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Thermo Analysis of Hydrogen Liquefaction System

Devender Kumar and R. S. Mishra***

ABSTRACT

Hydrogen is rich source of energy but its properties in gaseous state cannot be used efficiently but at the liquid state in can be used in various application but high cost of liquefaction of hydrogen cryogenic system and less efficiency component turned the cryogenic science toward optimization. Second law efficiency analysis system components on demand base parameters, reduces cost of whole system. A mathematical computational program is made on the basis of hydrogen system and second law analysis is done on different input parameters is studied. Second law efficiency of hydrogen system is 19.82 % and COP is 0.9746 is found when inputs are at ambient condition and compressor pressure at 15 bar is provided, but study of graph shows that both start decreasing with further increases of compressor pressure whereas liquefaction mass ratio and Total work done is increases with increase in compressor pressure.

Keywords: *Thermodynamics Analysis; Efficiency COP*.

1.0 Introduction

A low temperature environment is termed a cryogenic environment when the temperature range is below the point at which permanent gases begin to liquefy. Permanent gases are elements that normally exist in the gaseous state and were once believed impossible to liquefy. Lack of fossil fuels and increasing need to energy has made us to pay aspecial attention to replacing fossil fuels with renewable resources. Also the fossil fuels and their combustion products were causing global environment problems. These resources of energy are clean and do not pollute the environment. One these sources are hydrogenic energy. Hydrogen derived from renewable energies eventually will contribute to the sustainable development of such countries [1]. Hydrogen combustion produces water vapor that does not make any pollution. Hydrogen is gas form, occupies a large volume and has low density (0.0897 kg/m3) and high pressure [2]. So the dmand of dense form of hydrogen increses but liqifaction of hydrogen is a very slow process and it estimated that The fastest flow that a hydrogen

liquefaction system can bear in optimum hydrogen flow is 300 lit/hr[3]. Thus we need to liquefy hydrogen for an easier transportation and safety ,it also studied that thermodynamic performance (□ t) is low due to existing of nitrogen pre coolers I hydrogen system [4] In hydrogen liquefier the pre-compression of feed gas has generally higher stand-alone exergy efficiency than the cooling and liquefaction sub-process. Decreased feed pressure results in generally higher power consumption but also higher exergy efficiency, and vice versa [5]. Gianluca Valenti et al [6] in research show that the feed, 10 kg s_1, is refrigerated in heat exchangers catalytically promoting the ortho-para conversion down to the low temperature of 20.5 K and at the high pressure of 60 bar with turbo machine expansions show 48% of second law efficiency with low power consumption of hydrogen liquefaction system. SongwutKrasae-in et al [7] showed effect of mutlreferegerant at the hydrogen liquefaction plant. The MR system can be used to cool feed normal hydrogen gas from 25 °C to the equilibrium temperature of -193 °C with a high efficiency. The overall power consumption of the plant is reduced from 5.35 kWh/kgLH2, to minimum of 2.89 kWh/kgLH2.GianlucaValenti et al [81 discuss the influence of the thermodynamic modeling of the fluid on the simulation outcomes. Various hydrogen forms

**Correspoinding Author: Department of Mechanical, Delhi Technological University, New Delhi, India
(E-mail: devenderdahiya@in.com)
**Department of Mechanical, Delhi Technological University, New Delhi, India*

(ortho hydrogen and Para hydrogen) and their mixtures (equilibrium-hydrogen and normal-hydrogen) are studied and described in his research. According to viewpoint of David O. Berstad [9] efficiency and cost is to a large extent dependent on the efficiency of the liquefier so high-efficiency hydrogen liquefier based on mixed-refrigerant (MR) pre-cooling has been developed. Based on his models, a reduction in power consumption obtain in the range of 45-48%. Akihiro Nakano et al [10] proposed a simple estimation method for the liquefaction rate and confirmed that the estimation method well explained the experimental result. A small-scale hydrogen liquefier with a two-stage 10 K Gifford-McMahon cycle (GM) refrigerator is confirmed the estimation method for predicting the liquefaction rate.

