

SIMULATION OF 1610 HELIUM LIQUEFIER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

**Master of Technology
in
Mechanical Engineering**

By

**AARIF B
(Roll No: 211ME3184)**



**Department of Mechanical Engineering
National Institute of Technology
Rourkela
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Under the guidance of
Prof. Ranjit Kumar Sahoo



**Department of Mechanical Engineering
National Institute of Technology
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2013**



**National Institute of Technology
Rourkela**

CERTIFICATE

This is to certify that the thesis entitled, “**SIMULATION OF 1610 HELIUM LIQUEFIER**” submitted by **Mr. AARIF B** in partial fulfillment of the requirements for the award of Master of Technology Degree in **Mechanical Engineering** with specialization in **Thermal Engineering** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

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ABSTRACT

Cryogenics is generally described as the science and technology of producing low temperature environment. The various cryogenic cycles such as Collins cycle, Linde cycle etc. govern the liquefaction of various industrial gases, namely, helium, nitrogen etc.

In this project work, helium liquefier has been simulated with the help of the simulation tool Aspen hysys and simulation work is carried out at steady state using MBWR (Modified Benedict–Webb–Rubin) equation of state in order to get the desired output.

The present analysis is carried out to assess the role of different component efficiencies in predicting overall system efficiency at the design and off design conditions. In this analysis, the temperature is assumed to evaluate the expander efficiency and heat exchanger effectiveness in order to optimize the plant efficiency. The evaluated thermodynamic parameters are obtained and the optimum mass fraction through expander for maximum liquid yield is calculated.

Key words: Cryogenics, helium liquefier, Aspen Hysys, MBWR, yield

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NOMENCLATURE

T = Temperature

P = Pressure

\dot{W} = Work transfer

\dot{m} = mass flow rate

y = yield ($\dot{m}_L / \dot{m}_{COMP}$)

h = specific enthalpy

s = specific entropy

ϵ = Effectiveness of heat exchangers

η = Efficiency of expanders (Expansion Engine)

X0 = Mass flow ratio diverted for precooling

X1 = Mass flow ratio diverted through Expander1

X2 = Mass flow ratio diverted through Expander 2

E30 = Heat Exchanger 1

E31 = Heat Exchanger 2

E32 = Heat Exchanger 3

E33 = Heat Exchanger 4

E34 = Heat Exchanger 5

E37 = Expander 1(Expansion Engine 1)

E39 = Expander 2(Expansion Engine 2)

C = Capacity rate

C_{min} = Smaller quantity of C_c and C_h

\dot{m}_{COMP} = mass of helium delivered from compressor

LN2 = Liquid nitrogen

\dot{m}_L = liquid production

Chapter 1

Introduction

1.1 Principle of Liquefaction :

The process in which gas is physically converted into liquid state is called liquefaction. Many gases like carbon dioxide can be converted into gaseous state by simple cooling at normal atmospheric pressure and some others require pressurisation. Liquefaction process is mainly used for analyse the fundamental properties of gas molecules, for storage of gases in air conditioning and refrigeration.

Liquefaction of gases is accomplished by refrigerating and cooling the gas below its critical temperature so that liquid can be formed at some suitable pressure below the critical pressure. Thus gas liquefaction process is a special case of gas refrigeration. In both cases, the gas is first compressed using compressor to an elevated pressure in an ambient temperature. This high-pressure gas is passed through heat exchanger to a throttling valve and expansion engine. When the gas is expanding to the lower pressure from the J-T Valve, cooling may take place, and some liquid may be formed. The remaining low-pressure gas returns to the compressor inlet to repeat the cycle. Both refrigerators and liquefiers operate on this basic principle.

In a liquefying system, the total mass of gas that is warmed in the heat exchanger is less than that of the gas to be cooled by the amount liquefied because of liquid accumulation, this will creating an imbalance mass flow in the heat exchanger. In a refrigerator the cool and warm gas flows are equal in the heat exchanger because there is no accumulation of refrigerant in any part of the system. This result shows as a "balanced flow condition" in a refrigerator heat exchanger. The refrigeration and liquefaction both, has identical thermodynamic principles. However the design and analysis of the two systems are quite

different because of the condition of balanced flow in the refrigerator and unbalanced flow in liquefier systems.

Liquefaction of helium (Helium-4) with the Hampson-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 helium-4 has many amazing properties, such as exhibiting super fluidity (under certain conditions it acts as if it had zero viscosity) and climbing the walls of the vessel. Liquid helium (Helium-4) is used as a cryogenic refrigerant; it is commercially used in superconducting magnets such as those used in MRI or NMR.

The liquefaction of gases is a complicated process that uses various compressions and expansions to achieve high pressures and very low temperatures; using for example turbo expanders. The liquefaction of air is used to obtain nitrogen, oxygen and argon by separating the air components by distillation.

This chapter discusses several of the systems used to liquefy the cryogenic fluids. We shall be concerned with the performance of the various systems, where performance is specified by the system performance parameters or payoff functions.

1.2 System performance parameters:

There are three payoff functions are used to indicate the performance of a liquefaction systems:

1. Work required per unit mass of gas compressed($-\dot{W}/\dot{m}$)
2. Work required per unit mass of gas liquefied($-\dot{W}/\dot{m}_f$)
3. Fraction of the total flow of gas that is liquefied($y=\dot{m}_f/\dot{m}$)

The last two functions are related to the first one by

$$(-\dot{W}/\dot{m}) = (-\dot{W}/\dot{m}_f)y \quad (1.1)$$

In liquefaction system, we should maximize the fraction of gas that is liquefied and minimize the work requirements. These payoff functions are different for different gases; therefore we should also need another performance parameter that would allow the comparison of the same system using different fluids. That parameter is called figure of merit (FOM) for a liquefaction system. It is defined as the theoretical minimum work requirement divided by the actual work requirement for the system:

$$\text{FOM} = \dot{W}_i / \dot{W} = (-\dot{W}_i / \dot{m}_f) / (-\dot{W} / \dot{m}_f) \quad (1.2)$$

The figure of merit is a number between 0 and 1. It gives the actual system how approaches closely the ideal system performance.

There are various performance parameters that apply to the components of systems. These are

1. Compressor and expander adiabatic efficiencies.
2. Compressor and expander mechanical efficiencies.
3. Heat exchanger effectiveness.
4. Pressure drops through piping, heat exchanger. And so on.
5. Heat transfer to the system from ambient surroundings.

1.3 The Thermodynamically ideal system:

This system is thermodynamically ideal, but it is not ideal for practical system. The Carnot cycle is perfect cycle of thermodynamics. Liquefaction is an open system process, therefore for an ideal liquefaction we choose the first two processes in the Carnot cycle; a reversible isothermal compression followed by a reversible isentropic expansion. The gas is compressed reversibly and isothermally from ambient conditions to some high pressure. If this high pressure is selected so that gas will become saturated liquid upon reversible isentropic expansion through the expander. The final pressure and the initial pressure are equal. The pressure attained at the end of isothermal compression is extremely high in the order of 70

GPa or 80GPa for nitrogen. It is not possible to attain this pressure in a liquefaction system, which is the reason it is not an ideal process for a practical system.

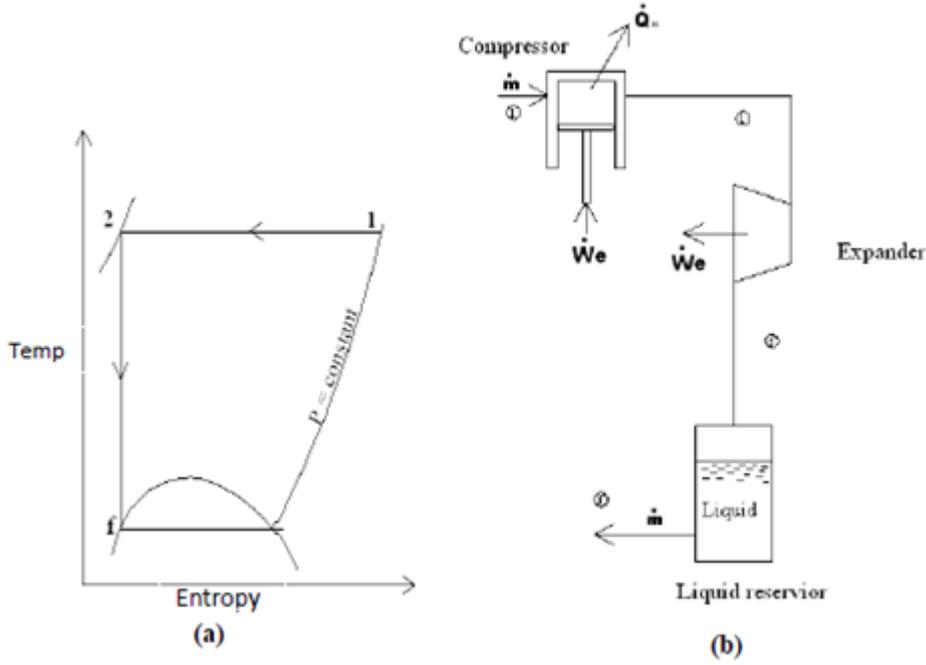


Fig 1.1: (a) T-S plane of thermodynamic cycle (b) Experimental set-up

The First law of thermodynamic for steady flow:

$$\dot{Q}_{net} - \dot{W}_{net} = \sum_{outlets} \dot{m}h - \sum_{inlets} \dot{m}h \quad (1.3)$$

Applying the First law to the system shown in figure:

$$\dot{Q}_R - \dot{W}_i = \dot{m}(h_f - h_1) = -\dot{m}(h_1 - h_f) \quad (1.4)$$

The heat transfer process is reversible and isothermal in the Carnot cycle. Thus, from the second law of Thermodynamics:

$$\dot{Q}_R = \dot{m}T_1(s_2 - s_1) = -\dot{m}T_1(s_2 - s_f) \quad (1.5)$$

Because the process from point 2 to point f is isentropic, $S_2 = S_3$, where S is the entropy of the fluid. Substituting Q_R , we may determine the work requirement for the ideal system.

$$-\left(\frac{\dot{W}_i}{\dot{m}}\right) = T_1(s_1 - s_f) - (h_1 - h_f) = -\left(\frac{\dot{W}_i}{\dot{m}_f}\right) \quad (1.6)$$

1.4 Production of low temperature:

1.4.1 Joule-Thomson effect:

The Joule-Thomson valve or an expansion valve used in many practical liquefaction systems to produce low temperature. If we apply the first law for steady flow to the expansion valve, with the assumption of zero heat transfer and zero work transfer and for negligible kinetic and potential changes, we find $h_1 = h_2$. So the flow within the valve is irreversible and is not an isenthalpic process, the inlet and the outlet 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. So 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-Thomson coefficient.

