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Thermodynamic (Exergy-Energy) Analysis of a Low Pressure Kaptiza Claude System for Liquefaction of Gases

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ABSTRACT

From various Cryogenics systems, lot of a detailed thermodynamic analysis of cryosystems have been reported in literature however the modification of Claude systems for low pressurefor high yield of liquefied mass of gases is very limited available in literature so far.A comprehensive energy and exergy analysis of Claude Kaptiza cryogenic system for various gases is carried out in this paper by using various properties variables (i.e temperature, pressure etc) in system to find out the more efficient statics of system included exergy destructions in system .Numerical computations have been carried out for various gases in Claude Kaptiza system and it was observed that the inlet variables like pressure temperature and intermediate mass ratio respectively are 3-6 bar,280-290 K and 0.7for optimized result of considered variables such liquefaction mass, liquidation temperature and second law efficiency in low pressure Kaptiza Claude system.

Keywords: *Thermodynamics Analysis Claude Kaptiza System; Energy-Exergy Analysis; First and Second Law Analysis.*

1.0 Introduction

It's a natural phenomenon that heat flow from high temperature to low temperature and the reverse process without any aid or external work is impossible and if so it just the violation of second law of thermodynamics A device which is which act as intermediate device is called refrigerator.

The difference between refrigeration and cryogenics systems lies in the achievable temperature with the dividing line being of-lOOoF or -74°C [1]. Now a day the process industries are faced with an increasingly competitive environment, ever changing market conditions and government regulations.

Yet they a still have to increase productivity and profitability.

In order to have a means of comparison of liquefaction systems through the figure of merit and exergy efficiency.

Most of system is ideal in the thermodynamic sense, but it is not ideal as far as practical system is concerned.

The perfect cycle in thermodynamics is the Carnot cycle [2]. Today a cryogenics industry is a billionaire industry and lots of research is going on to achieve best one improved process.

Cryogenic process to liquefy air which is further extent to extract various particular gas like oxygen, nitrogen, feron etc.

Always various analyses is done to identify the loop hole of process and to rectify it to their upper level, electro caloric cooling is a transiting to new cooling principle's is critical and one of the most promising alternatives may be [3].

Various particular part are taken under study to increase overall performance of cryogenic system e.g A good exergetic design of a heat exchanger would allow for an increase in the global efficiency of the process, by defining a thermodynamic cycle in which the exergetic losses would be limited

[4] apart from this other parts like expander, mass ratio and input variables are considered to improve cryosystems.

2.0 Thermo analysis of Claude Kaptiza system for liquefaction of gases:

A complete analysis of Kaptiza Claude cycle

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Compressor Work:

$$\eta_c = W_t / W_{comp} \quad (1)$$

$$W_t = mRT \ln P_2/P_1 \quad (2)$$

$$-W_c = m*(T_1*(s_1-s_2)-(h_1-h_2)) \quad (3)$$

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

$$W_{net} = W_c + W_e \quad (5)$$

Expander:

$$T_8/T_3 = (P_8/P_3)^{(((Y-1)/Y)\eta_{expander})} \quad (6)$$

$$W_e = m_e*h_3 - m_e*h_e \quad (7)$$

"Control volume except compressor"

$$m*h_2 = W_e + (m-m_f)*h_1 + h_f*m_f \quad (8)$$

$$y = m_f/m \quad (9)$$

"Work done per mass of gas"

$$z = -W_{net}/m \quad (10)$$

"Work done per mass of liq gas"

$$t = -W_{net}/m_f \quad (11)$$

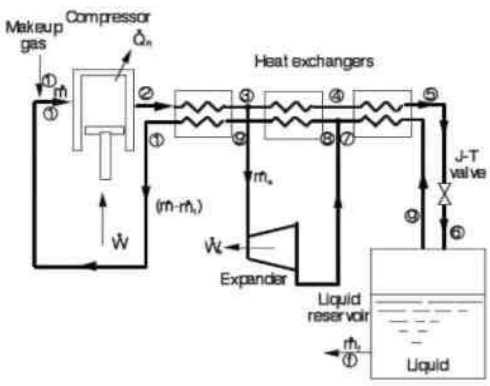
Coefficient of performance of system

$$COP = ((h_1-h_f)/W_{net}) \quad (12)$$

Second law analysis:

$$\eta_{2nd\ law} = ((((h_f-h_1)-T_0*(s_f-s_1))/(W_{net})*m_f)*100)$$

Fig 1: Block Diagram of Kaptiza System



is performing with the help of numerical computation technique for various gases. Kaptiza Claude cycle as shown in Fig 1 is taken for analysis. Kaptiza Claude system is almost same as simple Claude system except arrangement of first expander. In Kaptiza system expanderis situated in between the first and second heat exchanger other than this it also consist a compressor, expander, two heat exchangers with throttle valve and separator. The fluid which has to liquefy first fed to compressor in its gaseous form at atmospheric pressure and temperature which circulate from all system and in last fractional mass of total mass get liquefied and remaining again fed in system with additional mass to recirculate in system again. Various results are drawn for particular inlet temperature, pressure and intermediate pressure for low pressure side of expander for different six type gases such oxygen, argon, methane, air, fluorine and nitrogen are considered for study.

