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Thermodynamic Analysis of Linde System for Liquefaction of Gases

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Abstract

Cryogenics systems are which are capable of producing temperature below -150 .Linde cryogenics cycle is carefully observe and various gases are liquefy by it. A comprehensive exergy analysis and other analysis of linde system is carried out by using various different gases with variable properties. Numerical computation is carried out to find out mutually dependency and effect of various properties on other properties and their involvement in exergydestruction. It was observed that inlet properties and every part performance put huge impact on overall out of system Inlet pressure ranging from 3 to 6 bar and inlet Temperature at 298 K while compressor pressure ranging from 300 to 400 bar is optimum values of performance parameters for linde system.

Nome culture

m_2=mass of air compressed I compressor
m_5=mass of liquefied in the separator
m_6=mass of low pressure air passing through heat exchanger
h=Enthalpy
s=Entropy
X=Dryness fraction
T=temperature
P=Pressure
η_{comp}=Efficiency of compressor (approx. 80%)
$\eta_{2nd\ law}$=Second law efficiency
ε=Effectiveness of heat exchanger (approx. 80%)
C=Specific heat capacity fluid or gas
W_t=Work of reversible isothermal compression
W_{comp} =Shaft work supplied to compressor per unit mass
R=Universal gas constant

1. Introduction

Cryogenics is a process producing very low temperature (Below -150 or 123 K), But according to National Institute of Standard and Technology Boulder, Colorado the temperature of cryogenics is start below from -180 (93.15 K) ,This Temperature consider as the dividing line because boiling point of permanent gases (helium, hydrogen, oxygen, nitrogen and air like gases).Various process are design and invent to achieve cryo temperature at different level of lower temperature Cryogenics is used in various important process at different level with different naming like cryobiology, cryonics, cryo-electronics, cryotrons, cryosurgery etc. The liquefy gases are store in special containers called Dewar flask. To transfer this liquid from carrier to tank the pump which used are called cryogenics transfer pumps. Cyogenic Process to liquefy air which is further extent to extract various particular gases like oxygen, nitrogen, feronetc. Today cryogenics industries are a billionaire industry and lots of research is going on to achieve best one improved process. Always various analyses is done to identify the loop hole of process and to rectify it to their upper level. Various research and different method are employed to increase efficiency of cryo system. Second law efficiency are very low in all system, it value ranging from 3% to 23 % for most of systems. Advance technology like different cryofluid includesnano one (nano fluid and nano lubricants) is also tried to reduces the losses.

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Ceramic technology is also used in separator to increase the high output with less losses. Low increase in exergy efficiency is noticed in various different systems. Exergy efficiency are mainly depend upon the inlet condition of system and in most of cases the inlet conditions are NTP (normal temperature pressure) conditions that is 298 K temperature and one atmosphere pressure.

Except to increase the whole system efficiency stress are done on particular parts of system and research are done on that systems. Air separation unit and compressor, condenser and evaporator of cryo system are the center of research because most of exergy destruction takes place in these parts. This paper mainly dealed with thermodynamic (exergy and anergy) analysis of Linde system for determining the effect of every component of system with varying conditions for maximum second law efficiency.

2. Literature Review

In last several decades, exergy analysis has used for system optimization. Exergy analysis is power tool in thermal engineering which not only show the loop hole but give us the idea about how much a system is useful corresponding our input. Exergy and anergy are two terms mostly used get idea of feasibility of a process economically. Exergy is define as the availability of maximum useful work that can be obtained from a system in a given environment conditions. In exergy analysis exergy destruction of each component is noted and efforts are put to minimize them. Irreversibility is just the two face of a coin it also represent exergy destroyed, waste potential and represent energy that could not converted into work except wasted. So irreversibility which always should keep low as possible as an optimizer can do without effecting other properties. In the analyses of open cycle desiccant cooling systems, The analysis shows that an exergy analysis can provide some useful information with respect to the theoretical upper limit of the system performance, which cannot be obtained from an energy analysis alone. The analysis allows the determination of the sites with the losses of exergy, and therefore showing the direction for the minimization of exergy losses to approach the reversible COP [1].