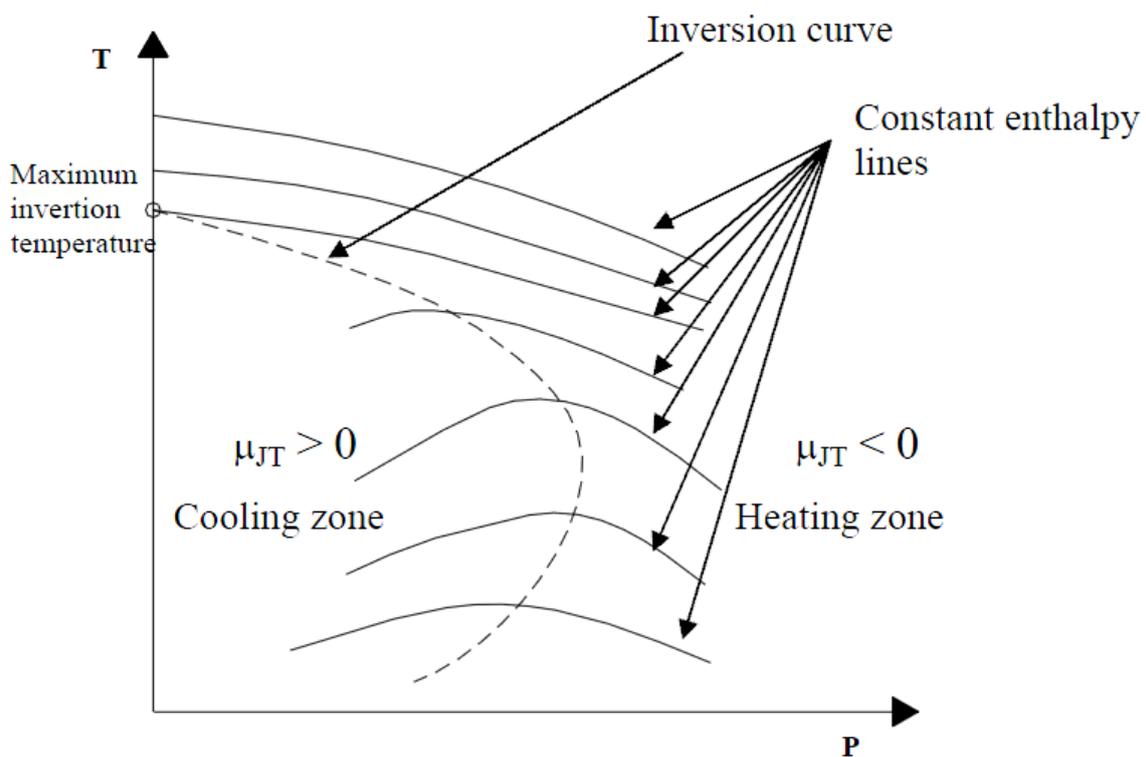


Fig 1.2: Isenthalpic expansion of a real gas

1.4.2 Adiabatic expansion:

The adiabatic expansion is the second method for producing low temperatures. This will be accomplished by the gas passing through a work producing device (expansion engine). In the ideal case, the expansion would be adiabatic and reversible therefore isentropic. In this case we can define the isentropic coefficient which expresses the temperature change due to a pressure change at constant entropy.

$$\mu_s = \left(\frac{\partial T}{\partial P}\right)_s \quad (1.7)$$

1.5 Objective:

The present research work has following objectives

1. Simulate the liquefiers for helium and investigate the effects of different operating parameter on the output of liquefaction process efficiency using ASPEN HYSYS simulator.
2. Process design means, determination of the type of thermodynamic processes included in the fixing the points (pressure and temperature) and thermodynamic cycle.
3. While designing the process, constraints, equipment availability and cost should be kept in mind. Process design also includes the setting the parameters up to the optimum condition that maximum amount of liquid will be obtained.

Chapter 2

Literature review

2.1 Literature review:

Hubbell and Toscano [1] presented an entropy generation concept for carrying out thermodynamic optimisation of the helium liquefaction cycle. Minta and Smith [2] used a similar method of minimisation of the generated entropy in a cycle model with continuous precooling. Khalil and McIntosh [3] carried out an exhaustive study to optimise inlet pressure, temperature of first expander and number of expanders. Also, Hilal [4] analysed the effect of the number of expansion engines in cascade form or in the independent form and pressure on the COP of the refrigerator and liquefier. He showed that there is a significant increase in coefficient of performance (COP) value in case of independent expansion engines over the one obtained in case of cascaded form. The required optimum pressure is also lower. In the recent past, this topic of cycle simulation is again gaining importance due to the increasing need of the efficient helium liquefiers for cooling of superconducting magnets. Nobutoki et al. [5] and Malaaen et al. [6] have presented simulation programs for the Large Helical Device (LHD) and the Large Hadron Collider (LHC) projects, respectively, for helium liquefaction/refrigeration plants in order to estimate, understand and analyse the performance of cryogenic processes before investing in the actual manufacturing of these plants. Helium liquefier based on the Collins cycle consisting of six heat exchangers and two reciprocating expanders, Atrey [7] has evaluated the relative importance of the effectiveness of each heat exchanger and efficiency of expanders on the performance of the liquefier. For the simulation of helium systems, a 32-parameter modified Benedict–Webb–Rubin (MBWR) EOS, which has been developed by McCarty and Arp [8] is widely accepted and considered as the most accurate one. Rijo Jacob Thomas et al.[9] evaluated that Substituting MBWR EOS by simpler equations of state (EOS(s)) at selected thermodynamic planes, where the simpler EOS(s) have the similar accuracy as that of MBWR EOS may enhance ease of computation. Some studies have investigated the importance of heat exchangers on a helium

liquefaction/refrigeration cycles. Daus et al. [10] have shown the power consumption, heat transfer surface and the relative plant costs as functions of the temperature difference of heat exchanger. Toscano et al. [11] have evaluated the thermodynamic performance of the central helium liquefier of Fermi National Accelerator Laboratory (FNAL) for different sets of temperature approach of heat exchangers. Khalil et al. [12] have given the practical temperature approaches of heat exchangers for different multi-expander Claude based helium refrigeration cycles having up to five expanders. Research on helium liquefiers has gained momentum due to the demand for more efficient large-scale helium liquefiers for cooling the superconducting magnets used in applications like particle accelerators, tokomaks, etc. Aronson [13] has discussed the factors affecting the expansion efficiency and the considerations to be made while using multi-expanders in a cycle. Khalil and McIntosh [14] has determined the optimum inlet temperature to expander for Claude-based refrigeration cycles up to six expanders. Hilal [15] has optimized both refrigeration and liquefaction cycles in terms of number of expanders, their arrangements and inlet temperature to expanders. For a 1.8K refrigerator with two expanders, Hilal and Eyssa [16] determined the optimum inlet temperature to expander and the flow fraction through expander.

2.2 Various Liquefaction systems:

2.2.1 Claude System:

The system consists of a compressor, three heat exchangers, expansion engine and a joule-thomson valve. The expansion engine is diverts a fraction of the incoming high-pressure gas stream performing work as the gas expands into low-pressure side. Modern liquefier is more complex than the Claude system but use similar combinations of expansion processes. The Claude system provides following advantages over the simple Joule-Thomson refrigeration scheme.

1. It has more efficient because part of the process is isentropic with inherently higher thermodynamic efficiency.
2. The efficiency can be improved by taking advantage of the work produced by the expansion circuit, an option that makes sense particularly for large systems/
3. There are two or more coupled flow circuits, the main cooling circuit and that through expander, it is possible to vary the fraction of the flow to achieve higher performance characteristics.

A flow scheme of the Claude liquefaction system is shown in fig 2.1

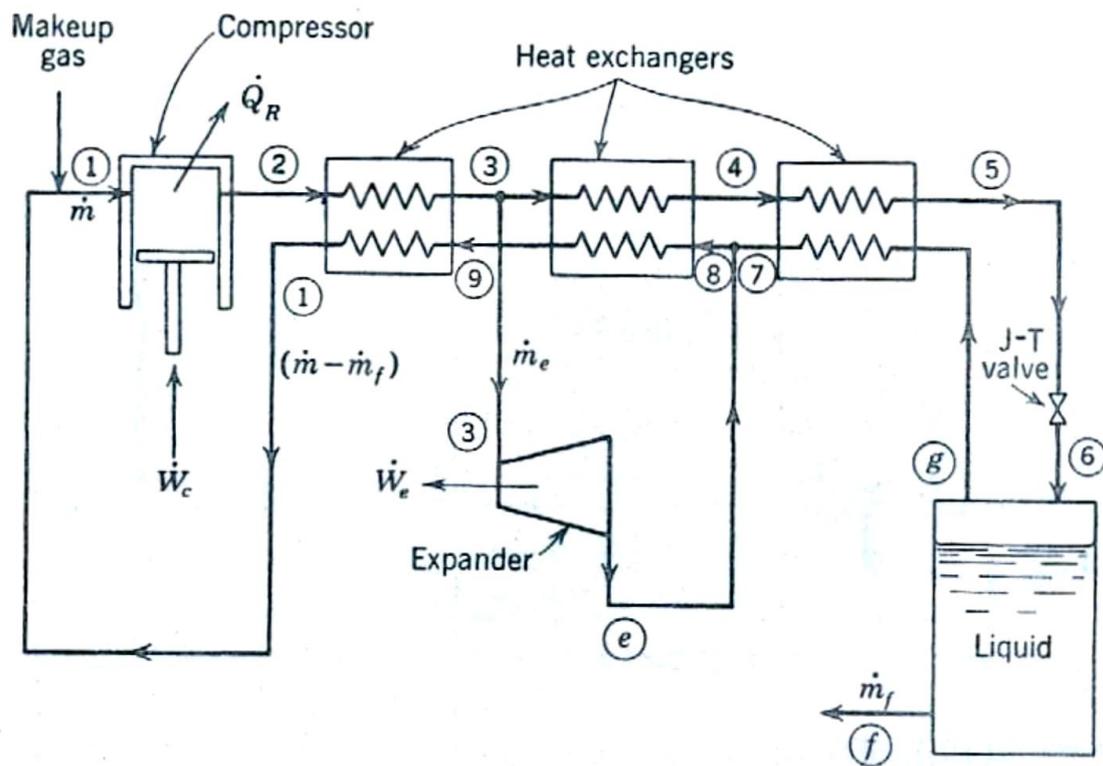


Fig 2.1: Claude liquefaction systems

is first used by Pictet for liquefaction of O_2 . The Cascade liquefaction system is special case of this concept, consist of a series of closed-cycle systems each using the change of state from liquid to gas to achieve cooling. Thus the true cascade system has working fluids with overlapping two-phase coexistence regions. Helium liquefiers based on the Claude systems or a modification of it have considerably higher liquefaction yield when liquid nitrogen precooling is included in the system.

The application of such a hybrid cascade system is shown in fig 3. The system consists of many circuits each containing a different working fluid. All circuits(except helium liquefier) operate in a closed-cycle mode, Where the liquids provides the cooling to next lower stage. So the system uses the Joule-Thomson effect for the working fluid to be below its inversion temperature before cooling occur. The working fluid has inversion temperatures above the boiling point of the next higher working fluid in the system. The helium is precooled by a closed cycle hydrogen liquefier as shown in fig 2.3. The inversion temperature of hydrogen is 202K. it can be precooled by liquid nitrogen or a similar fluid with $T < 202K$.

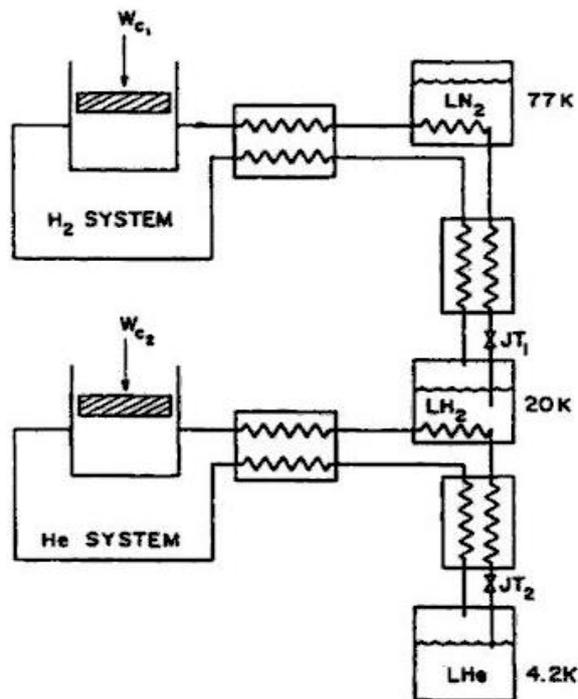


Fig 2.3: Hybrid cascade liquefaction system for liquefaction of helium.

2.2.3 Collins Helium Liquefaction System:

In 1940s the Collins helium liquefier worked out of an effort to produce a commercial system using expansion engines to precool several heat exchangers. The Collins system actually similar to the Claude system except uses between two and five expansion engines rather than just one. A schematic diagram of a two-engine Collins system is shown in fig 2.4. Depending on the number of expansion circuits, i , there are equal number of expansion circuit mass flows to select, \dot{m}_{e_i} . The temperature at the inlet to each expansion engine determined to compute the yield. Once these quantities are known a straightforward computation to determine the yield for the Collins system,

$$y = \frac{h_1 - h_2}{h_1 - h_l} + x_1 \frac{\Delta h_{e1}}{h_1 - h_l} + x_2 \frac{\Delta h_{e2}}{h_1 - h_l} \quad (2.1)$$

The first Collins liquefiers were developed with two expansion engines. During steady state operation the approximate values for the expander mass flow fractions are $x_1=0.30$ and $x_2=0.55$ at 15 bars. Insertion of these numerical values into (1) leads to yield of only 3.6%. However, it has been demonstrated the liquid yield could be improved by a factor of 2-3 by liquid nitrogen precooling.

