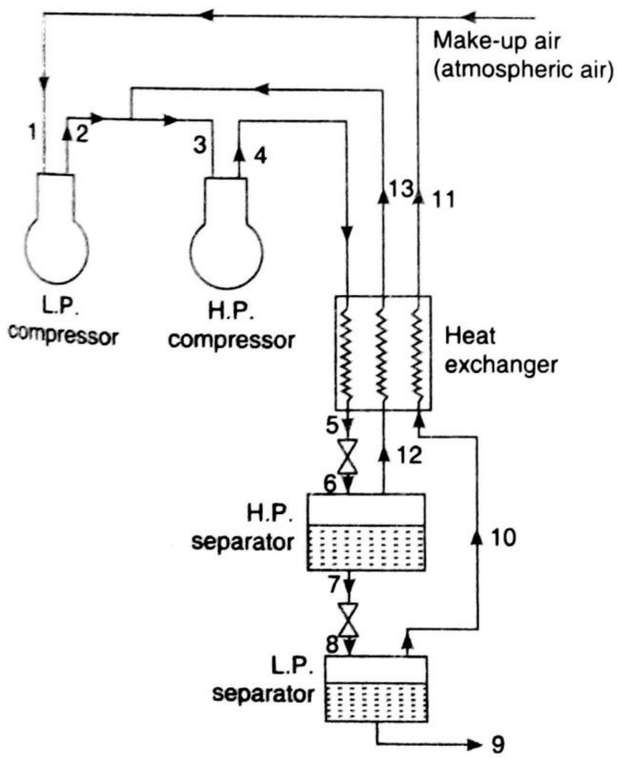
and for the heat balance of the separator,

$$m_2 h_4 = m_5 h_5 + m_6 h_6 = m_5 h_5 + (m_2 - m_5)\, h_6 \qquad \ldots (ii)$$

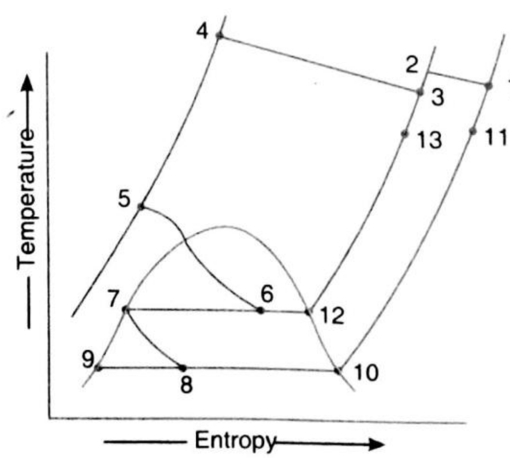
Since the process 3-4 is a throttling process, therefore

$$h_3 = h_4 \qquad \ldots (iii)$$

From equations (*i*) and (*ii*), the mass of air liquefied by the Linde process may be obtained.

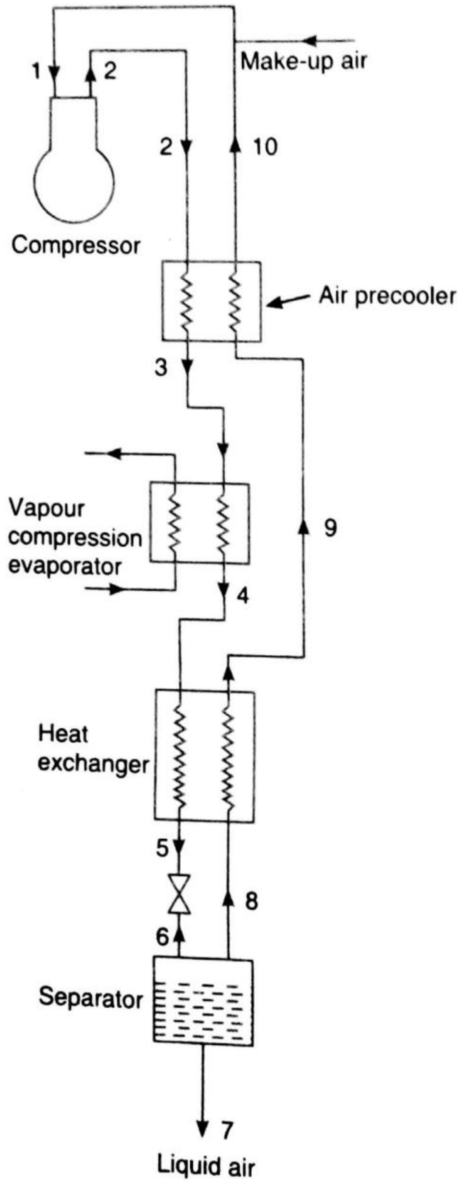


(*a*) Dual pressure Linde system.