Various research are done to examine the exergy losses in a process and It is found that the evaporating and condensing temperatures have strong effects on the exergy losses in the evaporator and condenser, and on the second law of efficiency and COP of the cycle but little effects on the exergy losses in the compressor and the expansion valve. The second law efficiency and the COP increases, and the total exergy loss decreases with decreasing temperature difference between the evaporator and refrigerated space and between the condenser and outside air[2] and if advance technology like Nano fluid include it noiced that Nano fluid and Nano lubricant cause to reduce the exergy losses in the compressor indirectly [3].

Various components are taken under studied and ASU (air separation unit) using distillation columns are one of the main methods used for separating air components. Exergy analysis, inefficiencies were identified in the distillation system for an efficient cryogenic air separation plant producing large-tonnage quantities of nitrogen [4]. Exergy efficiency of a double diabetic column, with heat transfer all through the length of the column, is 23% higher than that of the conventional adiabatic double columns. In a simple adiabatic distillation column, most of the exergy losses occur in the column itself (57%) [5].Now as advancement goes on technology switching toward more efficient method of separation; polymeric membrane and membrane on ceramic technology are used for separating oxygen [6].

Number of parameters for optimization are taken but still compressor are the main element which determining the energy parameters of low cryogenic technology. So, we have to first eliminate not only compressor part but use of all these type of machines which are not only efficient but also eco friendly too. In other word, the problem of making a transiting to new cooling principles is critical and for this one of the most promising alternatives may be electro caloric cooling [7]. Lindehampson cycle is one of the oldest and very prominent type of process which cryo technology used form last decades efficiently but its low mass producing inefficiency still a major drawback in advancement of Linde cycle. Linde cycle is suitable for large number of gases liquefaction. It is shown that more than half of the exergy loss takes place in the liquefaction unit and almost one-third in the air compression unit. Minor exergy losses are taking place in the distillation unit and the main heat exchanger. The major cause of exergy loss is the use of compressors and to a lesser extent the use of turbines [8].

3. Thermodynamic analysis of Linde system for liquefaction of gases

Compressor work

$$\eta_{comp} = \frac{W_t}{W_{comp}} \quad (1)$$

$$W_t = mRTln\frac{P_2}{P_1} \quad (2)$$

$$W_{comp} = h_2 - h_1 - T_1 (s_2 - s_1) \quad (3)$$

$$W_{reversible} = W_{actual} - T_0 s_{gen} \quad (4)$$

$$W_{actual} = \frac{W_{comp}}{x} \quad (5)$$

$$W_{reversible} = h_5 - h_1 - T_0 (s_5 - s_1) \quad (6)$$

Heat Exchanger

$$m_2(h_2 - h_3) = m_6(h_1 - h_6) \quad (7)$$

$$m_2(h_2 - h_3) = (m_2 - m_5)(h_1 - h_6) \quad (8)$$

$$: m_6 = (m_2 - m_5) \quad (9)$$

$$\varepsilon = \frac{C_h (T_2 - T_3)}{C_{min} (T_2 - T_6)} \quad (10)$$

Throttling process

$$h_3 = h_4 \quad (11)$$

Heat Balance of the separator

$$m_2 h_4 = m_5 h_5 + m_6 h_6 = m_5 h_5 + (m_2 - m_5)(h_6) \quad (12)$$

Second law analysis

$$\eta_{2nd} = \frac{W_{rev}}{W_{actual}} \quad (13)$$

COP (coefficient of performance)

$$COP = \frac{h_2 - h_1}{h_2 - h_1 - T_1 (s_2 - s_1)} \quad (14)$$

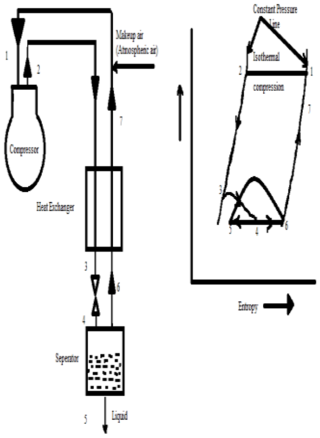

Fig: 1. (LindeHampson System)

