

Thermodynamic (Exergy-energy) Analysis of a Low Pressure Improved Claude Cycle Using Control Volume Technique For Liquefaction of Gases

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Abstract

Comprehensive energy and exergy study of improved Claude system to liquefy various gases is carried out in this paper. Numerical computational technique is used to find out the effect of various properties variables like temperature, pressure on system performance and exergy destruction in system and their sub-components. It was observed that the inlet variables like pressure, temperature and intermediate mass ratio respectively are in ranges from 3 to 6 bar pressure, 280 to 290 K temperature and 0.5-0.7 mass ratio respectively, desirable for high liquefaction rate and second law efficiency in improved low pressure Claude cycle.

Keywords: Thermodynamics analysis, Energy-Exergy analysis, first and second law analysis

NOMENCLATURE

m = Total mass of gas

m_f = liquified mass of gas

h = Enthalpy

s = Entropy

X = Dryness fraction

T = temperature

P = Pressure

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

η_{expander} = Efficiency of expander (80%)

$\eta_{2nd\ law}$ =Second law efficiency

ϵ =Effectiveness of heat exchanger (80%)

C =Specific heat capacity fluid or gas

W_t =Work of reversible isothermal compression

W_c =Shaft work to compressor per unit mass

R =Universal gas constant

W_{net} =Net work done in system

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 a refrigeration and cryogenics systems lies in the achievable temperature with the dividing line being of -100°F 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]. 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 different input variables are considered to improve cryogenic systems

2.0 THERMAL ANALYSIS OF IMPROVED CLAUDE SYSTEM FOR LIQUEFACTION OF GASES:

Compressor work

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

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

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

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

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

Expander

$$\frac{T_8}{T_3} = \left(\frac{P_8}{P_3}\right)^{\left(\frac{\gamma-1}{\gamma}\right) \eta_{\text{expander}}} \quad (6)$$

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

"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"

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

"Work done per mass of liquefaction gas"

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

Coefficient of performance of system

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

Second law analysis

$$\eta_{\text{2nd law}} = (((h_f - h_1) - T_0 * (s_f - s_1))/(W_{\text{net}} * m_f) * 100) \quad (13)$$

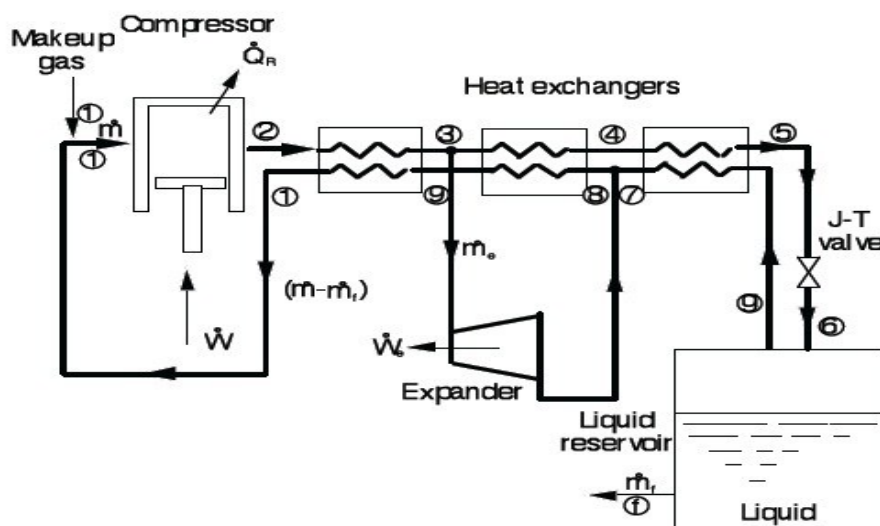


Fig 1 Block diagram of low pressure Claude system

A complete analysis of Improved Claude cycles performed with the help of numerical computation technique for various gases. Improved Claude cycles shown in Fig 1 is taken for analysis. Improved Claude system is almost same as simple Claude system except arrangement of first expander. In Improved Claude system expander is 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 gases such oxygen, argon, methane, air, fluorine and nitrogen are considered for study.