2.0 Thermodynamic Analysis of Hydrogen Liquefaction System

The design is quite critical at low temperatures due to changes in thermo physical properties of hydrogen gas. Fig 1 showed the block diagram hydrogen liquefaction system in which liquefy nitrogen chamber is introduced to reduce the further temperature up to the critical temperature before J-T which is required to liquefy the hydrogen gas. "Compressor"

$$Wc_{ideal} = m_2 * R * T_1 * ln * (\frac{P_2}{P_1}) \quad (1)$$

$$-Wc = (h_1 - h_2) - T_0 * (s_1 - s_2) \quad (2)$$

"Heat Exchanger A"

$$m_a * h_2 + m_4 * h_{13} = h_3 * m_a + m_4 * h_{14} \quad (3)$$

$$\varepsilon = \frac{m_a * (T_2 - T_3)}{m_a * T_2 - T_{13} * m_{13}} \quad (4)$$

$$P_3 = P_2 \quad (5)$$

"Heat Exchanger B"

$$m_b * h_2 + m_{LN_{evop}} * h_7 = h_4 * m_b + h_8 * m_{LN_{evop}} \quad (6)$$

$$\varepsilon = \frac{m_b * (T_2 - T_4)}{m_b * T_2 - T_7 * m_{LN_{evop}}} \quad (7)$$

"Mixing of two different tem helium"

$$m_3 * c_p * (T_3 - T_5) = m_b * c_p * (T_5 - T_4) \quad (8)$$

"Heat Exchanger C"

$$Q_{LN_{evop}} = m_2 * (h_5 - h_6) \quad (9)$$

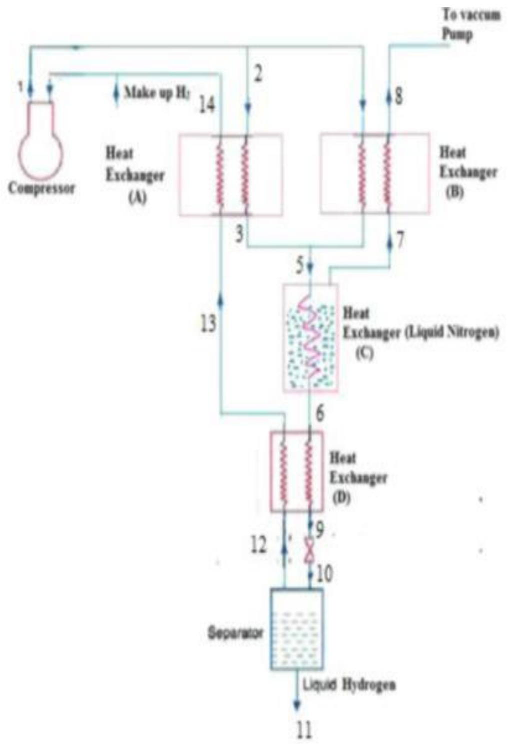
$$m_{LN_{evop}} * L_{LN} = Q_{LN_{evop}} \quad (10)$$

$$m_2 * h_5 + m_{LN} * h_{LN} = m_{LN_{evop}} * h_7 + m_2 * h_6 \quad (11)$$

"Heat Exchanger D"

$$m_2 * h_6 + m_4 * h_{12} = h_9 * m_2 + m_4 * h_{13} \quad (12)$$

Fig 1: Block Diagram of Hydrogen Liquefaction System



$$\varepsilon = \frac{m_2 * (T_6 - T_9)}{m_2 * T_6 - T_{12} * m_4} \quad (13)$$

"Expansion Valve"

$$h_9 = h_{10} \quad (14)$$

$$h_{10} = h_{11} + x_{10} * h_{12} \quad (15)$$

Separator"

$$m_2 * h_{10} = h_{11} * m_3 + m_4 * h_{12} \quad (16)$$

3.0 Result and Discussion

By computational mathematical technique various variable are noticed which are playing high role in hydrogen Liquefaction system and its optimization andto fully understand the effect of these variables on system different values are given and graphs are generated. Fig 1 show the variation of second law efficiency with respect to compressor pressure it show that as increase the compressor pressure after 12 bar the efficiency of system start decreasing whereas Fig 2 show just reverse of this and show increase in liquefaction mass of helium with increase of compressor pressure. Total work is summation of all type of work used in system like compressor work, expander work. Fig 3 shows there not much high fluctuation in variation of total work of system with increase in compressor pressure. At low pressure COP of system is quiet good as comparison with COP at high pressure. Fig 4 show COP of system start decreasing with increase in compressor pressure.

