

NITROGEN AND HELIUM LIQUEFIER DESIGN AND SIMULATION USING ASPEN PLUS

A PROJECT REPORT SUBMITTED IN THE PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology

in

Chemical Engineering

by

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Roll – 108CH048



Department of Chemical Engineering

National Institute of Technology

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Under the Guidance of
Prof Madhusree Kundu



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National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the thesis entitled “**NITROGEN AND HELIUM LIQUEFIER DESIGN AND SIMULATION USING ASPEN PLUS**” submitted by Abhijit Dalai in the partial fulfillment of the requirement for the award of **BACHELOR OF TECHNOLOGY Degree** in Chemical 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.

Date: 5th May, 2012

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ABSTRACT

Cryogenics is the branch of engineering that is applied to very low temperature refrigeration applications such as in liquefaction of gases and in the study of physical phenomenon near temperature of absolute zero. The various cryogenic cycles as Linde cycle, Collins cycle etc. govern the liquefaction of various industrial gases, namely, Nitrogen, Helium etc. Aspen Plus solves the critical engineering and operating problems that arise throughout the lifecycle of a chemical process by doing process simulation using thermodynamic data and operating conditions of the process with the help of rigorous Aspen Plus equipment models. The process simulation capabilities of Aspen Plus using mass and energy balances, phase and chemical equilibrium, and reaction kinetics helps the engineers to predict the behaviour of a process. In this project work nitrogen and helium liquefier have been designed with the help of the simulation tool ASPEN Plus and the simulation work was carried out at steady state using Peng-Robinson equation of state in order to get the desired liquefied output. The different process conditions were varied to find out that for maximum pressure of 10 atmosphere inside the Linde-Hampson liquefier system, the liquefied output of nitrogen was found to be maximum which is 92.23 % and the liquefaction of helium using Aspen plus could not be carried out as the cooling components of Aspen plus could not cool below 10 K temperature.

Keywords: Aspen plus, Nitrogen and Helium Liquefaction, Peng-Robinson equation of state

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Chapter – 01

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION AND LITERATURE REVIEW

1.1 LIQUEFACTION OF GAS

Liquefaction is a process in which gas is physically converted into liquid state. Many gases can be converted into gaseous state by simple cooling at normal atmospheric pressure and some others require pressurisation like carbon dioxide. Liquefaction is used for analysing the fundamental properties of gas molecules, for storage of gases and in refrigeration and air conditioning^[1].

Liquefaction is the process of cooling or refrigerating a gas to a temperature below its critical temperature so that liquid can be formed at some suitable pressure which is below the critical pressure. Using an ambient-temperature compressor, the gas is first compressed to an elevated pressure. This high-pressure gas is then passed through a counter-current heat exchanger or an air-cooler to a throttling valve (Joule-Thompson valve) or an expansion engine. Upon expanding to a certain lower pressure below the critical pressure, cooling takes place and some fraction of gas is liquefied. The cool, low-pressure gas returns to the compressor inlet through a recycle stream to repeat the cycle. The counter-current heat exchanger warms the low-pressure gas prior to recompression, and simultaneously cools the high-pressure gas to the lowest temperature possible prior to expansion^[2].

1.2 NITROGEN AND HELIUM

Only fluids having triple point below 100 K are considered “cryogenic” i.e., they are still in either liquid or gaseous form below this temperature. Both nitrogen, helium are considered as cryogenic fluids. Table 1 shows some properties of nitrogen, helium as cryogenic fluids^[3]. In atmospheric air, nitrogen present is almost 78% whereas helium is 0.000524%.

Figure 1.1. Composition of Nitrogen and Helium in air

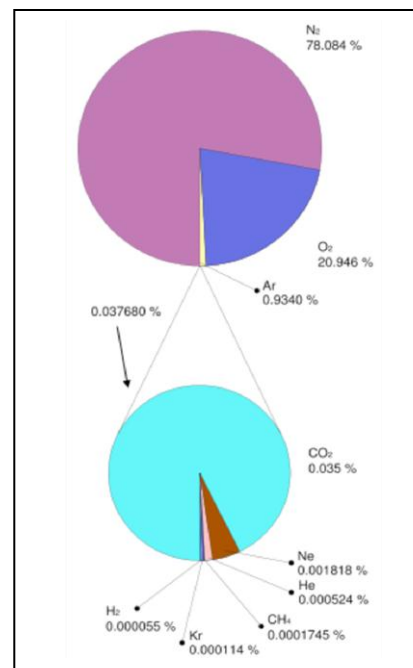


Table1. Thermodynamic property data of Nitrogen and Helium

Property Data / Fluid	N ₂	⁴ He
Normal boiling point (K)	77.40	4.22
Critical temperature (K)	126.0	5.20
Critical pressure (M Pa)	03.39	0.23
Triple point temperature (K)	63.01	2.18*
Triple point pressure (K Pa)	12.80	5.04*

*: Lambda point

Helium shows the particularity that it has no triple point; it may solidify only at pressures above 2.5 M Pa. The commonly given lambda point refers to the transition from normal to superfluid helium. The critical temperature of the fluid refers to the temperature of the critical point where the saturated liquid and saturated vapour states are identical.

Like dry ice, the main use of liquid nitrogen is as a refrigerant. Among other things, it is used in the cryopreservation of blood, reproductive cells (sperm and egg), and other biological samples and materials ^[4]. It is used in the clinical setting in cryo-therapy to remove cysts and warts on the skin ^[5]. It is used in cold traps for certain laboratory equipment and to cool infrared detectors or X-ray detectors. It has also been used to cool central processing units and other devices in computers that are overclocked, and that produce more heat than during normal operation ^[6].