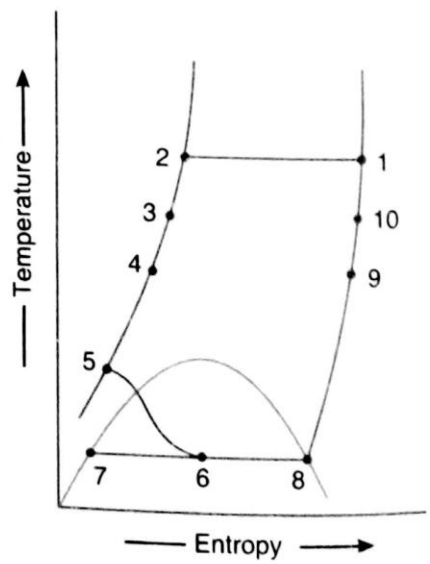


(*b*) *T-s* diagram for dual pressure Linde system.

The simple Linde or Hampson system for liquefying air is comparatively inefficient and is used only when small quantity of liquid air is needed. In order to increase the efficiency, a dual pressure Linde system as shown in Fig. 14.12 (*a*) is used. Its corresponding *T-s* diagram is shown in Fig. 14.12 (*b*). In this system, a portion of the gas after the first throttling process from point 5 to point 6 is bled back through a heat exchanger into the discharge of the first (low pressure) stage of compression. The increased economy results from this system because the majority of the gas undergoes only one expansion to the intermediate pressure and one compression from this intermediate pressure to the high pressure.



(*a*) Linde system with precooling by vapour compression system evaporator.



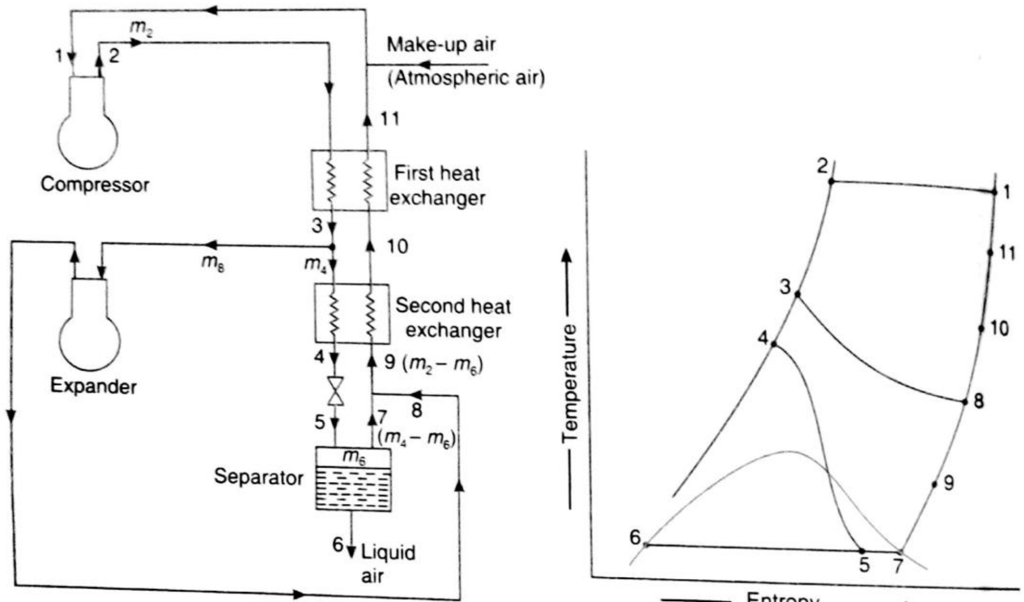
(*b*) *T-s* diagram.

Fig. 14.13

3. Explain Claude liquification system

The Claude air liquefaction system differs from the simple Linde system by the addition of an expander and a second heat exchanger as shown in Fig. 14.15 (*a*). In this system, the air is compressed isothermally in a compressor to approximately 40 atmospheres between points 1 and 2. This high pressure air is partially cooled by passing through the first heat exchanger between points 2 and 3.