An analysis of various parameters is measured for Lindehamspson cycle with the help of Engineer equation solver for various gases. Simplest cycles as shown in Fig. 1 are taken for analysis and measured the loop holes responsible for inefficiencies in various processes in cycle. In linde system fluid in gases form are fed into the system at atmospheric condition, after that the air is isothermally compresses up to great pressure, then this pressurize and high temperature air is fed into the heat exchanger where it is cooled to a great extent after that the it is throttled where it become convert into partially liquid and partially gaseous form. A separator is provided to separate gaseous form to liquid form .Gaseous form is again fed to the compressor after passing through the same heat exchanger and after mixing with the makeup gaseous form.

Linde system is used to liquefy various forms of gases as per our convenience of our system efficiency of system for a particular gas. After reviewing literature it conclude that every part of system has its own and equal importance because ones effect on another whether it is small or big create a lot of difference in proper analysis of system. Ignoring one small system due less effect can put gap in complete research analysis of system that why it quite important take all parts of system as one and finding out the every part impact on another to calculate right equation for high output. Heat exchanger and expansion valve, expander and other addition parts should also properly analyze. Advanced technologies are used in very limited way and only on some part of system. From literature it noticed that exergy efficiency depend upon mainly upon the inlet condition of the system but which inlet condition best suit for a particular type of the system that is main work of research.

4. Results and Discussion

Fig. 2 shows the variation of liquefaction mass and compressor pressure and it is observed that compressor pressure increases liquefaction mass also increases but as seen above after compression pressure 350-400 the liquefaction mass start decreasing for most of gases and become stable for like methane. Fig. 3 COP is inversely proportional to the compressor pressure as it increases COP of system decreasing. In Fig. 4 the second law efficiency is best suited between 300-400 compressor pressure ranges.

In Fig. 5 show that there is increase in liquefaction mass of gas if the inlet pressure increases but as from graph this increase very low

COP is directly proportional to the inlet pressure as it increases COP increases significantly. Inlet pressure ranging from 4 to 6 bars in Fig. 6 show very good statics of COP.

Inlet pressures play a very important role in case of work input. In Fig. 7 it shows that as the pressure increases work input start decreasing. From 1 to 4 atmospheric there is significant drop of work input after that the drop is very marginal.

At NTP condition the liquefaction temperature of any gas is very low and keep that temperature in storage of Liquefy gas is very challenging task. In Fig. 8 the Inlet pressure increase also increases the liquefaction temperature of gas.

In Fig. 9 the graph show that there is increase in second law efficiency with increase in Inlet pressure but the increase is very less as shown in above graph. Liquefaction mass decreases as the inlet temperature increases, in Fig. 10 there is swift decrease in mass from 298 to 308 K but after that the decrease factor slow down for further increase in inlet temperature. Fig. 11 show inlet temperature is directly proportional to the COP for fluorine and methane gas but for other gas it seems from graph trend that they become constant or very marginal increases in COP with increase in inlet temperature.

As the temperature increases work required increases but in case of methane the increase is very large as compare to other gas as show in Fig. 12.

There is decrease in second law efficiency corresponding to increase in inlet temperature. Methane gas show very large drop of efficiency compare to other gases as shown in Fig. 13 graph.

	Air	Methane	Oxygen	Nitrogen	Fluorine	Argon
Inlet Temp (K)	298	298	298	298	298	298
COP	0.07324	0.5161	0.4755	0.4954	0.4932	0.3454
inlet mass (kg)	1	1	1	1	1	1
liquefied mass (Kg)	0.0778	0.1991	0.1072	0.07564	0.07665	0.1154
$\eta 2^{nd}$ (%)	12.64	27.8	16.77	12.3	12.67	17.61
Inlet pressure (Atmosp)	1.013	1.013	1.103	1.013	1.013	1.103
Compressor work (Wc) (kJ/kg gas)	450.8	772.6	401.9	468.2	341	322.2
Compressor outlet pressure	200	200	200	200	200	200
Dryness Fraction	0.9222	0.8009	0.8298	0.9244	0.9233	0.8846
liquefied Temp (K)	81.5	111.7	90.19	77.35	85.03	87.3

Table: 1.

