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CRYOGENICS: A Brief Review

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Abstract: This paper is a review work of Cryogenics. In this paper, a brief introduction of cryogenics and its applications have been discussed. This paper describes the different gas liquefaction cryogenics system and their configuration. The basic system methodologies like Joule Thomson effect and adiabatic expansion is also discussed in it.

Indexing: Cryogenics, Liquid Nitrogen, FOM, Linde- Hampson System

1. INTRODUCTION

The word cryogenics originates means "the production of freezing cold". It has the Greek origination.[1-5]. The word cryogenics has been taken from Greek language where "cryos" means frost or cold and "gen" is the common root for the English verb "to generate" [1-5].It is not well-defined that at what point on the temperature scale, refrigeration ends and cryogenics begins, but most scientist assume, that it starts at or below -150 °C or 123 K (about -240 °F). The National Institute of Standards and Technology at Boulder, Colorado has chosen to consider the field of cryogenics as that of involving temperatures below −180 °C (-292 °F or 93.15 K). This is a logical dividing line, since the normal boiling points of the so-called permanent gases (such as helium, hydrogen, neon, nitrogen, oxygen, and normal air) lie below −180 °C while the Freon refrigerants, hydrogen sulfide, and other common refrigerants have boiling points above −180 °C[1-5].

Table 1 Liquefaction Temperatures for some gases [1]

System	CH_4	O_2	Ar	CO_2	N_2	H_2	He
Temp (K)	111.7	90.1	87.4	81.1	77.3	20.2	4.3

2. GAS LIQUEFACTION SYSTEMS

In order to convert a gas into a liquid state, the Liquefaction of gases goes through a number of phases. Liquefaction has many purposes to serve. The process of Liquefaction is used for scientific, industrial and commercial purposes. Many gases can be put into a liquid state at normal atmospheric pressure by simple cooling; a few, such as carbon dioxide, require pressurization as well. Liquefaction is used for analyzing the fundamental properties of gas molecules (intermolecular forces), for storage of gases, for example: LPG, and in refrigeration and air conditioning. In refrigeration and air-conditioning, the gas is liquefied in the condenser, where the heat of vaporization is released, and evaporated in the evaporator, where the heat of vaporization is absorbed. Ammonia was the first such refrigerant, but it has been replaced by compounds derived from petroleum and halogens.

Talking about the medical purposes, the Liquid oxygen is provided to hospitals for patients suffering from breathing problems, and liquid nitrogen is used by the dermatologists and by inseminators to freeze semen. Liquefied chlorine is transported for eventual solution in water, after which it is used for water purification, sanitation of industrial waste, sewage and swimming pools, bleaching of pulp and textiles and manufacture of carbon tetrachloride, glycol and numerous other organic compounds.

Liquefaction of helium (4He) with the Hamps on-Linde cycle led to a Nobel Prize for Heike Kamerlingh Onnes in 1913. At ambient pressure, the boiling point of liquefied helium is 4.22 K (-268.93°C). Below 2.17 K liquid 4, it has many amazing properties, such as climbing the walls of the vessel, exhibiting zero viscosity, and offering no lift to a wing past which it flows.

2.1 Production of low temperatures

2.1.1 Joule Thompson effect [2]

The Joule Thompson valve is used to produce low temperatures and most of the practical liquefaction systems utilize an expansion valve or a Joule Thomson valve to produce low temperatures. When the first law for steady flow is applied to the expansion valve, for zero heat transfer and zero work transfer and for negligible kinetic and potential changes, we find h1= h2 .Although the flow within the valve is irreversible and is not an isenthalpic process, the inlet and the outlet do lie on the same enthalpy curve. We note that there is a region in which an expansion through the valve produces an increase in temperature, while in another region the expansion results in a decrease in temperature. Obviously we should operate the expansion valve in a liquefaction system in the region where there is a net decrease in temperature results. The curve that separates two regions is called the inversion curve. The effect of change in temperature for an isenthalpic change in pressure is represented by the Joule-Thompson coefficient.

2.2 Existing Gas liquefaction systems

1: Simple Linde-Hampson system
2: Precooled Linde Hampson system
3: Linde dual pressure system
4: Cascade system

2.2.1Simple Linde-Hampson system

Another system used to liquefy gases is the Linde-Hampson system (the cascade system was the first), and the the simplest of all the liquefaction system. The diagram is show in Figure 1 and cycle is show in T-S plane in Figure 2.
A basic differentiation between the various refrigeration cycles lies in the expansion device. This may be either an expansion engine like expansion turbine or reciprocating expansion engine or a throttling valve. The expansion engine approaches an isentropic process and the valve an isenthalpic process. Isentropic expansion implies an adiabatic reversible process while isenthalpic expansions are irreversible.