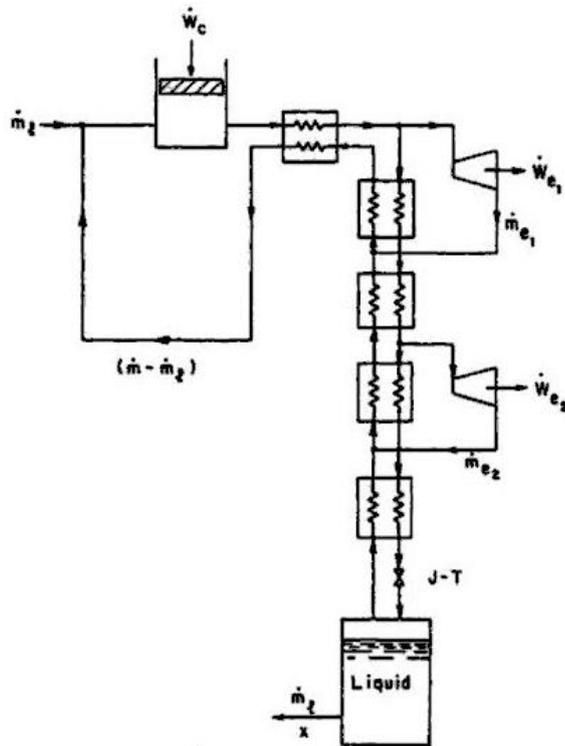


Fig 2.4: Collins helium liquefaction system

2.2.4 Stirling Cycle:

An alternative concept for the production of helium has worked out of the application of a heat engine cycle invented by Stirling in 1827. The Stirling cycle produces cooling by operating in reverse. The Phillips Company was the first to produce a liquefier that operated on this principle. The cycle consists of two isothermal and two isochoric processes. Cooling is achieved by adiabatic expansion of the working fluid, but instead of heat exchangers, the Stirling cycle uses the regenerator. The regenerator is a porous material used for storing the thermal inertia of the system. A schematic diagram of the Stirling system is shown in Fig 2.5. There are three main components: compressor, regenerator (R) and displacer (D). The displacer works in concert with the compressor to provide low-temperature compression and expansion processes.

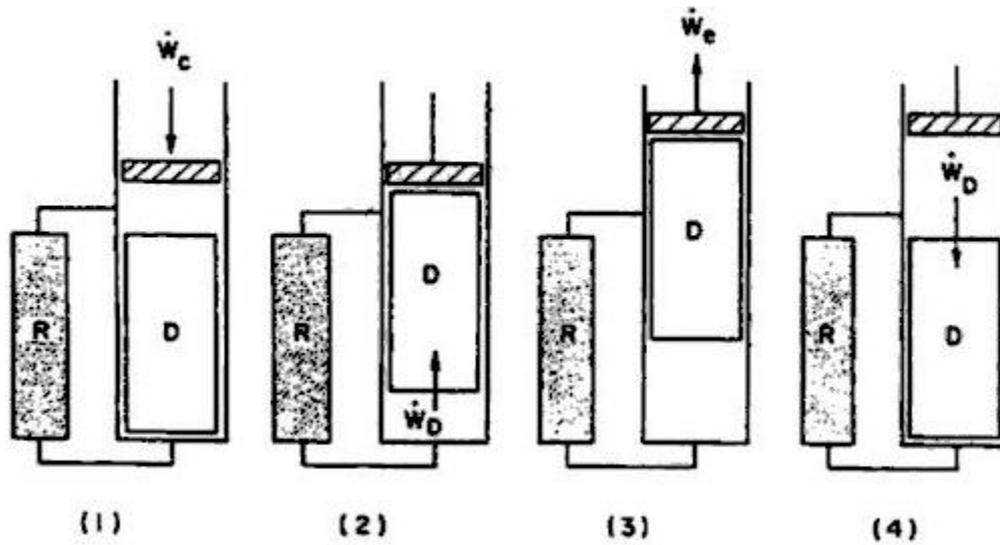


Fig 2.5: Stirling cycle refrigerator

At (1) - The helium is compressed

(2) - The displacer is moved to its upper position forcing the fluid through the regenerator into the expansion chamber. This process takes place at constant volume.

(3) - An expansion of the fluid in the lower chamber achieved by moving the displacer upward with the compressor.

(4) - The displacer is returned to its lowest position, forcing the fluid back through the regenerator to the compression chamber.

Chapter 3

Process design

3.1 Process design of helium liquefier:

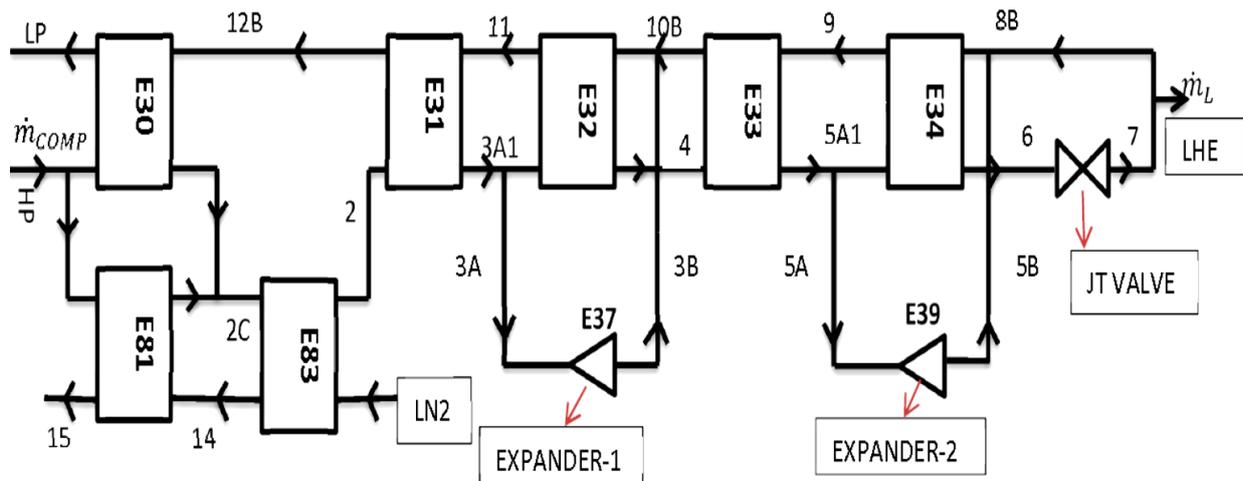


Fig 3.1: Schematic of helium-1610 liquefier

The helium liquefier consist of seven heat exchanger (includes 2 heat exchanger for liquid nitrogen precooling), two reciprocating expanders which is connected in parallel. When the design data in terms of nodal temperatures across expanders and heat exchanger, efficiencies of expanders and effectiveness of heat exchangers, mass flow rate through expanders, compressor and J-T valve, etc. are available then the helium liquefier is possible.

The design is critical at low temperature due to changes in thermophysical properties of helium gas the parameters like heat exchanger effectiveness, expander efficiencies, total mass flow rate, mass flow fraction through expanders, and temperature of gas before expansion, etc., and affects the performance of helium liquefier.

3.2 Simplification of process flow-sheet:

The computational complexity has been reduced simplification of process flow diagram. In order to reduce computational complexities following assumptions have been made without affecting the accuracy of the simulation results.

1. The pressure drops in the piping and adsorbers have been added to the valves or heat exchangers placed nearby.
2. Pressure, temperature, mass flow rate have been kept constant.
3. Compressor station and gas management system ignored
4. The by-pass lines and manual valves ignored. So that the straight forward cool-down sequence adopted.

This led to the simplification of the original PFDs, shown in fig.3.1.

3.3 Component and parameter analysis:

A. Effectiveness of heat exchangers, ϵ :

The effectiveness of heat exchangers, ϵ , is defined as

$\epsilon = \text{actual heat transfer} / \text{maximum possible heat transfer}$

$$\epsilon = C_c(T_{co} - T_{ci}) / C_{min}(T_{hi} - T_{ci}) \quad (3.1)$$

$$= C_h(T_{hi} - T_{ho}) / C_{min}(T_{hi} - T_{ci}) \quad (3.2)$$

Where,

C – Capacity rate (product of mass flow rate and specific heat capacity of gas)

Suffix c and h – cold and hot fluid respectively

Suffix o and i - outlet and inlet respectively

C_{min} – Smaller quantity of C_c and C_h

B. Efficiency of expansion engine, η :

The efficiency of expansion engine, η , is defined as

$\eta = \text{actual enthalpy drop} / \text{maximum possible}$

$$\text{Enthalpy drop} = (h_1 - h_2) / (h_1 - h_{2i}) \quad (3.3)$$

Where,

h_1 - The enthalpy at the point where expansion takes place

h_2 - The enthalpy at the actual point after expansion

h_{2i} - The enthalpy at the point if the expansion is isentropic in nature.

C. Throttle valve (J-T Valve):

Throttling is an isenthalpic process. Equating the enthalpies before and after throttling

$$h_i = h_o \quad (3.4)$$

Where,

h_i - Enthalpy before throttling

h_o - Enthalpy after throttling

D. Yield:

The rate of liquid production (\dot{m}_L) is nondimensionalized as the fraction of the total compressor flow (\dot{m}_{COMP}).

$$\text{Yield} = \dot{m}_L / \dot{m}_{COMP} \quad (3.5)$$

3.4 T-S Diagram:

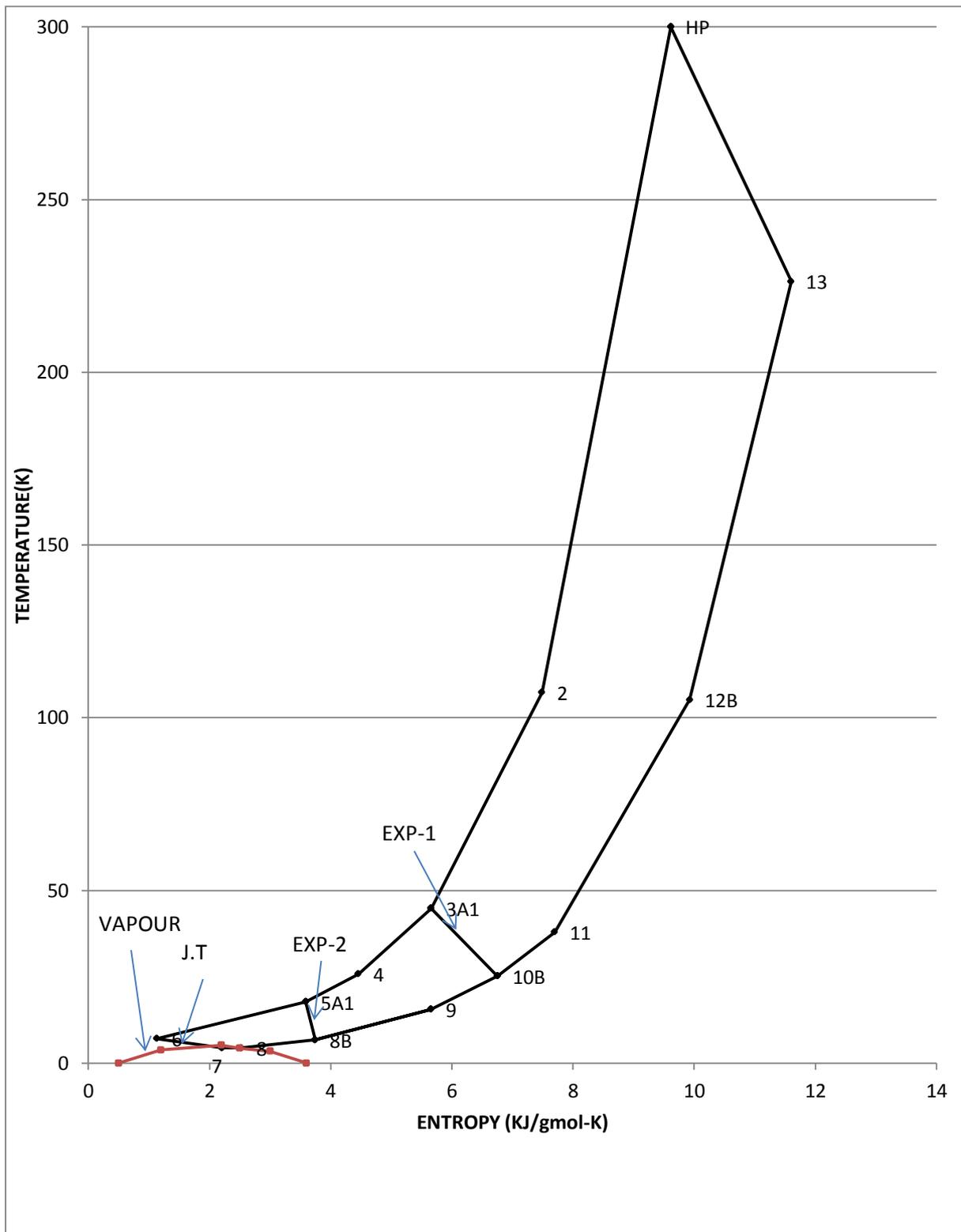


Fig 3.2: T-S Diagram of helium liquefier

3.5 Aspen One:

A. Introduction:

Aspen one is software and it is AspenTech's comprehensive set of software solutions and professional services designed to help process companies achieve their operational excellence objectives. It gives the value of simulation models to help process companies increase operational efficiency and profitability across their global enterprise. Aspen-one cover four major fields Chemical, Energy, Polymer, Pharmaceuticals.