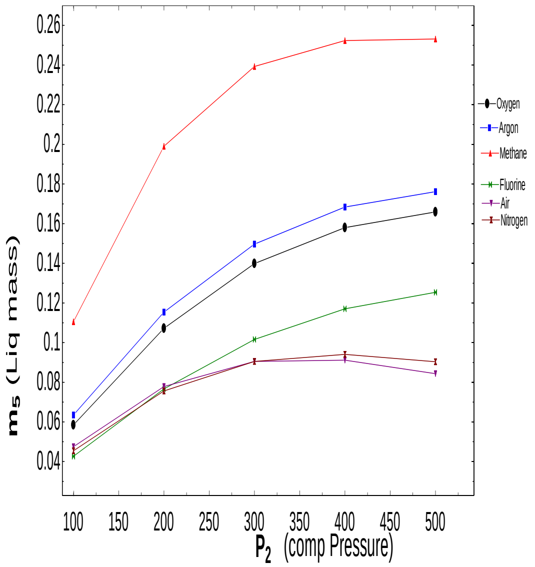

Fig: 2. Variation of liqufecation mass with compressor pressure

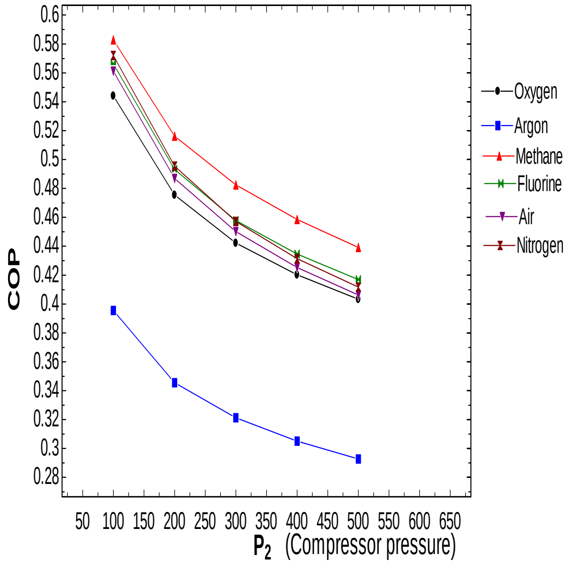

Fig: 3. Variation of COP with compressor pressure

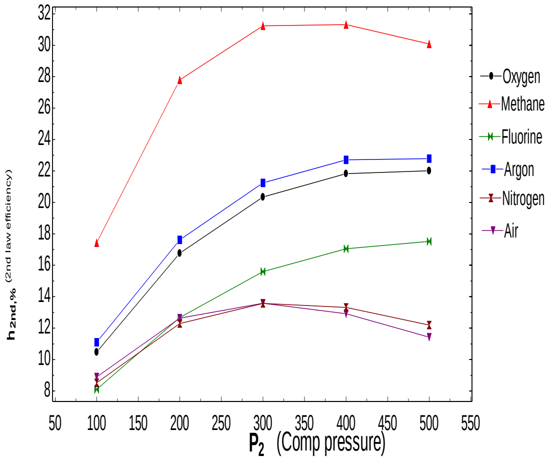

Fig: 4. Variation of Second law Efficiency with Compressor Pressure

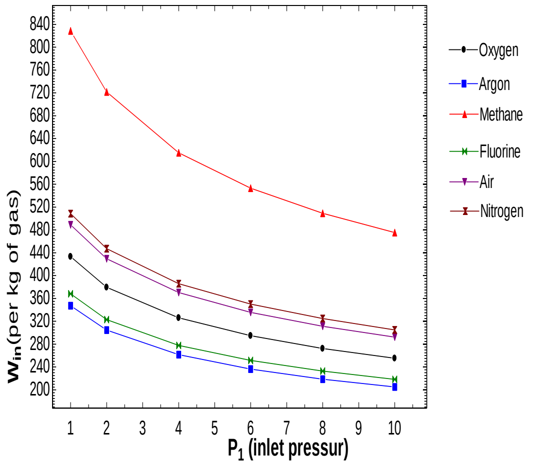

Fig: 7. Variation of W_{in} (Compressor work/kg gas) with inlet Pressure

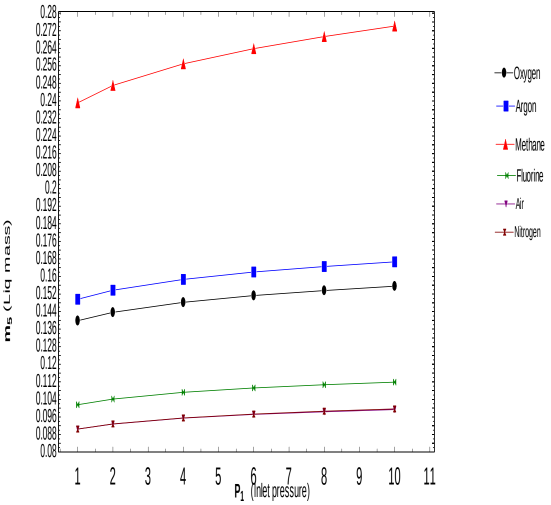

Fig: 5. Variation of liquefaction mass with inlet Pressure

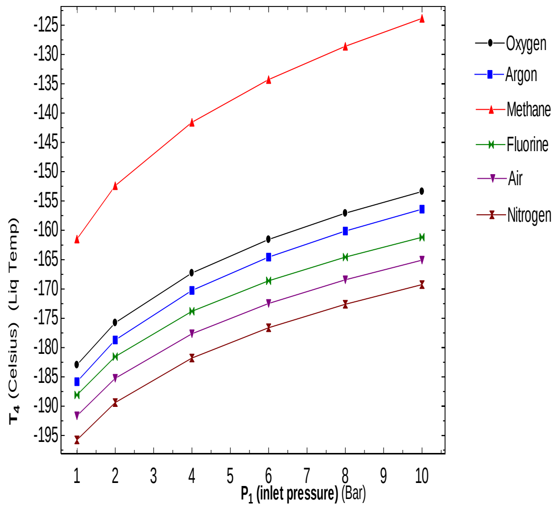