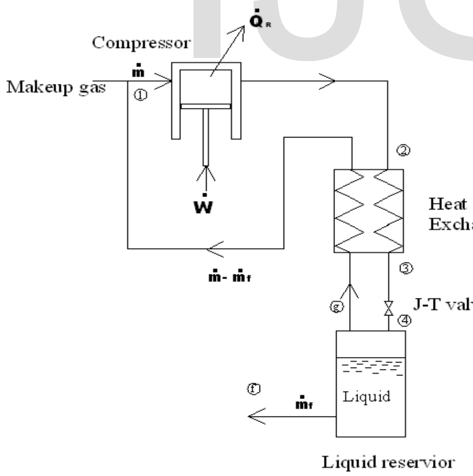

Fig. 1 Linde-Hampson System

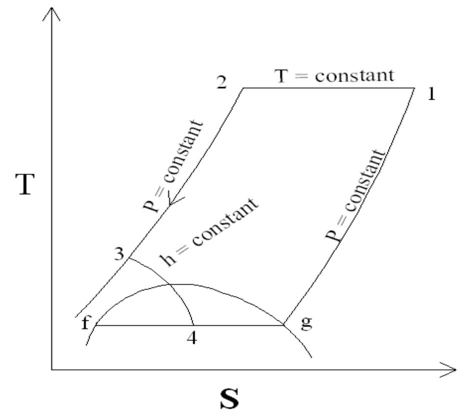

Fig. 2 Linde-Hampsonliquefication cycle(T-s plot)[1-5]

3 ADIABATIC EXPANSION

The second method of producing low temperatures is the adiabatic expansion of the gas through a work producing device, such as an expansion engine. In the ideal case, the expansion would be reversible and adiabatic and therefore isentropic. In this case we can define the isentropic coefficient which expresses the temperature change due to a pressure change at constant entropy.

3.1Working Principle of adiabatic expansion system

There lies another method which is thermodynamically more efficient method to achieve the cooling of a liquid–gas system. It is to make the fluid do the expansion work. If done carefully, this kind of expansion can be nearly adiabatic and reversible, thereby approaching an isentropic process, $\Delta S=0$. Since the Carnot cycle is comprised of isothermal and isentropic stages, it is clear that the expansion by the performance of work is a very good method to produce cooling. In the isentropic expansion systems energy is removed from the gas stream by allowing it to do some work in an expansion engine or an expander. If the expansion engine is reversible and adiabatic, the expansion process is isentropic and a much lower temperature is attained than that for an isenthalpic expansion.

Some systems like Claude, Kapitza and Heylandt the basic principle cycle involve both isentropic and isenthalpic expansion procedure

1: The Claude system
2: The Kaptiza system
3: The Heylandt

3.1.1The Kapitza system

Kapitza (1939) modified the basic Claude system by eliminating the third heat exchanger or low temperature heat exchanger. Several notable practical modifications were also introduced in this system. A rotary expansion engine was used instead of reciprocating expander. The first or high temperature heat exchanger in the kapitza system was actually a set of valved regenerators, which combined the cooling process with the purification process. The incoming warm gas was cooled in one unit and impurities were deposited there, while the outgoing stream warmed up in the other unit and flushed out the frozen impurities deposited in it. Kapitza did a careful analysis of turbo-refrigeration and developed radial flow turbines for air refrigeration.

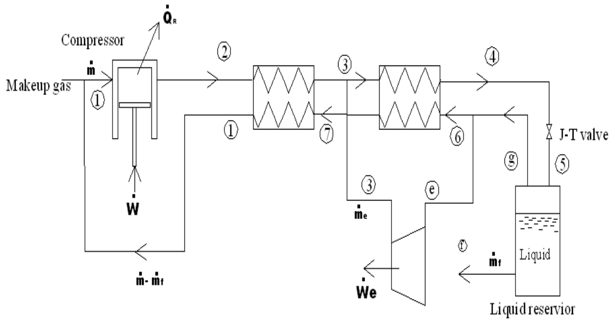

Fig. 3 Kapitza system[1,2,3,6]