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 Intel 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 Improved Claude system

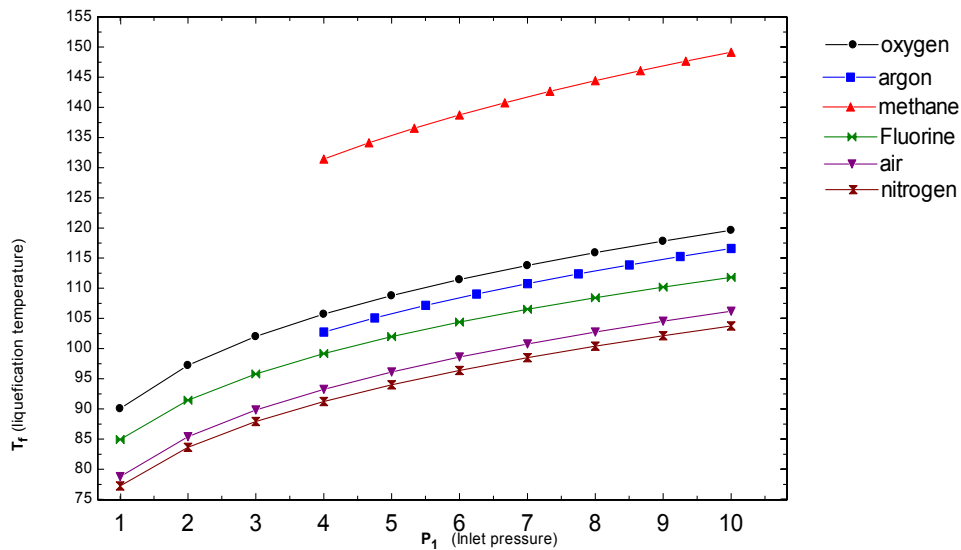


Fig: 2 Variation of liquefaction temperature with inlet Pressure

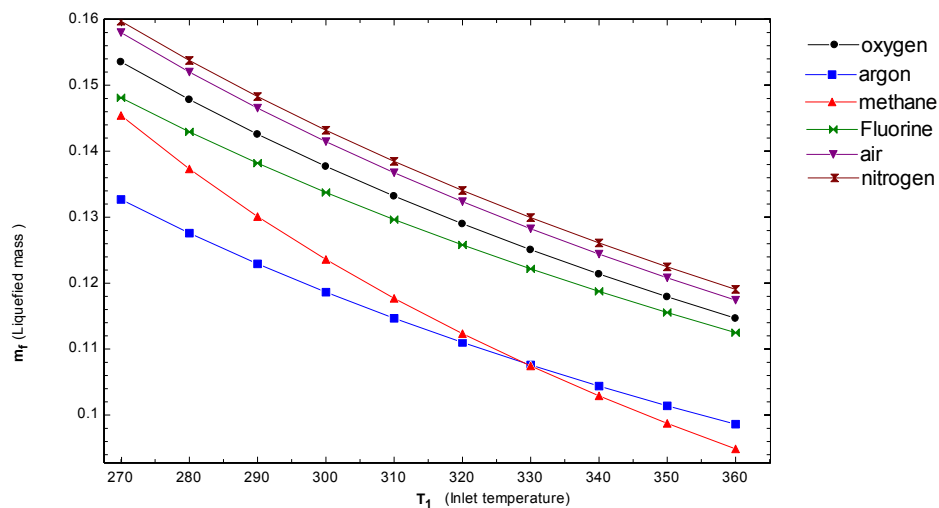


Fig:3 Variation of liquefied mass with inlet temperature

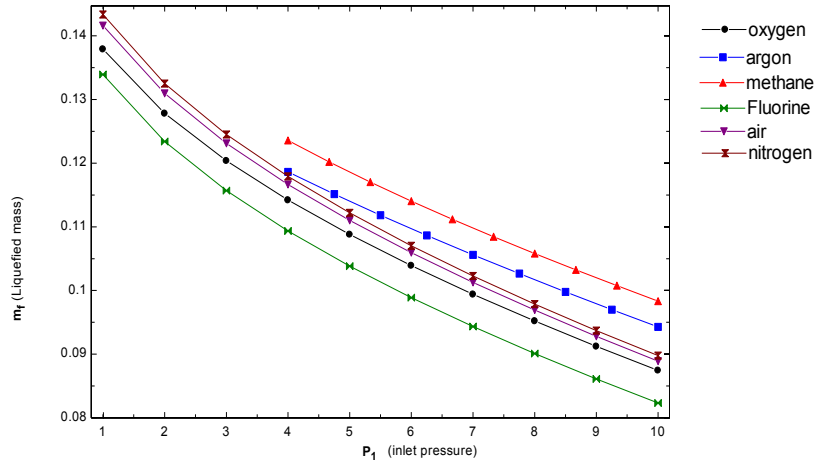


Fig:4 Variation of liquefied mass with inlet Pressure