3.0 Results and Discussion

Various results are drawn on the basis of numerical equations of system. In fig 2 variation of liquefaction temperature with inlet pressure as we increases the pressure Liquefaction temperature rises but after crossing 10 bar the increment in liquefaction temperature is start reducing and its slope with inlet pressure start become straighten. Fig 3 show fall of liquefaction mass with increase of inlet temperature and it also show that at 330 k the liquefied mass of methane and argon is same. Fig 4 shows decreases in liquefaction mass with increase of inlet pressure. Fig 5-7 show variation in second law efficiency with intlet temperature, intermediate mass and inlet pressure respectively. Graph analysis of these 5-7 fig shows that second law efficiency is decreases with increase of inlet temperature while with increases of intermediate mass second law efficiency increases whereas it again decreases with increase of inlet pressure. Fig 8 -9 show variation in COP of system with inlet pressure and temperature. They show that increase in pressure is beneficial for system and COP of system is increases with increase in inlet pressure while its increment with increase in inlet temperature is very less. From above graph study it determined that increment and decrement in a very concern range of various variables is good for optimization of Kaptiza Claude System

Fig 2: Variation of Liquefaction Temperature with Inlet Pressure

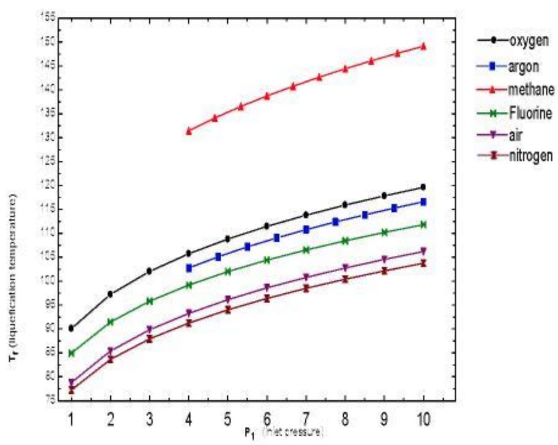


Fig 3: Variation of Liquefied Mass with Inlet Temperature

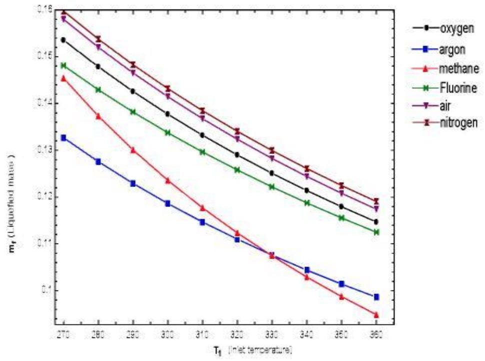