Fig: 8. Variation of liquefaction Temperature with inlet Pressure

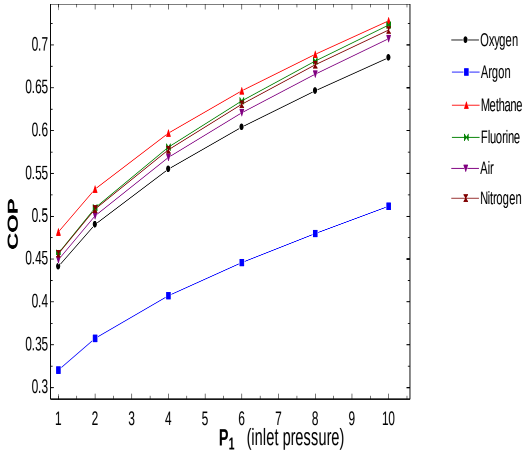

Fig: 6. Variation of COP with inlet Pressure

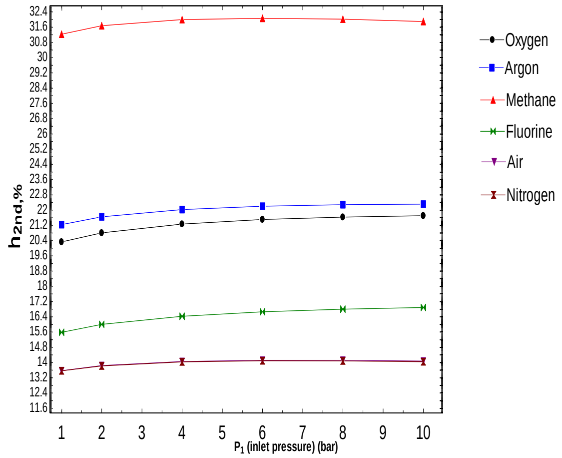

Fig: 9. Variation of Second law Efficiency with inlet Pressure

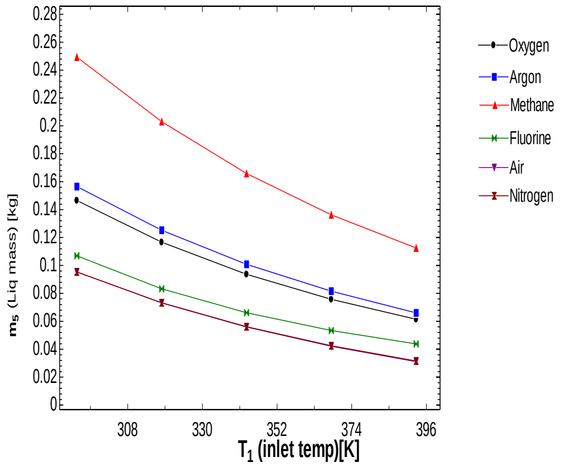

Fig: 10. Variation of liquefaction mass with inlet Temperature

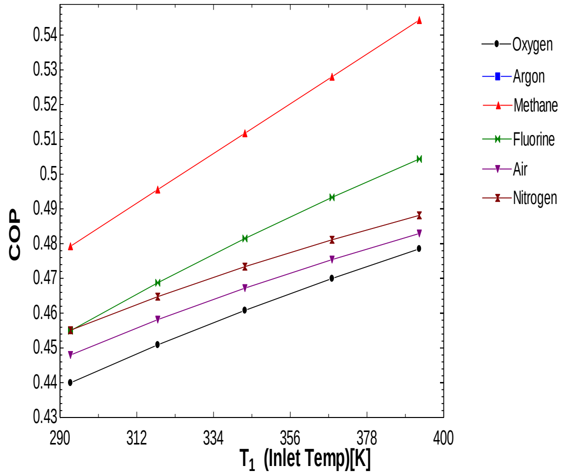

Fig: 11. Variation of COP with inlet Temperature

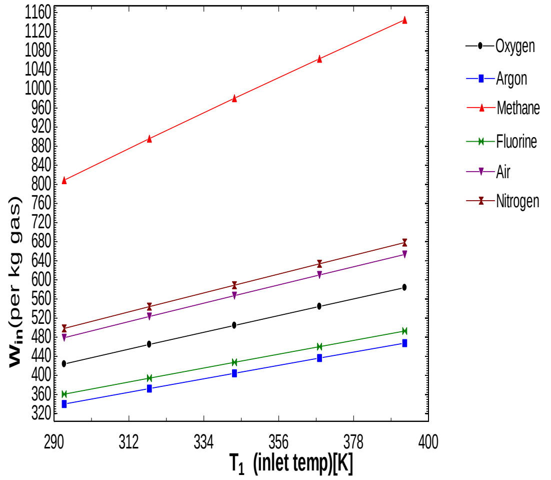

Fig: 12. Variation of W_{in} (Compressor work/kg gas) with inlet Temperature