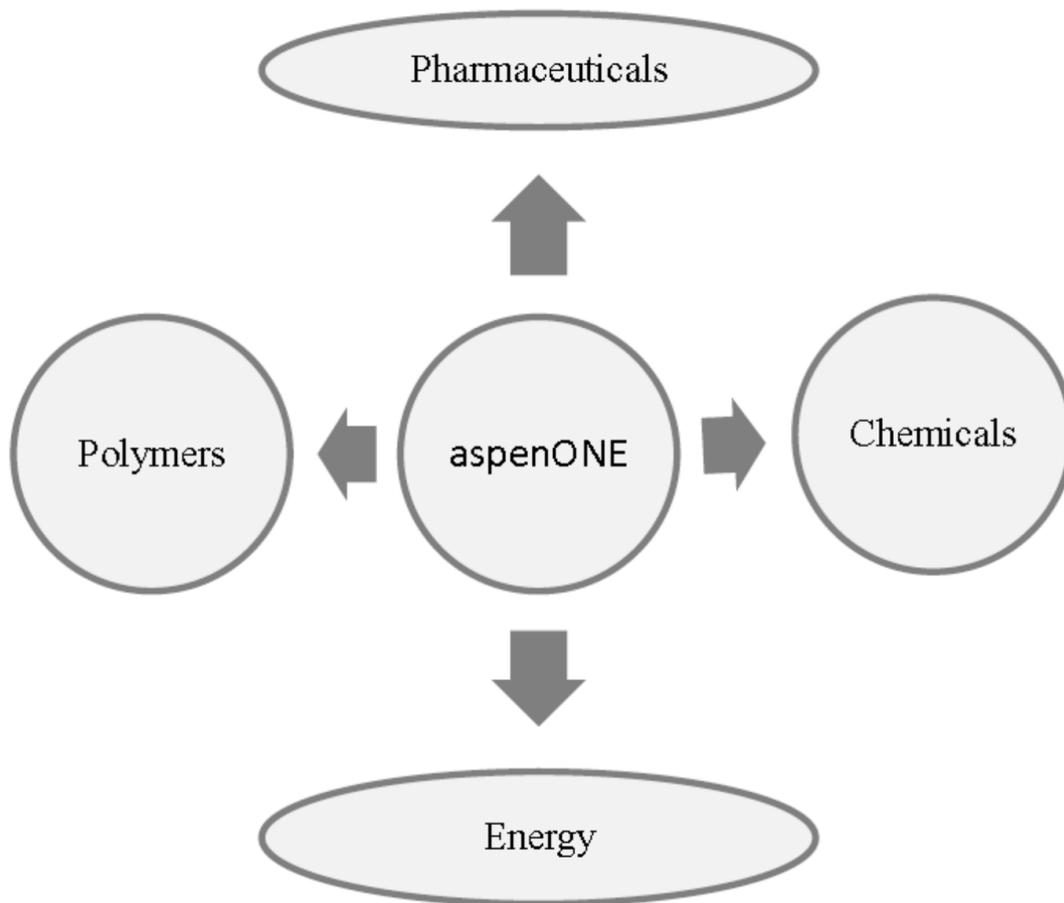


Fig 3.3: Business areas of aspen one

B. Aspen one engineering classification:

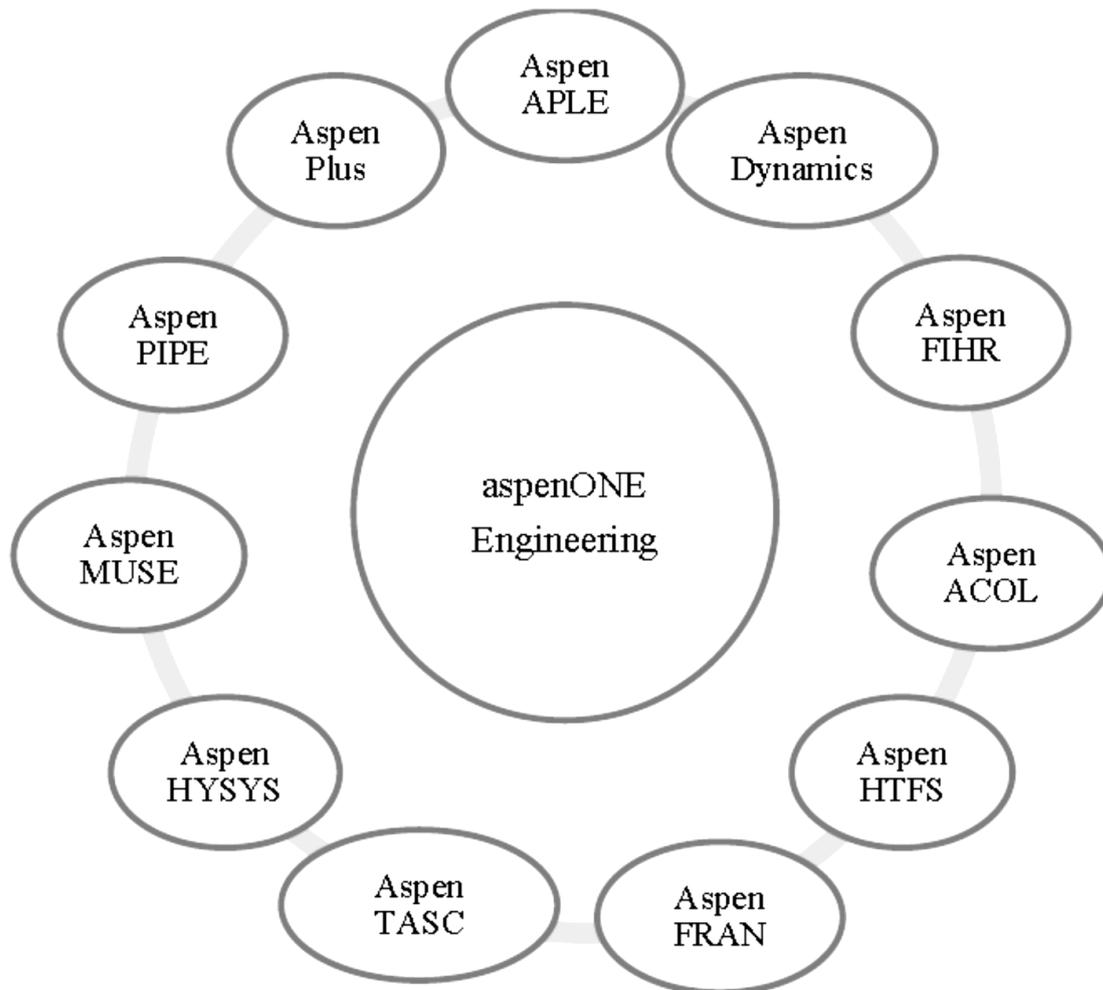


Fig 3.4: aspen one engineering classification

Aspen Hysys is a process simulation environment used in many processing industries like Gas & Oil and Refining. With Aspen Hysys can create rigorous steady state and dynamic models for plant design, troubleshooting, performance monitoring, business planning, operational improvement, and asset management. Through Aspen Hysys interface, can easily manipulate process variables and unit operation topology as well as fully customize your simulation using its customization and extensibility capabilities. The process simulation of Aspen Hysys enables to predict the behaviour of a process using basic engineering relationships such as mass and energy balances, phase and chemical equilibrium and reaction kinetics. With reliable thermodynamic data, realistic operating conditions and the rigorous Aspen Hysys equipment models, they can simulate actual plant behaviours. Some of the important Aspen Hysys features are listed below:

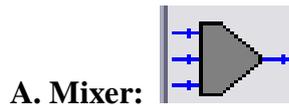
- **Windows Interoperability:** Hysys interface contains a process flow sheet view for graphical layout, data browser view for entering data the patented Next expert guidance system to guide the user through a complete and consistent definition of the process flow sheet.
- **Plot Wizard:** Hysys can enable the user to easily create plots of simulation results.
- **Flow sheet Hierarchy and Templates:** Collaborative engineering is supported through hierarchy blocks that allow sub-flow sheets of greater detail to be encapsulated in a single high-level block. These hierarchy blocks can be saved as flow sheet templates in libraries.
- **Equation-Oriented Modelling:** Advanced specification management for equation oriented model configuration and sensitivity analysis of the whole simulation or specific parts of it. The combination of Sequential Modular and Equation Oriented solution technology allows the user to simulate highly nested processes typically in the chemical industry.

- Thermo physical Properties: Physical property models and various data are keys to generating accurate simulation results that can be used with confidence. Aspen Hysys uses the extensive and proven physical property models, data, estimation methods available in Aspen Properties™, which covers a wide range of processes from simple ideal behaviour to strongly electrolytes and non-ideal mixtures. The built-in database contains parameters for more than 8500 components, covering organic and inorganic, aqueous, and salt species and more than 37000 sets of binary interaction parameters for 4000 binary mixtures.
- Convergence Analysis: to automatically analyse and suggest optimal tear streams, flow sheet convergence method and solution sequence for even the largest flow sheets with multiple stream and information recycles.
- Sensitivity Analysis: to easily generate tables and plots showing how process performance varies with changes to selected equipment specifications and operating conditions.
- Design Specification: Hysys has capabilities to automatically calculate operating conditions or equipment parameters to meet specified performance targets.
- Data-Fit: to fit process model with actual plant data and ensure an accurate validated representation of the actual plant.
- Determine Plant Operating Conditions that will maximize any objective function specified, including process yields, stream purities, energy usage, and process economics.
- Simulation Basic Manager: This feature available in Aspen Hysys for using different fluids like air, acetylene, nitrogen, helium as per requirement. Also several fluid packages like ASME, BWRS, and MBWR are provided to calculate properties at different states.

3.6 The components or blocks or equipment:

The description of the various components and the conditions at which they operate are described as below.

1. Aspen Hysys Object:

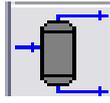


The Mixer operation combines two or more inlet streams to produce a single outlet stream. A complete balance of heat and material is performed with the Mixer. That is, the one unknown temperature among the inlet and outlet streams is always calculated rigorously. If the properties of all the inlet streams to the Mixer are known (temperature, pressure, and composition), the properties of the outlet stream is calculated automatically since the composition, pressure, and enthalpy is known for that stream.



The LNG (Liquefied Natural Gas) exchanger model solves heat and material balances for multi-stream heat exchangers. The solution method can handle a wide variety of specified and unknown variables. For the overall exchanger, we can specify various parameters, including heat leak or heat loss, UA and temperature approaches. Two solution approaches are employed; in case of a single unknown, the solution is directly calculated from an energy balance. In case of multiple unknowns, an iterative approach is used that attempts to determine the solution that satisfies not only the energy balance, also any constraints, such as temperature approach or UA.

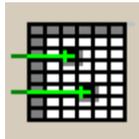
C. Separator:



Multiple feeds, one vapour and one liquid product stream. In Steady State mode, the Separator divides the vessel contents into its constituent vapour and liquid phases

2. Logical units:

A. Spreadsheet:



The Spreadsheet applies the functionality of Spreadsheet programs to flowsheet modelling. With essentially complete access to all process variables, the Spreadsheet is powerful and has many applications in HYSYS. The HYSYS Spreadsheet has standard row and column functionality. You can import/export a variable, or enter a number or formula anywhere in the Spreadsheet.

The Spreadsheet can be used to manipulate or perform custom calculations on flowsheet variables. Because it is an operation calculations are performed automatically; Spreadsheet cells are updated when flowsheet variables change.

One application of the Spreadsheet is the calculation of pressure drop during dynamic operation of a Heat Exchanger. In the HYSYS Heat Exchanger has constant pressure drop on both sides regardless of flow. However, using the Spreadsheet, the actual pressure drop on one or both sides of the exchanger could be calculated as a function of flow. Complex mathematical formulas can be created, by using syntax which is similar to conventional Spreadsheet. Arithmetic, trigonometric, and logarithmic functions are examples of the mathematical functionality available in the Spreadsheet. The Spreadsheet also provides logical programming in addition to its comprehensive mathematical capabilities.