Fig 4: Variation of Liquefied Mass with Inlet Pressure

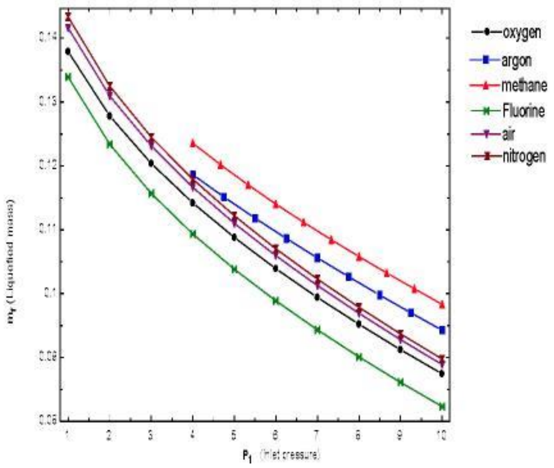


Fig 5: Variation of 2nd Law Efficiency with Inlet Temperature

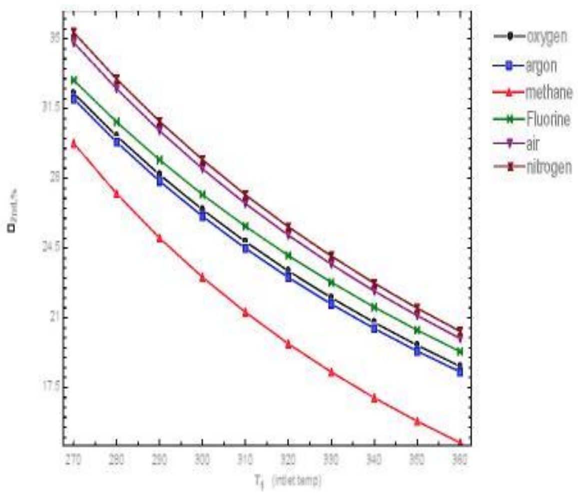


Fig 6: Variation of 2nd Law Efficiency with Intermediate Mass Ratio

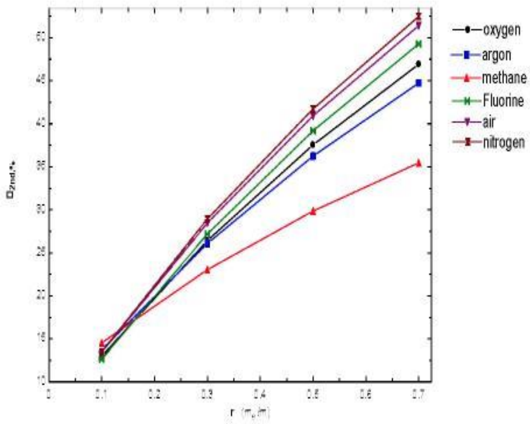


Fig 7: Variation of 2nd Law Efficiency with Inlet Pressure

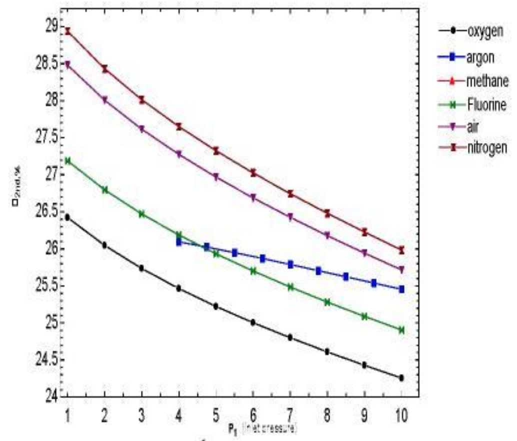


Fig 8: Variation of COP with inlet Temperature

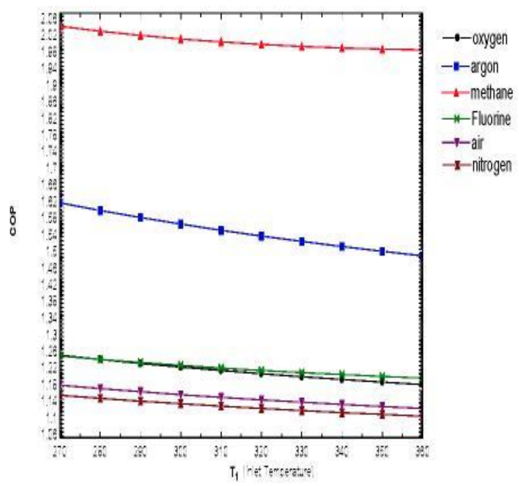
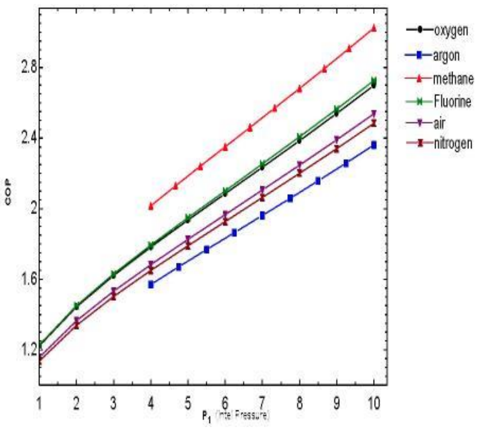


Fig 9: Variation of COP with Inlet Pressure



4.0 Conclusion

From above study following results are concluded

1. The optimize range of inlet variables like pressure temperature and intermediate mass ratio respectively are 3-6 bar,280-290 K and 0.7for good result of considered variables such liquefaction mass, liquidation temperature and second law efficiency.
2. Intermediate pressure of low pressure side expander should be in minimum range for high second law efficiency.
3. Increase in inlet temperature decrease the COP, second law efficiency, liquefaction mass.

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Nomenclature

m= Total mass of gas

m_f=liqified mass of gas

m_4=mass of air in second heat exchanger

m_8=mass of air liquefied in the separator

h=Enthalpy

s=Entropy

X=Dryness fraction

T=temperature

P=Pressure

η_{comp}=Efficiency of compressor (approx. 80%)

$\eta_{expander}$= Efficiency of expander (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_c=Shaft work supplied to compressor per unit mass

R=Universal gas constant

W_{net} =Net work done in system