A portion of air (about 80 per cent) at point 3 is bled and cooled by expansion in an expander between points 3 and 8. The remaining portion of air (*i.e.* 20 per cent) passes through the second heat exchanger between points 3 and 4. The air from the second heat exchanger is throttled irreversibly between points 4 and 5 at atmospheric pressure. The liquid air is removed from the separator at point 6. The low temperature air from the expander at point 8 is mixed with the unliquefied air from the separator at point 7, giving increased mass flow of air at point 9. This air passes back through the two heat exchangers to the compressor. The *T-s* diagram for the Claude air liquefaction system is shown in Fig. 14.15 (*b*).



(*a*) Claude system for air liquefaction.

(*b*) *T-s* diagram for Claude air liquefaction system.

Fig. 14.15

The Claude system is more efficient than the Linde system because the expansion of air in the expander results in lower temperature than the Linde system.

Let

m_2 = Mass of compressed air,

m_8 = Mass of air bypassed to expander,

m_4 = Mass of air passing through the second heat exchanger $= m_2 - m_8$, and

m_6 = Mass of air liquefied in the separator,

Now for the heat balance of the first heat exchanger,

$$m_2 (h_2 - h_3) = (m_2 - m_6)(h_1 - h_{10}) \quad \dots (i)$$

For the heat balance of the second heat exchanger

$$m_4 (h_3 - h_4) = (m_2 - m_6)(h_{10} - h_9) \quad \dots (ii)$$

and for the heat balance of the separator,

$$m_4 h_5 = m_6 h_6 + (m_4 - m_6) h_7 \quad \dots (iii)$$

The air from the expander at point 8 is mixed with the unliquefied air from the separator at point 7. The combined condition of air is represented by point 9 on the *T-s* diagram as shown in Fig. 14.15 (*b*). The enthalpy at point 9 is given by

$$(m_4 - m_6 + m_8) h_9 = m_8 h_8 + (m_4 - m_6) h_7$$

$$\therefore \quad h_9 = \frac{m_8 h_8 + (m_4 - m_6) h_7}{m_4 - m_6 + m_8} = \frac{m_8 h_8 + (m_4 - m_6) h_7}{m_2 - m_6} \quad \dots (iv)$$

$$\dots (\because m_4 = m_2 - m_8)$$

From the above expressions, we may find out the mass of air liquefied by the Claude system

Advantages of Claude system over Linde system

The following are the advantages of Claude system over Linde system for the liquefaction of gases :

1. In Claude system, the air is to be compressed only up to 40 atmospheres, as compared to 100-200 atmospheres in Linde system.
2. About 80 per cent of the air is expanded reversibly in the expander and the remaining 20 per cent of the compressed air is subjected to irreversible throttling. In Linde system, all the air is throttled irreversibly.
3. Claude system gives an enhanced liquefaction.
4. The specific work of Claude system is less than that of simple Linde system.

4. Explain the various Cryogenics Applications

Superconductivity:- The first property he investigated was the electrical resistance of metals. Electrical resistance is the tendency of a substance to prevent the flow of an electrical current through it. Scientists had long known that electrical resistance tends to decrease with decreasing temperature. They assumed that resistance would completely disappear at absolute zero.

Research in this area had great practical importance. All electrical appliances (ovens, toasters, television sets, and radios, for example) operate with low efficiency because so much energy is wasted in overcoming electrical resistance. An appliance with no electrical resistance could operate at much less cost than existing appliances.

In some metals, electrical resistance drops to zero very suddenly at temperatures above absolute zero. The effect is called superconductivity and has some very important applications in today's world. For example, superconductors are used to make magnets for particle accelerators (devices used, among other things, to study subatomic particles such as electrons and protons) and for magnetic resonance imaging (MRI) systems (a diagnostic tool used in many hospitals).

The discovery of superconductivity led other scientists to study a variety of material properties at cryogenic temperatures. Today, physicists, chemists, material scientists, and biologists study the properties of metals, as well as the properties of insulators, semiconductors, plastics, composites, and living tissue. Over the years, this research has resulted in the identification of a number of useful properties. One such property common to most materials that are subjected to extremely low temperatures is brittleness. The recycling industry takes advantage of this by immersing recyclables in liquid nitrogen, after which they are easily pulverized and separated for reprocessing.