B. Recycle:

The streams are recycled by using this logical operation. The logical block connects the two streams around the tear (remember the tear does not have to be the official "recycle", but instead should be the best place in the loop to make the break for convergence purposes). The flow sheet must have completed before you can install the RECYCLE. That means there need to be values for both the calculated stream and the assumed stream. Once the Recycle is attached and starts to run, HYSYS compares the two values between two streams, adjusts the assumed stream, and runs the flow sheet again. HYSYS repeats this process until the two streams match within specified tolerances.

Those tolerances are set on the Parameters Page. There are tolerances for temperature, pressure, Vapour Fraction, Flow, Enthalpy, and Composition. The tolerances you enter are *not* absolute. They are multipliers for HYSYS internal convergence tolerances. For example, the internal value for Temperature is .01 degrees (note that is in Kelvin, because HYSYS does all of its calculations in an internal unit set), above explanation defines multiplier often means the two streams must be within a tenth of a degree of each other.

On the Numerical Page, among other things, you may set the RECYCLE to either Nested (the Op is called whenever it is encountered in the flow sheet) or Simultaneous (all of the RECYCLES are invoked).

3.7 Procedure of process design using Aspen Hysys:

To create a new case, from the File menu, select New. In the sub-menu, click Case. Then the Simulation Basis Manager window will appear.

The Simulation Basis Manager is the important property view of the Simulation environment. One of the important concepts that HYSYS is based upon is Environments. The Simulation

Basis environment allows to input or access information within the Simulation Basis manager while the other areas of HYSYS are put on holds avoiding unnecessary Flowsheet calculations. Once enter the Simulation environment, all changes that were made in the Simulation environment will take effect at the same time. Conversely, all thermodynamic data is fixed and will not be changed as manipulations to the Flowsheet take place in the Simulation environment. The minimum information required before leaving the Simulation Basis manager is atleast one installed Fluid Package with an attached Property Package and At least one component in the Fluid Package. The Components Manager is available on the Components tab of the Simulation Basis Manager. This tab provides a location where sets of chemical components being modelled may be retrieved and controlled. These component sets are stored in the form of Component Lists that may be a collection of library pure components. The Components Manager always contains a Master Component List that cannot be deleted. This master list contains every component available from "all" component lists. If add components to any other component list, they automatically added to the Master Component List. Also, if delete a component from the master component, it also gets deleted from any other component list that is using that component.

The Fluid Package Manager is available on the Fluid Pkgs tab of the Simulation Basis Manager. This tab provides a location where multiple fluid packages can be created and controlled. Each fluid package available to simulation is listed in the Current Fluid packages group with the following information: name, number of components attached to the fluid package, and property package attached with the fluid package. From the Fluid Pkgs tab of the Simulation Basis Manager click either the View or Add button to open the Fluid Package property view. Make sure select the proper fluid package when using the view option. Click on the Set Up tab. From the Component List Selection drop-down list, select the components you want to use in your fluid package.

3.8 Fluid package:

The applicability of Equation of state in modelling helium system has been explained by Rijo Jacob Thomas [9]. For modelling helium system proper equation of state is used. The application of proper EOS increase the accuracy of the simulation result because the accuracy is depends upon the property data. For computation of thermodynamics properties of helium 32-parameter MBWR equation of state is used and it eliminates the difficulties in computation process.

The thermodynamics properties are generated from the ALL PROPS[®] software, by giving the input values in terms of temperature and pressure. This generated thermodynamics properties are compared with Apen Hysys simulation result. From this comparison gives small percentage of divergence so using 32-parameter MBWR EOS gives accurate solution when compared with other equation of state. The comparison of MBWR EOS with ALL PROPS[®] are shown in fig.

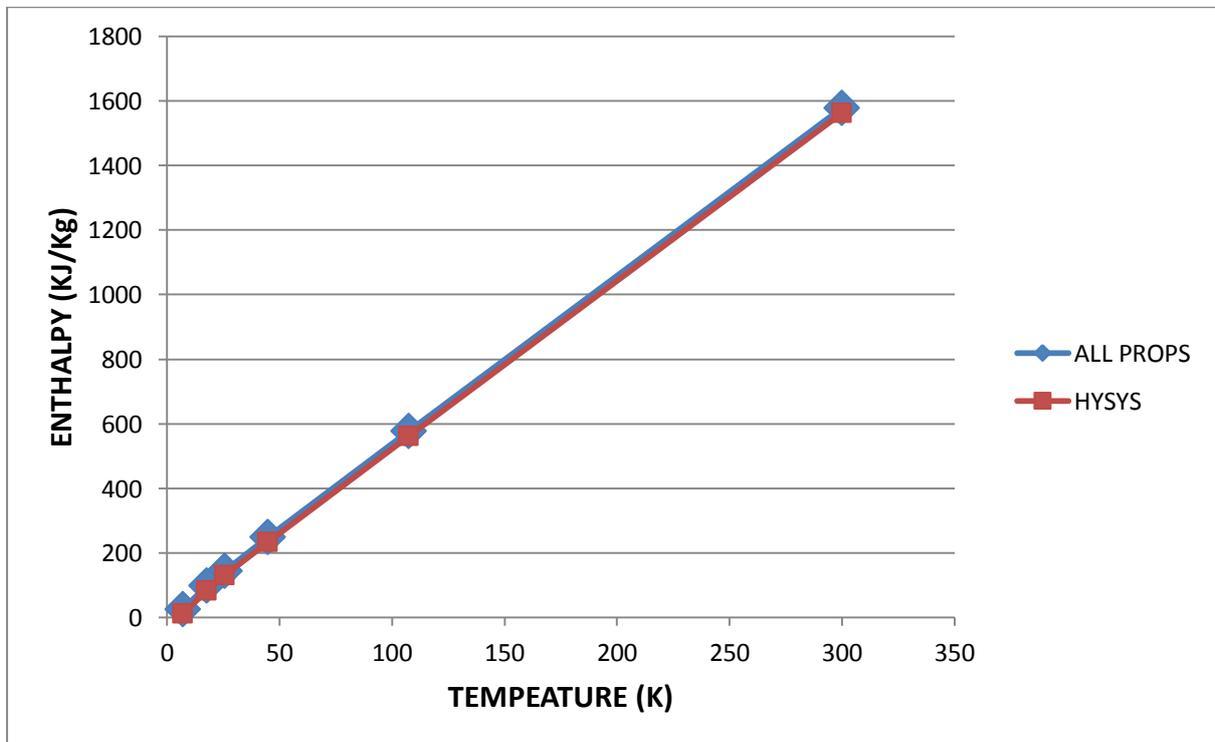


Fig 3.5: Variation of temperature with Enthalpy

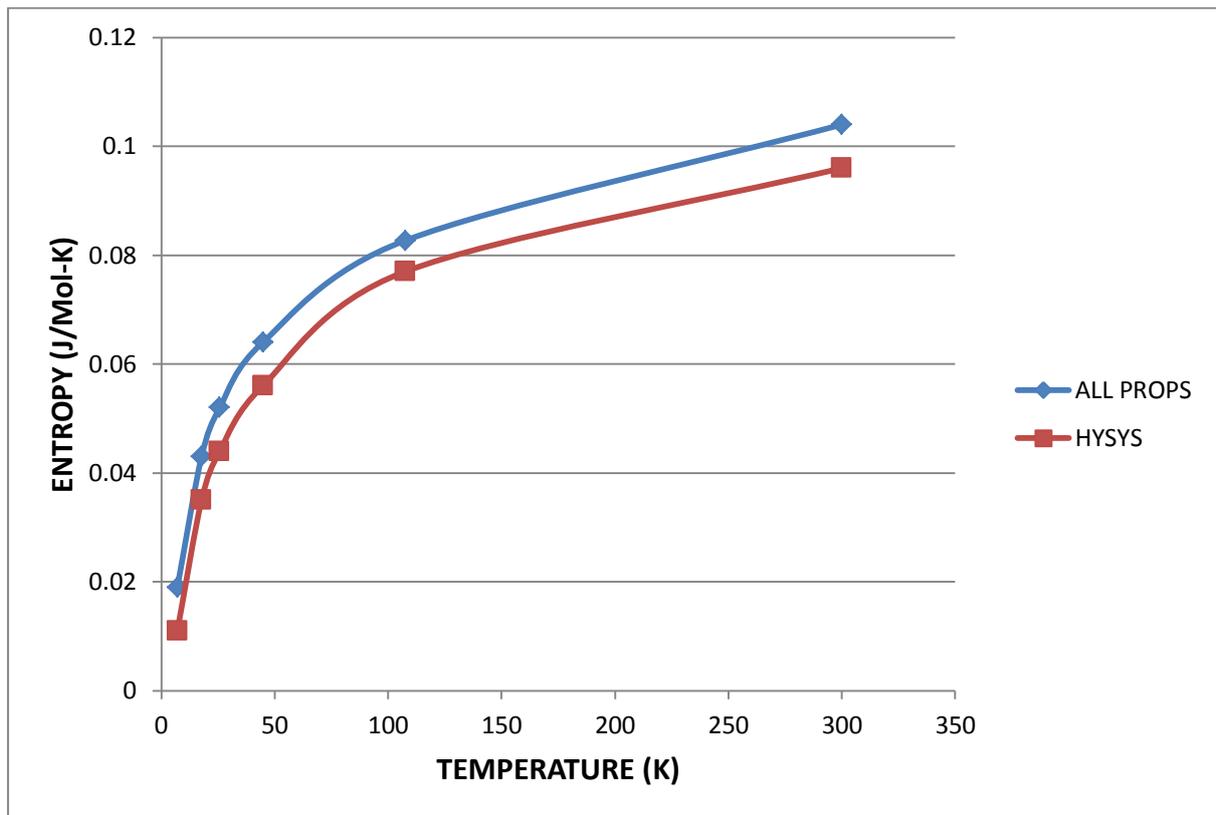


Fig 3.6: Variation of temperature with Entropy

3.9 Input value:

From simulation basis manager in the component pure helium is taken as material stream and MBWR as fluid packages. There all unit operations are arranged in order and linked by material streams. For each unit operations following input values are entered.

1. HP (inlet stream)

Mass flow rate = 300 kg/hr

Inlet temperature = 300 K

Inlet pressure = 15 bar

2. LN2 (Liquid nitrogen inlet streams)

Mass flow rate = 300 kg/hr

Inlet temperature = 77.35 K

Inlet pressure = 1.013 bar

3. Separator-1

Flow ratio through liquid nitrogen precooling = 0.40

4. Separator-2, 3

Flow ratio through expansion engine = 0.40

5. Expansion Engine (E37)

Efficiency = 75%

Outlet pressure = 1.548 bar

6. Expansion Engine (E39)

Efficiency = 75%

Outlet pressure = 2.732 bar

7. Heat Exchanger (E30, E31, E32, E33, E34)

Pressure drops in all Hx = 0.1 bar

LMTD

E30 = 26.73 C

E31 = 3.94 C

E32 = 2.48 C

E33 = 0.93 C

E34 = 1.10 C

8. J-T Valve

Outlet pressure = 1.150 bar

3.10 Process flow in Aspen Hysys:

Amount of liquid yield can be seen from the tank. It comes 18.98 kg/hr.