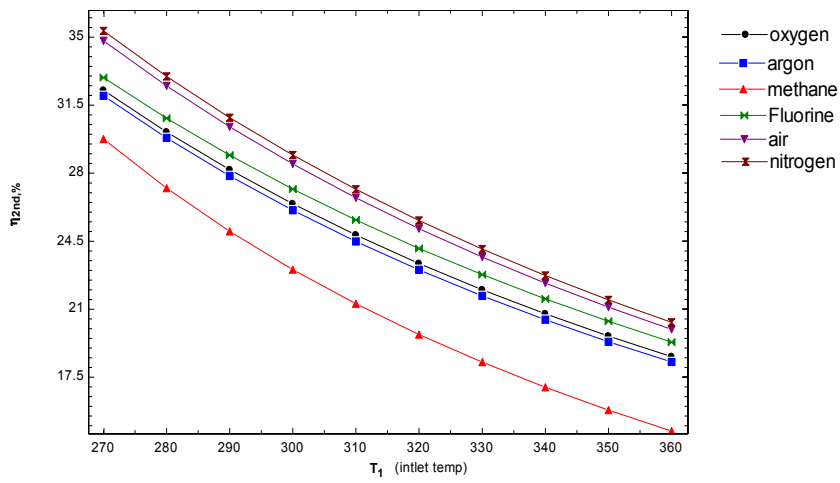


Fig:5 Variation of 2nd law efficiency with inlet temperature

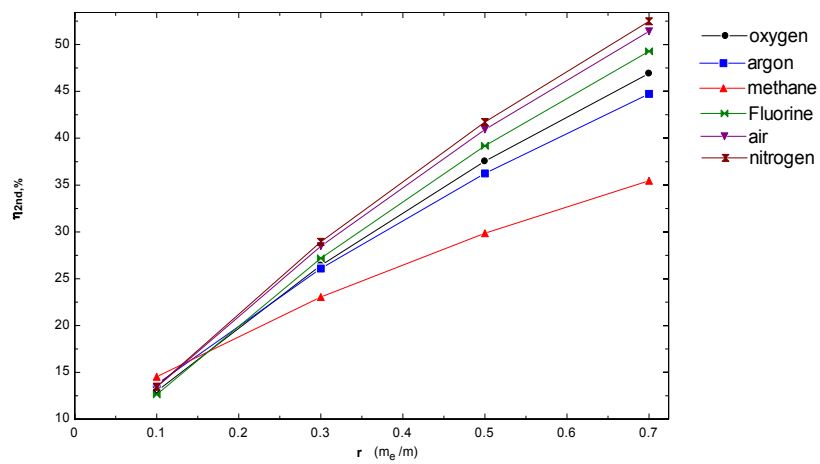


Fig:6 Variation of 2nd law efficiency with intermediate mass ratio

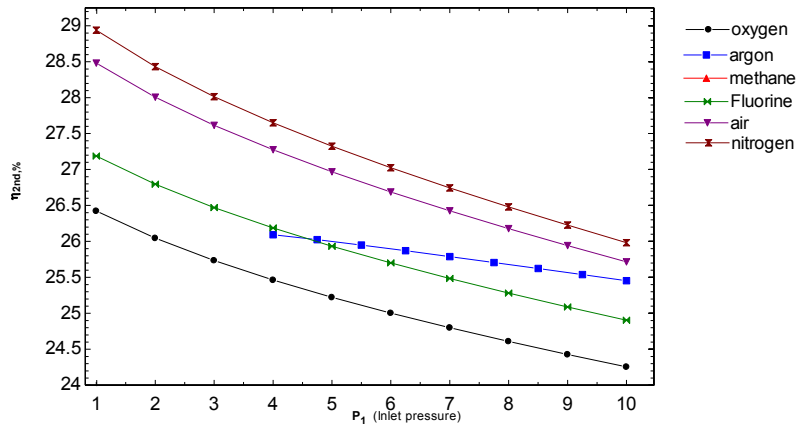


Fig:7 Variation of 2nd law efficiency with inlet Pressure

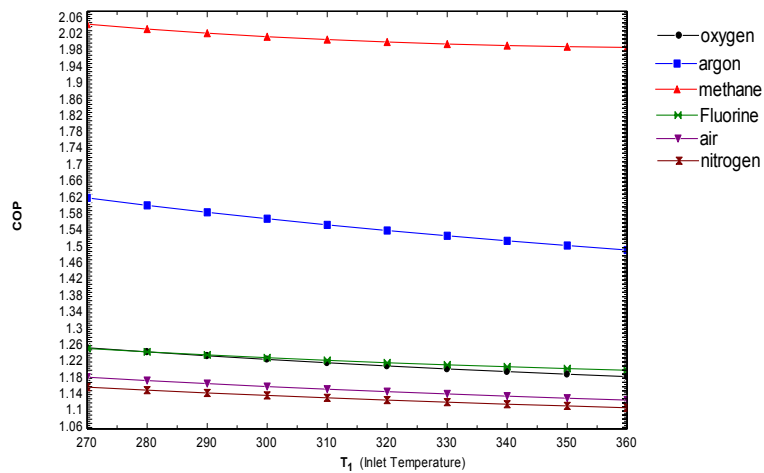


Fig:8 Variation of COP with inlet Temperature

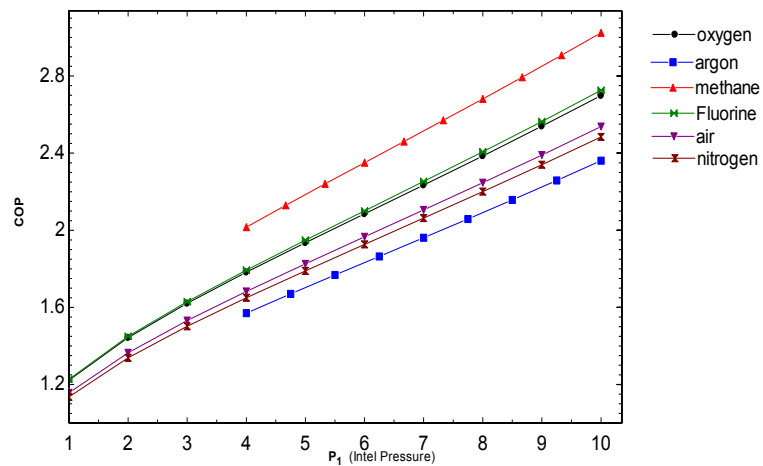


Fig:9 Variation of COP with inlet pressure

CONCLUSION

From above study following results are concluded

- 1) The optimum value of inlet variables like pressure temperature and intermediate mass ratio respectively ranges from 3 to 6 bar pressure, 280 to 290 K temperature and 0.7 mass ratio for 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 and output (liquefaction mass) of system.

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