Still another cryogenic material property that is sometimes useful is that of thermal contraction. Materials shrink when cooled. To a point (about the temperature of liquid nitrogen), the colder a material gets the more it shrinks. An example is the use of liquid nitrogen in the assembly of some automobile engines. In order to get extremely tight fits when installing valve seats, for instance, the seats are cooled to liquid nitrogen temperatures, whereupon they contract and are easily inserted in the engine head. When they warm up, a perfect fit results.

Space:-Cryogenic liquids are also used in the space program. For example, cryogenic materials are used to propel rockets into space. A tank of liquid hydrogen provides the fuel to be burned and a second tank of liquid oxygen is provided for combustion.

Another space application of cryogenics is the use of liquid helium to cool orbiting infrared telescopes. Infrared telescopes detect objects in space not from the light they give off but from the infrared radiation (heat) they emit. However, the operation of the telescope itself also gives off heat. What can be done to prevent the instrument from being blinded by its own heat to the infrared radiation from stars? The answer is to cool parts of the telescope with liquid helium. At the temperature of liquid helium (1.8 K) the telescope can easily pick up infrared radiation of the stars, whose temperature is about 3 K.

Medical Applications

Cryogenics has also been used by the medical industry. Surgical tools used by doctors, surgeons, dentists, and other specialists can all benefit from the increased wear resistance of the treatment. Surgical tools, like many other industrial tools, are expensive to replace, so cryogenic treatment can really pay off. In addition, many surgical implants are also treated. This helps prevent the part from wearing, it increases the tensile and bending strength of the part, as well as reducing the likelyhood of mircofracturing. Cryogenics really is a healthy choice for the medical field.

Other applications of cryogenics include fast freezing of some foods and the preservation of some biological materials such as livestock semen as well as human blood, tissue, and embryos. The practice of freezing an entire human body after death in the hope of later restoring life is known as cryonics, but it is not an accepted scientific application of cryogenics. The freezing of portions of the body to destroy unwanted or malfunctioning tissue is known as cryosurgery. It is used to treat cancers and abnormalities of the skin, cervix, uterus, prostate gland, and liver.

Industrial Applications

Cryogenic treatment works on Reamers (carbide or HSS), Tool Bits, Tool Punches (carbide or HSS), Carbide Drills, Carbide Cutters, Milling Cutters, Files, Shaping Equipment, Scissors, Razors, Clippers, Knives, Band Saw Blades, Saw Blades, Reciprocating Blades, Saber Saw, Steel Woodworking and Form Tooling, Cutting Tools and Dies. In all cases, this treatment will result a stronger and more wear resistant metal.

Automotive Applications

Imagine a racer and crew who would normally tear down their engine after every race or two, suddenly discovering a process that would allow them to safely go up to 30 races or more without a major rebuild. Cryogenic treatment of automotive parts can certainly help make this a reality.

Cryogenics works with almost all metal engine parts. Pistons, rings, rockers, push rods, connecting rods, valves, the crank and camshaft and even the block itself. Together, a treated engine can last substancially longer in terms of wear than any other process could achieve. Even parts like brake rotors, drums, and brake pads can benefit from cryogenic treatment. Really, almost any part that is normally subject to wear can benefit. Just imagine what cryogenic treatment would do for the parts in your family vehicle!

Other Applications

Cryogenics is used to treat many types of sports equipment, the most common being golf clubs. Because cryogenics increases the molecular density of treated materials, it improves the distribution of energy (in this case kenetic energy) through the object. The treatment also increases the rigidity of the metal, which in this case might affect the shaft of the golf club. Combined, the increases in kenetic energy distribution and rigidity of the shaft make for a longer and straighter drive. Basically, the club has significantly less give, so the performance increases. This type of treatment can be used on many other types of sports equipment where the same energy and rigidity characteristics would benefit the user.

Cryogenics is also used to treat many types of musical instruments. Because treated materials are denser, the surface area of an object is affected. Inside the instrument, the surface is smoother than an untreated instrument. This change in surface characteristics changes the quality of sound that the instrument can produce. In most cases, a crisper, clearer sound is acheived, especially amongst the brass section of instruments. The same type of effect can also be useful in stringed instruments by treating the strings themselves. There really is no end to the numerous ways cryogenics can assist, both at work and at play.