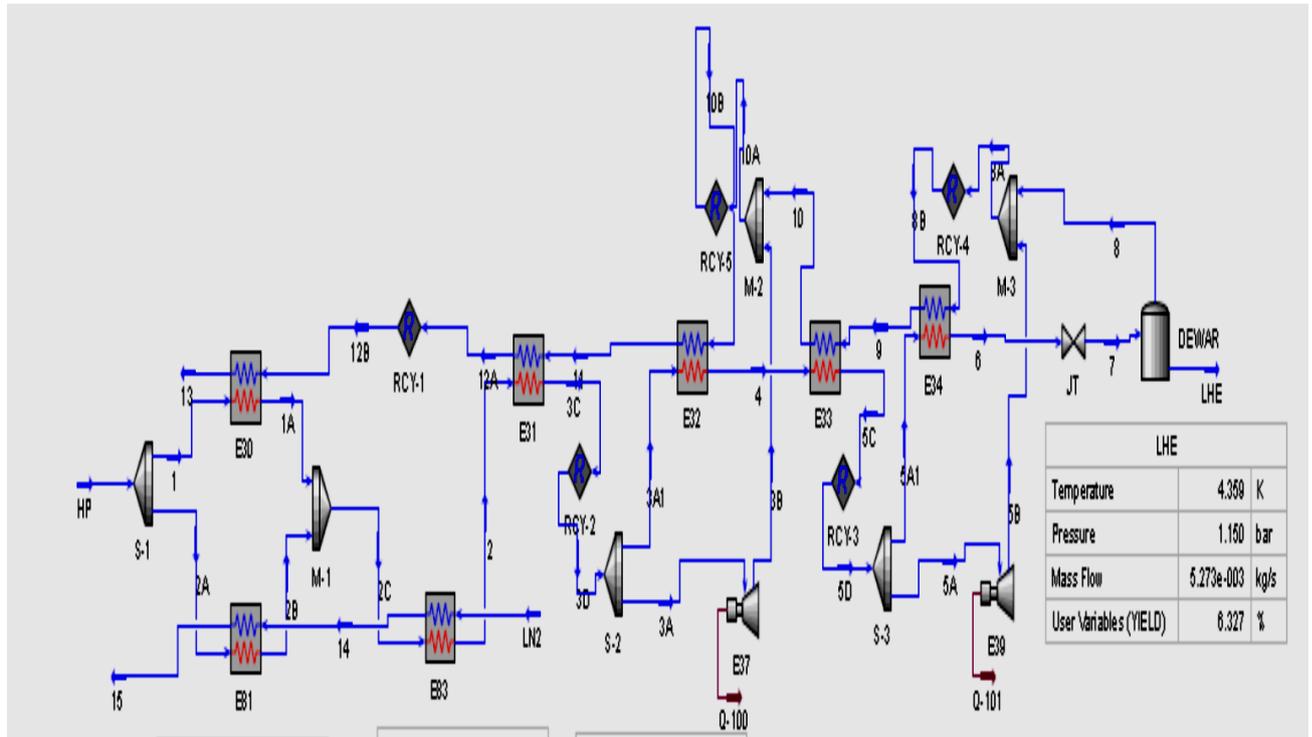


Fig 3.7: Process Flow Diagram of Helium Liquefier in Aspen Hysys

Fig 3.7 shows the process flow diagram that drawn in Hysys. Table 3.1 shows the state and properties of all the streams in the process flow diagram mass flow at LHE, gives the liquid helium that produced.

Name	HP	1	2A	1A	2B
Vapour Fraction	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature(K)	300.0	300.0	300.0	111.2	140.0
Pressure(bar)	15.00	15.00	15.00	14.90	14.90
Molar Flow (kgmole/s)	2.082e-002	1.249e-002	8.327e-003	1.249e-002	8.327e-003
Mass Flow(kg/s)	8.333e-002	5.000e-002	3.333e-002	5.000e-002	3.333e-002
Liquid Volume Flow(m3/s)	6.717e-004	4.030e-004	2.687e-004	4.030e-004	2.687e-004
Heat Flow(kW)	130.2	78.13	52.09	29.09	24.39
Name	2C	2	3D	3A1	3A
Vapour Fraction	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature(K)	122.7	107.5	44.70	44.70	44.70
Pressure(bar)	14.90	14.80	14.70	14.70	14.70
Molar Flow (kgmole/s)	2.082e-002	2.082e-002	2.082e-002	1.249e-002	8.327e-003
Mass Flow(kg/s)	8.333e-002	8.333e-002	8.333e-002	5.000e-002	3.333e-002
Liquid Volume Flow(m3/s)	6.717e-004	6.717e-004	6.717e-004	4.030e-004	2.687e-004
Heat Flow(kW)	53.48	46.86	19.44	11.66	7.775
Name	4	3B	5D	5A1	5A
Vapour Fraction	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature(K)	25.73	24.80	17.72	17.72	17.72
Pressure(bar)	14.60	1.548	14.50	14.50	14.50
Molar Flow(kgmole/s)	1.249e-002	8.327e-003	1.249e-002	7.494e-003	4.996e-003
Mass Flow(kg/s)	5.000e-002	3.333e-002	5.000e-002	3.000e-002	2.000e-002
Liquid Volume Flow(m3/s)	4.030e-004	2.687e-004	4.030e-004	2.418e-004	1.612e-004
Heat Flow(kW)	6.502	4.275	4.167	2.500	1.667
Name	6	5B	7	<i>LHE</i>	8
Vapour Fraction	1.0000	1.0000	0.8242	0.0000	1.0000
Temperature(K)	7.070	10.79	4.359	4.359	4.359
Pressure(bar)	14.40	2.732	1.150	1.150	1.150
Molar Flow(kgmole/s)	7.494e-003	4.996e-003	7.494e-003	1.317e-003	6.177e-003
Mass Flow(kg/s)	3.000e-002	2.000e-002	3.000e-002	5.273e-003	2.473e-002
Liquid Volume Flow(m3/s)	2.418e-004	1.612e-004	2.418e-004	4.250e-005	1.993e-004

Heat Flow(kW)	0.3567	1.037	0.3567	-2.367e-002	0.3804
Name	8B	9	10	10A	11
Vapour Fraction	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature(K)	6.739	15.50	25.42	25.14	37.81
Pressure(bar)	1.150	1.050	0.9500	0.9500	0.8500
Molar Flow(kgmole/s)	1.117e-002	1.117e-002	1.117e-002	1.950e-002	1.952e-002
Mass Flow(kg/s)	4.473e-002	4.473e-002	4.473e-002	7.806e-002	7.813e-002
Liquid Volume Flow(m3/s)	3.605e-004	3.605e-004	3.605e-004	6.292e-004	6.298e-004
Heat Flow(kW)	1.416	3.559	5.892	10.17	15.34
Name	12A	13	LN2	14	15
Vapour Fraction	1.0000	1.0000	0.0000	0.4066	1.0000
Temperature(K)	105.4	226.2	77.35	76.49	280.0
Pressure(bar)	0.7500	0.6500	1.013	0.9130	0.8130
Molar Flow(kgmole/s)	1.952e-002	1.952e-002	2.975e-003	2.975e-003	2.975e-003
Mass Flow(kg/s)	7.813e-002	7.813e-002	8.333e-002	8.333e-002	8.333e-002
Liquid Volume Flow(m3/s)	6.298e-004	6.298e-004	1.033e-004	1.033e-004	1.033e-004
Heat Flow(kW)	42.77	91.81	-10.12	-3.499	24.20
Name	12B	3C	5C	8A	10B
Vapour Fraction	1.0000	1.0000	1.0000	1.0000	1.0000
Temperature(K)	105.4	44.69	17.73	6.743	25.15
Pressure(bar)	0.7500	14.70	14.50	1.150	0.9500
Molar Flow(kgmole/s)	1.952e-002	2.082e-002	1.249e-002	1.117e-002	1.952e-002
Mass Flow(kg/s)	7.813e-002	8.333e-002	5.000e-002	4.473e-002	7.813e-002
Liquid Volume Flow(m3/s)	6.298e-004	6.717e-004	4.030e-004	3.605e-004	6.298e-004
Heat Flow(kW)	42.77	19.43	4.169	1.417	10.18

Table 3.1: Material stream properties from Aspen Hysys

Chapter 4

Results and Discussion

4.1 Performance analysis:

The parametric variation on the liquefaction system gives the optimum performance. This analysis also describe the off design performance analysis. The parameters are

- Effectiveness of heat exchangers, ϵ
- Efficiency of expanders(Expansion Engine), η
- Mass flow ratio diverted for precooling, X_0
- Mass flow ratio diverted through Expanders, X_1 , and X_2

4.1.1 Mass flow ratio diverted through Expanders, X_1 , and X_2 :

The cold produced in expanders and in the J-T expansion valve is responsible for bringing down the temperature of helium gas from 300K to below 7.5K. The mass flow rate diverted through the expander is directly proportional to the refrigeration effect produced in the expander. Temperature level of expanders decides if machine would function as a liquefier or as refrigerator.

When increasing expander flow the cooling produced by the expander is increased so the high pressure stream gets more cooling. The temperature before J-T valve is decreases it also increases the yield. At the same time vapour returning to the compressor is reduces so the mass flow through the expander is reduces consequently the yield is reduced.

To identify the optimum mass flow requirement of each expander, the distribution of the total expander flow between the two expander (E37, E39) is varied. When varying the expander flow other parameters affect the cycle performance such as isentropic efficiency of expanders, heat exchanger effectiveness, etc. are kept constant.

1. Mass flow ratio diverted through the expanders ($\epsilon_1=\epsilon_2=\epsilon_3=\epsilon_4=\epsilon_5=0.97$, $\eta_1=\eta_2=0.75$)

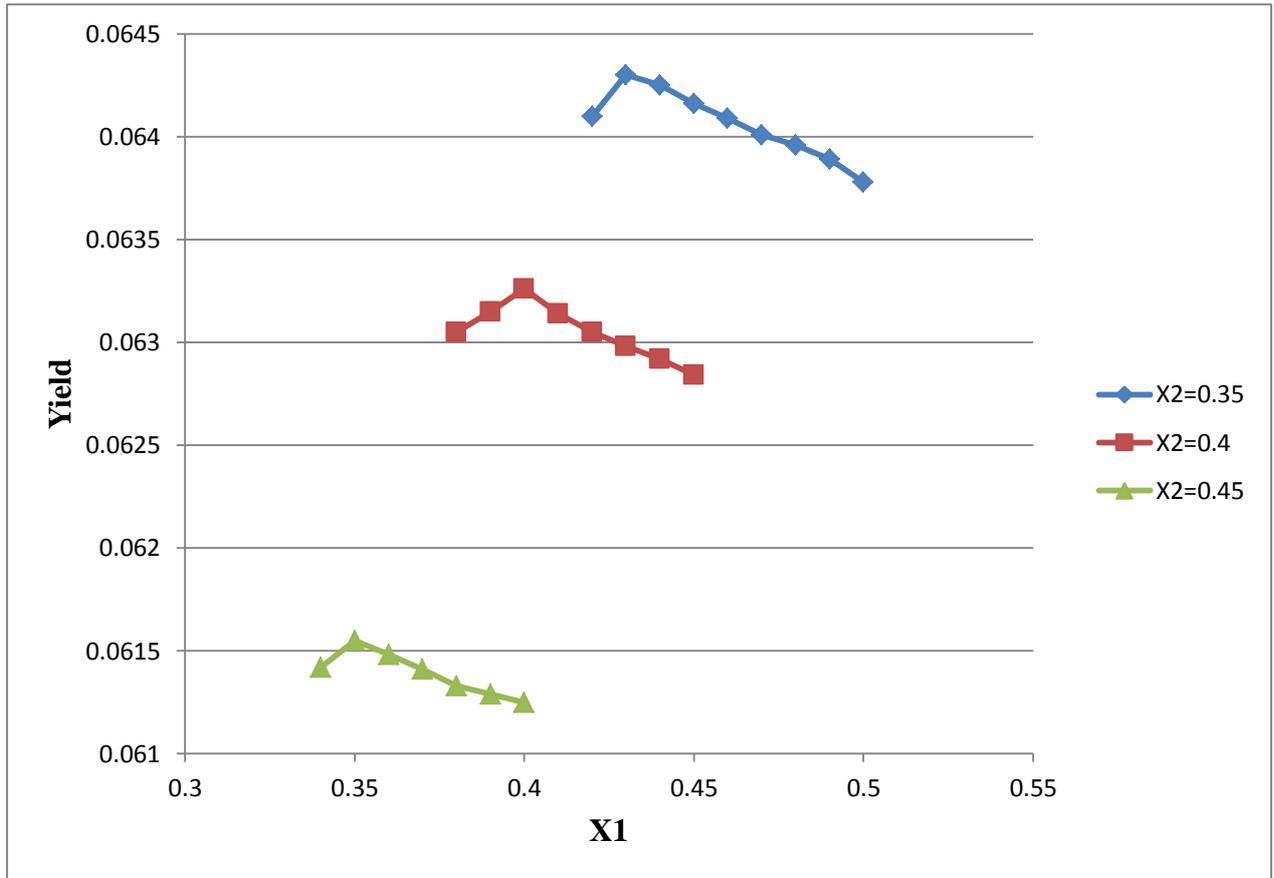


Fig 4.1: Variation of yield with mass flow ratio diverted through the expanders

Observations:

It is noticed from the Fig.4.1 that the combination of $X1=0.43$ and $X2=0.35$ shows the maximum value as compared to any other combinations of $X1$ and $X2$. This is the optimum value for the given ϵ and η indicated. It states that, for this combination of $X1$ and $X2$, the output in terms of liquefaction quantity is maximum. The optimum value lies at a combination where $X1$ and $X2$ together constitute about 78-79% of the total mass flow rate while the remaining 21-22% of the total mass flow rate goes through the J-T valve. Below the 77% there is no liquefaction indicated by the divergence of the program. This is due to the point of the isenthalpic line after J-T expansion translates into the gaseous region, i.e. outside dome.