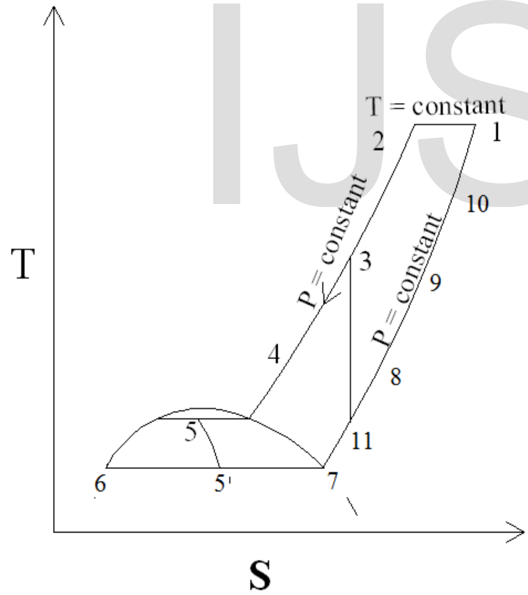

Fig. 4 Kapitza cycle on T-s plane [1,2,3]

Advantages

1. A rotary expansion engine of high isentropic efficiency is used instead of reciprocating engine as in Claude cycle.

2. First heat éxchanger is replaced by a set of valved regenerators which combined the cooling process with purification process.

3. Kapitza cycle can be operated at relatively low pressure is lower than critical pressure of nitogen gas.

4 FIGURE OF MERIT (FOM)

4.1FOM for Liquefaction Systems

Figure of merit: It is defined as the theoretical work requirement divided by actual work requirement for the system.

$$FOM = \frac{\dot{W}\_i/\dot{m}}{\dot{W}/\dot{m}_f}$$

(1)

$\dot{W}\_i/\dot{m}$ = Ideal work required per unit mass of gas.

$\dot{W}/\dot{m}_f$ = actual work required per unit mass of gas liquefied.

The figure of merit is a number between 0 and 1.It gives measure of how closely the actual system approaches the ideal system performance .If the figure of merit greater than unity, it would be in violation of the second law of thermodynamics. The above equation is of FOM is for liquefaction system.

4.2 FOM for Cryogenic Refrigeration Systems

COP = Coefficient of Performance for actual system

COP_i= Coefficient of Performance for Carnot refrigerator.

Figure of merit: $$FOM = \frac{COP}{COP_i}$$

(2)

5 APPLICATION OF LIQUID NITROGEN

1 Deflating of molded rubber parts requires a process known as CRYOTRIM.

2. Refrigeration for trucks, trailers, and railroad carts for in-transit preservation of fruits, vegetables, meats, and other perishable food items requires a process known as CRYO-GUARD.

3. Freezing of baked goods, shrimp, meats, soups, and so on requires a process known as CRYO-QUICK in the food processing industry.

4. Liquid nitrogen is widely used in food processing and food transportation because of minimum production costs.

5. Liquid nitrogen is used in the medical industry with many applications. It is used to remove warts and other skin lesions. Liquid nitrogen used in cryotherapy for removing

unsightly or potentially malignant skin lesions such as warts and actinic keratosis.

6. Liquid nitrogen is also used to preserve blood, sperm, eggs and other biological samples such as tissue samples.
7. It is also used in cryonic preservation when humans or pets are preserved in the hope that technological advances will lead to future reanimation.

8. It is also an important coolant used in applications such as; computers, CCD cameras in astronomy, in a high-temperature superconductor, in controlled-evaporation processes in chemistry vacuum pump traps and infrared homing missiles.

9. Liquid nitrogen used as coolant to increase the sensitivity of infrared homing seeker heads of missiles such as the Strela 3.

10. Liquid nitrogen used in food preparation, such as for making ultra-smooth ice creams, freezing of food (e.g. hamburgers).

11. Liquid nitrogen used in a Cryophorus to demonstrate rapid freezing by evaporation.

12. Pressurization of plastic bottles and aluminium cans containing drinks: a small quantity of LN is injected into the liquid just before sealing the bottle. The LN vaporizes and produces a pressure slightly above the atmospheric pressure, which makes the container very strong and capable of standing piling up (10mm^3 of LN in a bottle with 10cm^3 over the liquid produces an overpressure of about 0.5 atm);
13. Fixing of pipelines by freezing the liquid on either side of the leak, without emptying the whole system;
14. Ground freezing, to allow excavation and tunnelling operation in wet unstable soils.
15. Deflashing of moulded polymer products: deflashing can be obtained by a tumbling, process rather than by treating each piece individually;
16. Heat treatment of metals, e.g. steel tools to improve the wear resistance, temper of musical instruments, etc.;
17. The way how the solid explosive and bomb disposal works: freezing of explosives makes them temporarily harmless;

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