Fig 2: Variation of Second Law Efficiency to Compressor Pressure

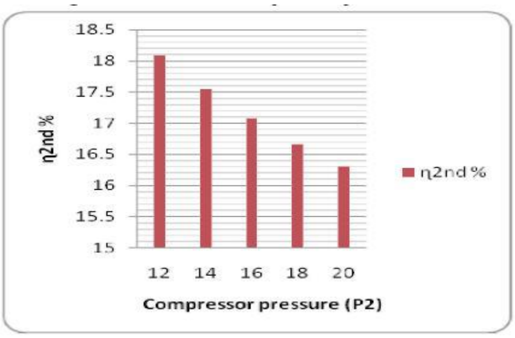


Fig 3: Variation of Liquefaction Mass Ratio to Compressor Pressure

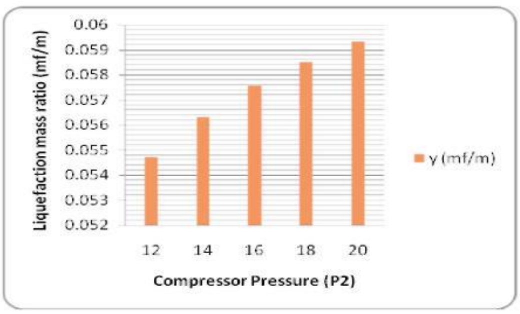


Fig 4: Variation of Total Work of System to Compressor Pressure

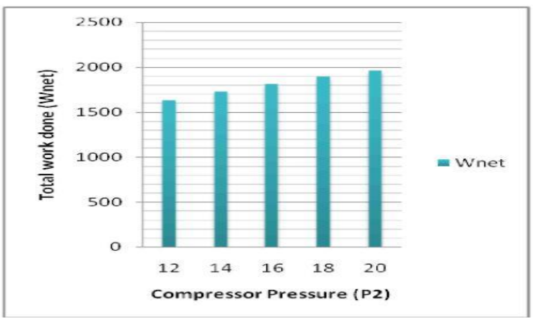
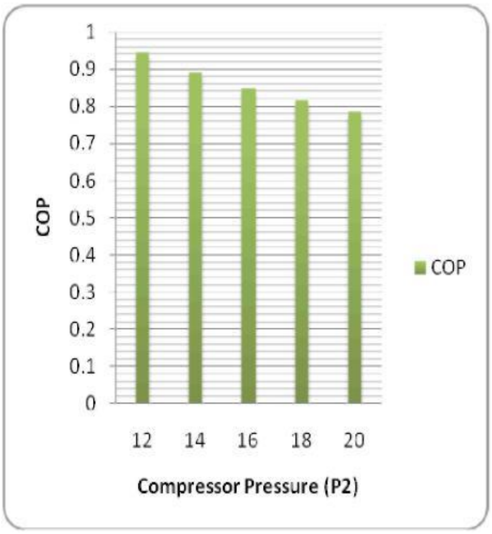


Fig 5: Variation of COP of System to Compressor Pressure



4.0 Conclusion

1) Second law efficiency of system is 17.29 % and it start decreasing with further increases of compressor pressure
2) COP of the system is 0.8687 when input at ambient condition and compressor pressure is 15 bar and as like second like efficiency it also start decresing with increases of compressor pressure.
3) Liquefaction mass ratio and Total work done is increases with increase in compressor pressure.

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Nomenclature

m=mass flow rate

m_f=Liquefaction mass

h=Enthalpy

s=Entropy

X=Dryness fraction

T=temperature

P=Pressure

$m_{LN_{evop}}$ =mass of liquid nitrogen

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

ε=Effectiveness of heat exchanger

C=Specific heat capacity fluid or gas

W_{net}=Total Work of compression

W_c=Compressor work