4.1.2 Mass flow ratio diverted for precooling, X_0 :

Mass flow ratio diverted for liquid nitrogen precooling gives some effect in the production of yield. The yield is reduced because the liquefaction produced in the cycle is directly proportional to the mass flow rate directed to expand through the J-T Valve. The variation of yield with mass flow ratio as shown in Fig.4.2

1. Mass flow ratio diverted for precooling ($\epsilon_1=\epsilon_2=\epsilon_3=\epsilon_4=\epsilon_5=0.97$, $\eta_1=\eta_2=0.75$)

MASS FLOW, X_0	YIELD
0.36	0.07321
0.38	0.06726
0.4	0.06327
0.42	0.05895
0.44	0.05606
0.46	0.05327

Table 4.1: variation of yield with precooling flow ratio

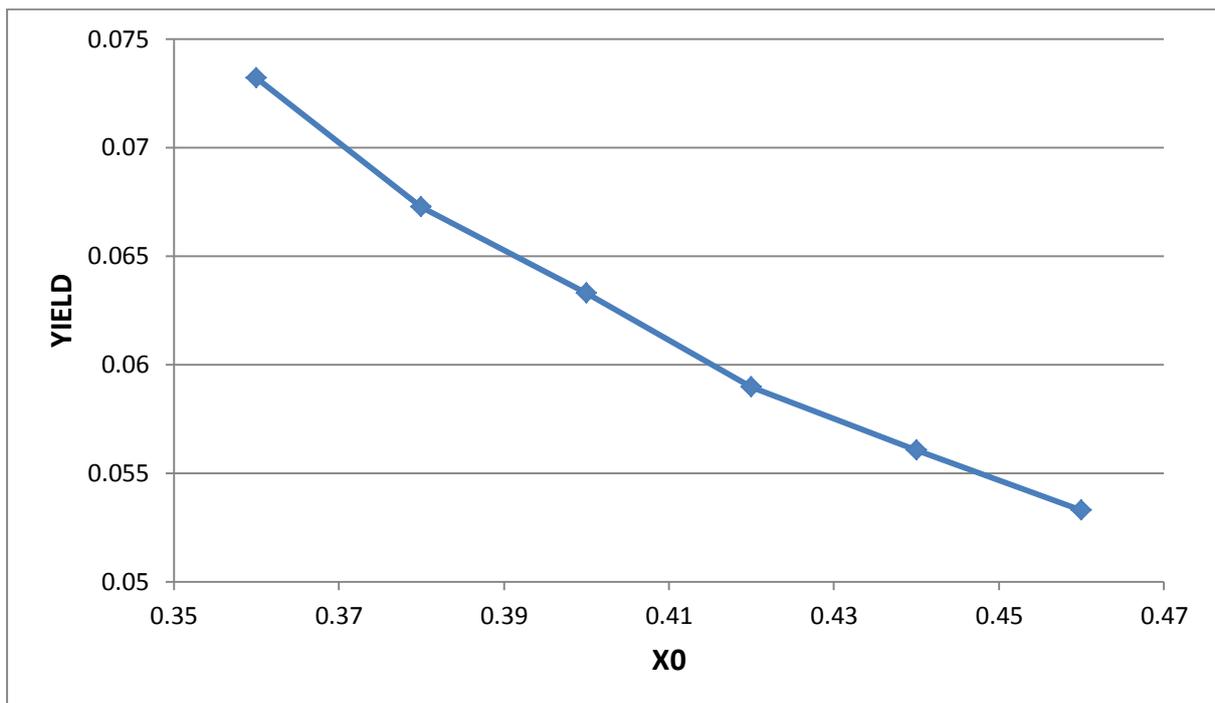


Fig 4.2: Effect of yield with mass flow X_0

4.1.3 Effectiveness of heat exchangers, ϵ :

The T-S shows that the temperature before J-T expansion is important to determine the amount of helium liquefied. The main purpose of heat exchanger is to reduce the temperature from 300K to a reasonable value of T7 in order to get the liquefaction after the J-T expansion.

The ϵ of the heat exchanger increases the performance of the liquefier is increases because decrease in final value of T7 for a given mass flow rate. The temperature of all points is not decreased by the same amount. The temperature of T7 decreases by various means i.e. by increasing the ϵ of any heat exchangers or any two or all heat exchangers, and also be to an increase in the η of any or all the expanders.

1. Heat exchangers, ($\eta_1=\eta_2=0.75$, $X1=X2=0.4$)

EFFECTIVENESS	YIELD				
	E30	E31	E32	E33	E34
95	0.06149	0.06158	0.06172	0.06268	0.06281
96	0.06244	0.06232	0.0625	0.06298	0.063035
97	0.06327	0.06327	0.06327	0.06327	0.06327
98	0.06416	0.06435	0.06406	0.06355	0.06354
99	0.065	0.06524	0.06488	0.06382	0.06385

Table 4.2: variation of yield with heat exchanger effectiveness

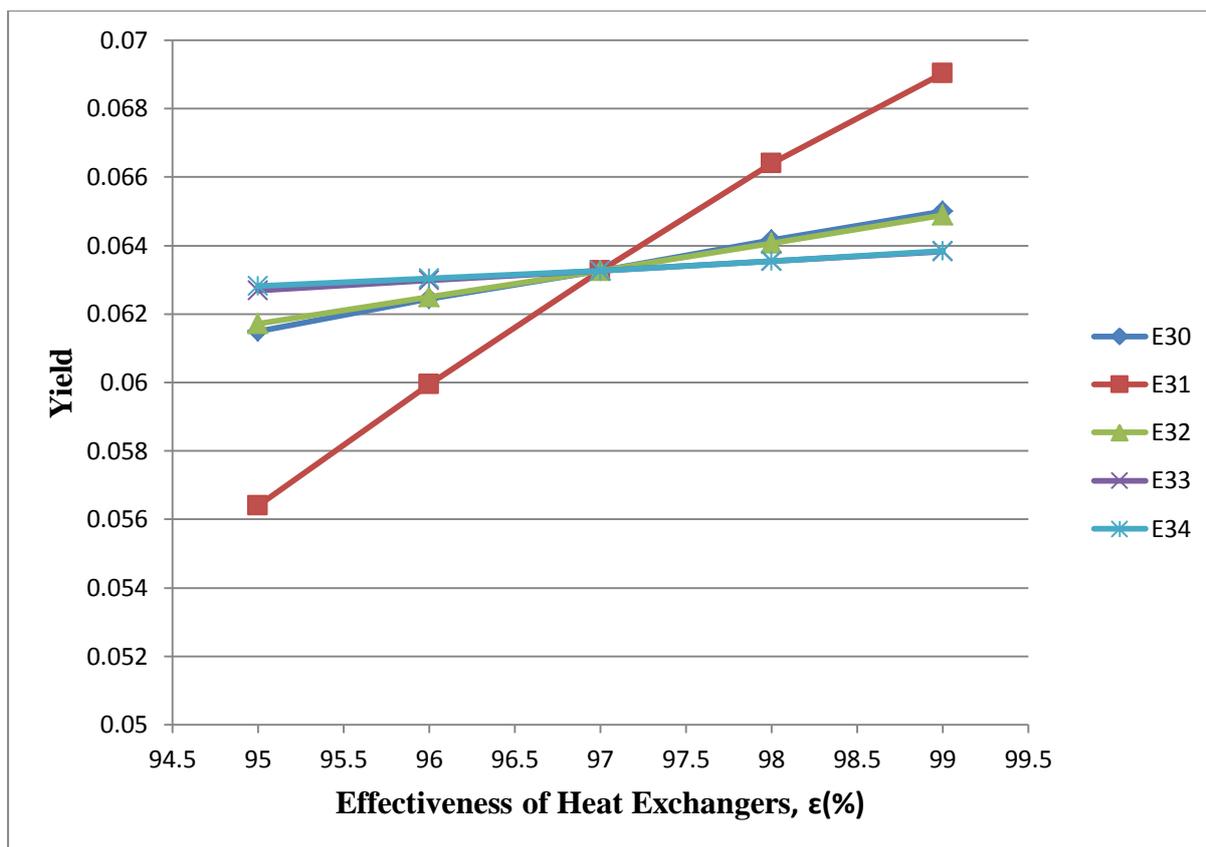


Fig 4.3: Variation of yield with Effectiveness of heat exchangers ($\eta_1=\eta_2=0.75$)

2. Heat exchangers, ($\eta_1=\eta_2=0.74$, $X_1=X_2=0.4$)

EFFECTIVENESS	YIELD				
	E30	E31	E32	E33	E34
95	0.05958	0.0554	0.05981	0.06061	0.0598
96	0.06051	0.05843	0.06049	0.06102	0.06061
97	0.06142	0.06142	0.06142	0.06142	0.06142
98	0.06247	0.06443	0.06241	0.06182	0.06223
99	0.06387	0.06748	0.06282	0.06235	0.06305

Table 4.3: variation of yield with heat exchanger effectiveness

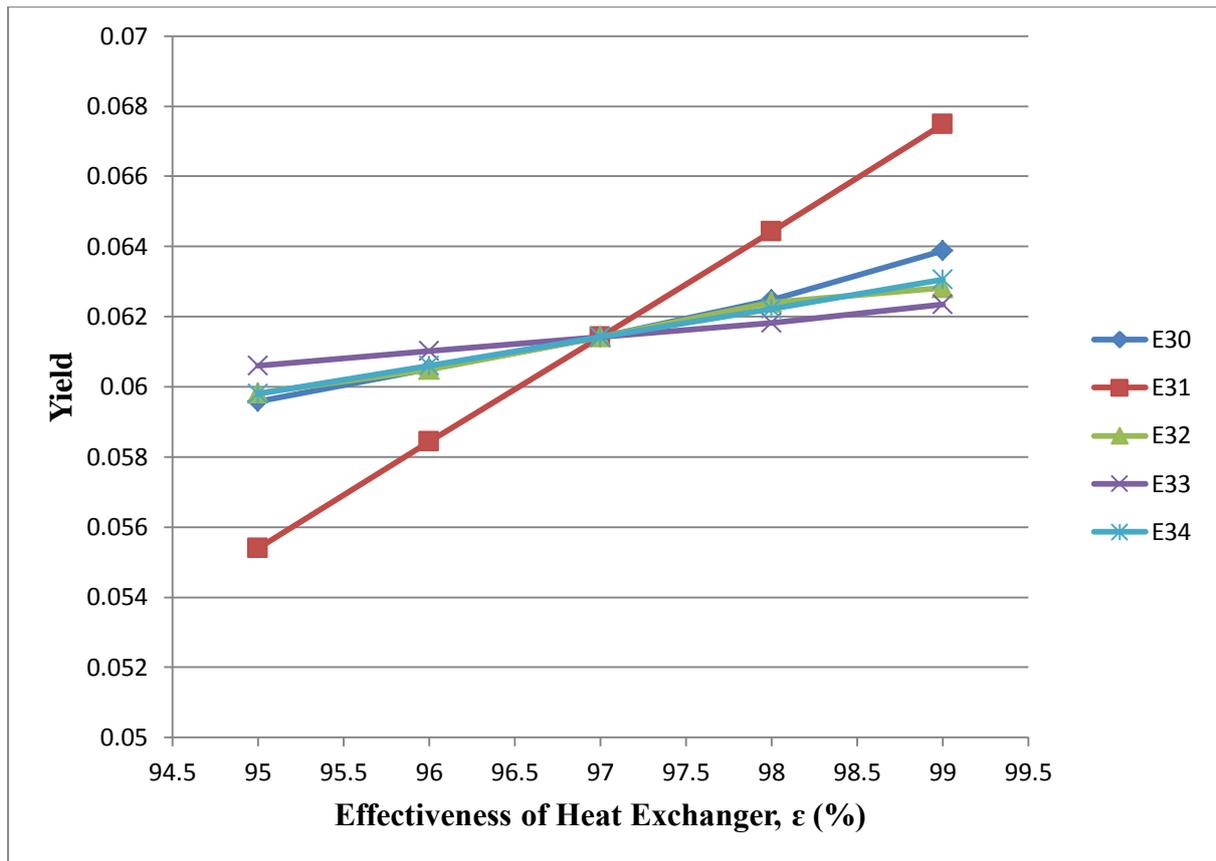


Fig 4.4: Variation of yield with Effectiveness of heat exchangers ($\eta_1=\eta_2=0.74$)

Observations:

The heat exchanger effectiveness is increased one by one to identify the individual influence in liquid production. When varying the effectiveness of heat exchanger, the other heat exchanger effectiveness kept constant (0.97, 0.96). The above figures(4.3,4.4) shows that heat exchanger effectiveness has linear relationship with liquid production and each heat exchanger has different gradient in the curve it shows that the effect of heat exchanger in liquid production are not same.