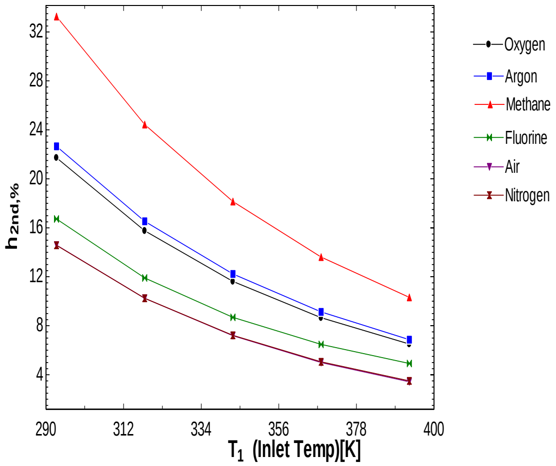

Fig: 13. Variation of Second law Efficiency with inlet Temperature

5. Conclusion

- Compressor pressure ranging from 300 to 400 bar is very efficient for system
- From above analysis it noticed that inlet pressure of system should keep between 3 to 6 bar for good result.
- Second law efficiency for inlet temperature is high at NTP temperature.
- It is not significant to say that mainly inlet condition are responsible for system output, every part of system put their own effect on output condition.

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