4.1.4 Effect of variation of Expanders (Expansion Engine) Efficiency, η :

The value of mass ratio through expander, effectiveness of heat exchangers is kept constant.

The effect of yield with the variation of expander efficiency is studied as shown in figure.

Yield increases with the increase in the efficiency of expander.

1. Expander , ($\epsilon_1=\epsilon_2=\epsilon_3=\epsilon_4=\epsilon_5=0.97$, $X1=X2=0.4$)

EFFICIENCY	YIELD	
	E37	E39
71	0.06135	0.05868
73	0.06201	0.06078
75	0.0629	0.0629
77	0.06397	0.0647
79	0.06506	0.06695
81	0.0665	0.06921

Table 4.4: Variation of yield with expander efficiency ($\epsilon_1=\epsilon_2=\epsilon_3=\epsilon_4=\epsilon_5=0.97$)

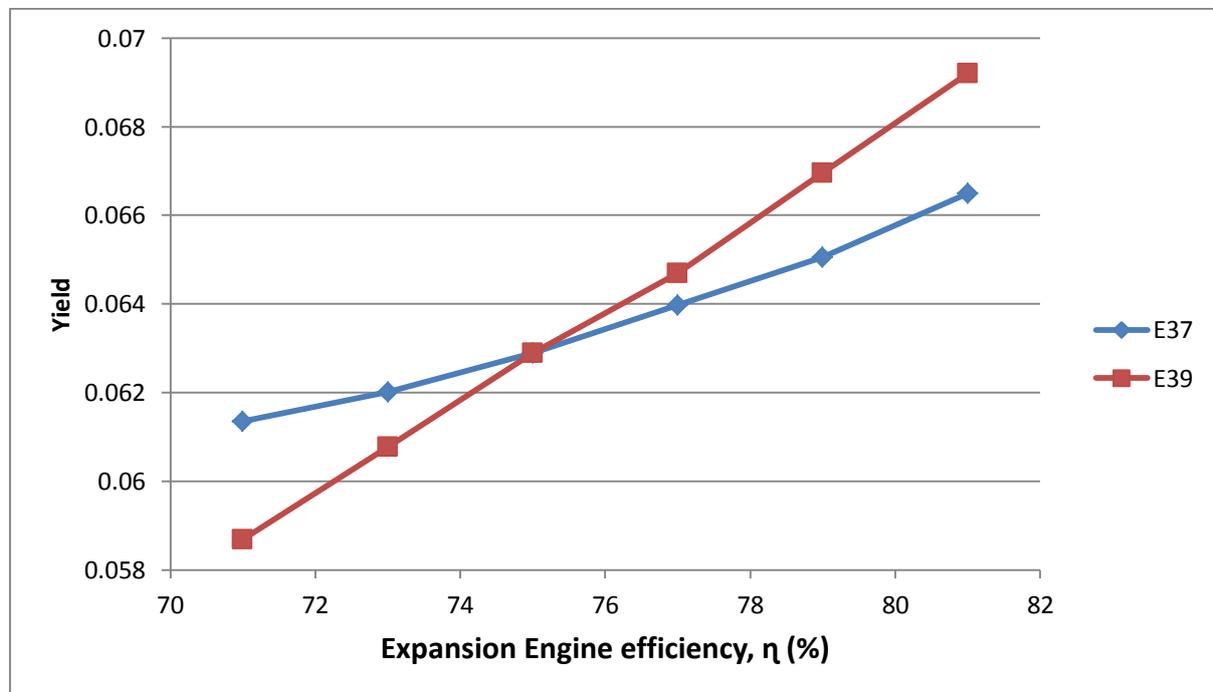


Fig 4.5: Variation of yield with Efficiency of Expander ($\epsilon_1=\epsilon_2=\epsilon_3=\epsilon_4=\epsilon_5=0.97$)

2. Expander, ($\epsilon_1=\epsilon_2=\epsilon_3=\epsilon_4=\epsilon_5=0.96$, $X1=X2=0.4$)

EFFECTIVENESS	YIELD	
	E37	E39
71	0.05458	0.05293
73	0.05568	0.05501
75	0.05701	0.05701
77	0.05805	0.05895
79	0.05905	0.06062
81	0.06	0.06275

Table 4.5: variation of yield with expander efficiency ($\epsilon_1=\epsilon_2=\epsilon_3=\epsilon_4=\epsilon_5=0.96$)

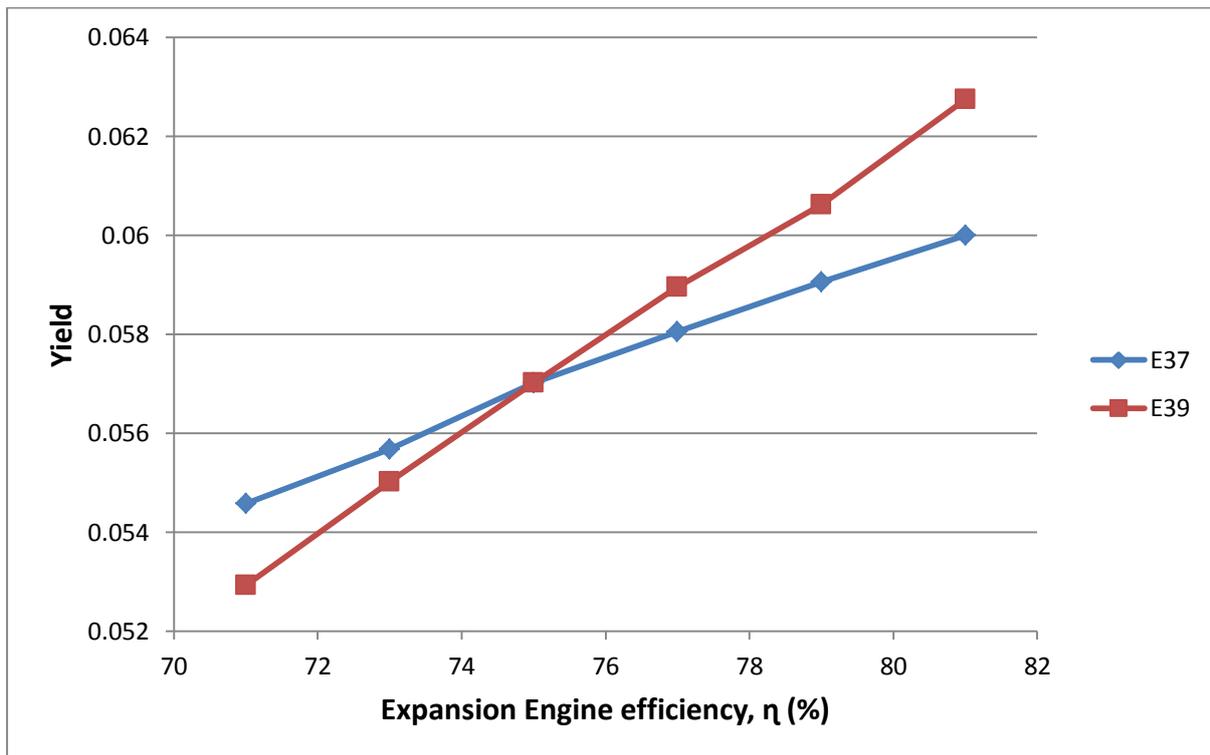


Fig 4.6: Variation of yield with Efficiency of Expander ($\epsilon_1=\epsilon_2=\epsilon_3=\epsilon_4=\epsilon_5=0.96$)

Chapter 5

Conclusion

Conclusion:

The above project work gives a cycle simulation for the helium liquefaction with heat exchanger, expander (expansion engine), JT valve. The simulation is carried out by using process simulation software, Aspen Hysys. The preliminary data required in terms of pressure and temperature, mass flow rate across heat exchanger, expander and other components of the helium liquefier are found out. The parametric study is carried out to study the role of different component efficiencies in deciding overall system efficiency. It is found that liquid yield is directly proportional to heat exchanger effectiveness, expander efficiency, mass flow rate diverted through the J-T Valve. When the effectiveness of heat exchanger and expander efficiency decreases production of liquid also decreases. So increasing the heat exchanger effectiveness increases the liquid production but increasing the efficiency of expander is increase only the small amount of liquid production. This simulation done and analysis carried out can serve as guide lines for the development of the helium liquefier in our nation for the future mission.

References:

1. Hubbell, R.H. and Toscano, W.M., Thermodynamic optimisation of helium liquefaction cycles. *Adv. Cryo. Engng.*, 1980, **25**, 551.
2. Minta, M. and Smith, J.L., An entropy flow optimisation technique for helium liquefaction cycles. *Adv. Cryo. Engng.*, 1984, **29**, 469.
3. Khalil, A. and McIntosh, G.E., Thermodynamic optimisation study of the helium multiengine Claude refrigeration cycle. *Adv. Cryo. Engng.*, 1978, **23**, 431.
4. Hilal, M.A., Optimisation of helium refrigerators and liquefiers for large superconducting systems. *Cryogenics*, 1979, **19**, 415.
5. Nobutoki, M., Iwamoto, K. and Matsuda, H., Simulation of the large helium refrigeration plant for LHD. *Proceedings of the 16th ICEC Cryogenics (Suppl)*, Vol. 36. 1996, 71.
6. Malaaen, E., Owren, G., Wadahl A. and Wagner, U., Simulation program for cryogenic plants at CERN. *Proceedings of the 16th ICEC Cryogenics (Suppl)*, Vol. 36. 1996, 99.
7. M.D.Attrey, Thermodynamic analysis of Collin's helium liquefaction cycle, *Cryogenics* 38(1998), 1199-1206
8. McCarty RD, Arp VD. A new wide range equation of state for helium. *Adv Cryo Eng* 1990;35:1465–75.
9. R.J. Thomas, R. Dutta, P. Ghosh, K. Chowdhury. Applicability of equations of state for modeling helium systems. *Cryogenics* 52 (2012) 375–381.
10. W. Daus, R. Ewald, A refrigeration plant with 300 W capacity at 1.8 K, *Cryogenics* 15 (1975) 591–598.
11. W.M. Toscano, F.J. Kudrika, Thermodynamic and mechanical design of the FNAL central helium liquefier, *Advances in Cryogenic Engineering* 23 (1978) 456–466.
12. A. Khalil, G.E. McIntosh, Thermodynamic optimization study of the helium multiengine Claude refrigeration cycle, *Advances in Cryogenic Engineering* 23 (1977) 431–436.

13. D. Aronson, Preliminary design studies of low temperature refrigeration plants, *Advances in Cryogenic Engineering* 3 (1960) 19–31.
14. A. Khalil, G.E. McIntosh, Thermodynamic optimization study of the helium multiengine Claude refrigeration cycle, *Advances in Cryogenic Engineering* 23 (1977) 431–436.
15. M.A. Hilal, Optimization of helium refrigerator and liquefiers for large superconducting system, *Cryogenics* 19 (1979) 415–420.
16. M.A. Hilal, Y.M. Eyssa, Minimization of refrigeration power for large cryogenic systems, *Advances in Cryogenic Engineering* 25 (1980) 350–357.
17. R.J. Thomas, P. Ghosh, K. Chowdhury, Role of expanders in helium liquefaction cycles: Parametric studies using Collins cycle, *Fusion Engineering and Design* 86 (2011) 318–324.
18. Barron, R.F. *Cryogenic systems*, Oxford university Press (1985)
19. Flynn, T.M. *Cryogenic Engineering*, Marcel-Dekker Inc. (1996)
20. Timmerhaus, K.D. and Flynn T.M, *Cryogenic Process Engineering* Plenum Press (1989)
21. Van Sciver, S.W., *Helium cryogenics*. Plenum Press, New York, USA, 1986.
22. Aspen Tutorial #1: Aspen Basic
23. Aspen Tutorial #4: Thermodynamic Method.