Liquefaction of helium (⁴He) 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 ⁴He 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 (⁴He) is used as a cryogenic refrigerant; it is produced commercially for use in superconducting magnets such as those used in MRI or NMR.

Cryogenic technology is the study of production of very low temperature (below -150⁰C or 123 K) and the behaviour of materials at those temperatures. For the liquefaction process, development of such low temperature working device, air separation and fundamental principles and procedures have been discussed in well-known text books of cryogenics ^[8-12].

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.

1.3 SYSTEM PERFORMANCE PARAMETERS

There are three payoff functions we might use to indicate the performance of the liquefaction systems:

1. Work required per unit mass of gas compressed, $-W/m$
2. Work required per unit mass of gas liquefied, $-W/m_f$
3. Fraction of the total flow of gas that is liquefied, $y = m_f/m$

The last two pay-off functions are related to the first one by

$$\left(\frac{-W}{m}\right) = \left(\frac{-W}{m_f}\right) * y \quad (1.1)$$

In any liquefaction system, we should want to minimize the work requirements and maximize the fraction of gas that is liquefied. 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. The figure of merit (FOM) for a liquefaction system is such a parameter. It is defined as the theoretical minimum work requirement divided by the actual work requirement for the system:

$$FOM = \frac{-W_i}{W} = \frac{(-W_i/m_f)}{(-W/m_f)} \quad (1.2)$$

The figure of merit is a number between 0 and 1. It gives a measure of how closely the actual system approaches the ideal system performance ^[8].

1.4 THE THERMODYNAMICALLY IDEAL SYSTEM

In order to have a means of comparison of liquefaction systems through the figure of merit, we shall first analyse the thermodynamically ideal liquefaction system. This 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. Liquefaction is essentially an open system process, therefore for an ideal liquefaction we shall choose the first two processes in the Carnot cycle; a reversible isothermal compression followed by a

reversible isentropic expansion. The gas to be liquefied is compressed reversibly and isothermally from ambient conditions to some high pressure. This high pressure is selected so that gas will become saturated liquid upon reversible isentropic expansion through the expander. The final condition is taken as the same pressure as the initial pressure. The pressure attained at the end of isothermal compression is extremely high in the order of 70 G Pa and it is highly impracticable to attain this pressure in a liquefaction system, which is the reason it is not an ideal process for a practicable system [8].

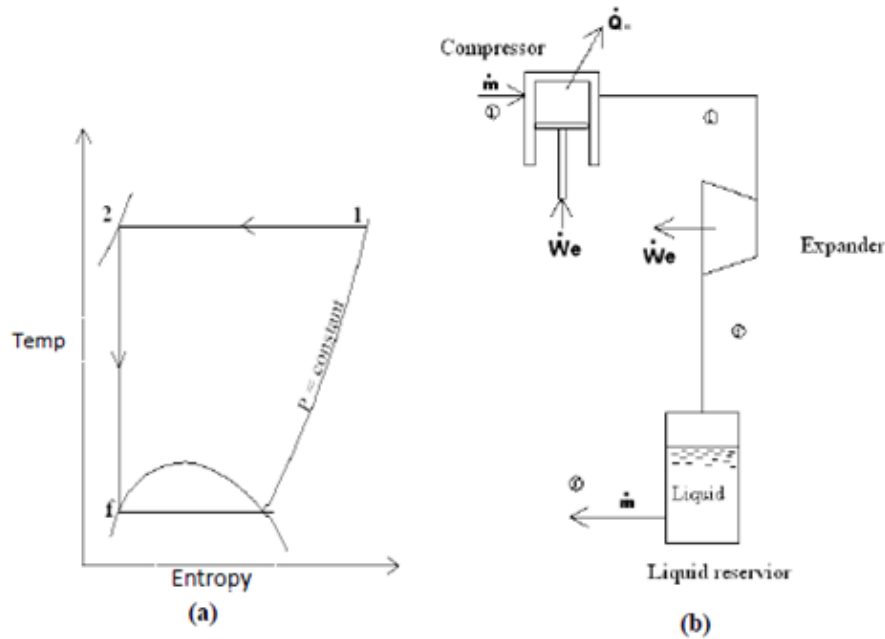


Figure 1.2. (a) Thermodynamic cycle T-S plane (b) Apparatus Set-up

The First law of thermodynamic for steady flow may be written as:

$$Q_{\text{net}} - W_{\text{net}} = \sum_{\text{outlet}} m h - \sum_{\text{inlet}} m h \quad (1.3)$$

Applying the First law to the system shown in figure:

$$Q_R - W_1 = m (h_f - h_1) \quad (1.4)$$

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

$$Q_R = m T_1 (S_2 - S_1) = - m T_1 (S_1 - S_f) \quad (1.5)$$

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:

$$-(W_i/m) = T_1 (S_1 - S_f) - (h_1 - h_f) \quad (1.6)$$

1.5 PRODUCTION OF LOW TEMPERATURE

1.5.1 Joule – Thompson effect

Most of the practical liquefaction systems utilize an expansion valve or a Joule Thomson valve to produce low temperatures. If we apply the first law for steady flow to the expansion valve, for zero heat transfer and zero work transfer and for negligible kinetic and potential changes, we find $h_1 = h_2$. Although the flow within the valve is irreversible and is not an isenthalpic process, the inlet and the outlet do 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 through the valve produces a decrease in temperature, while in another region the expansion results in a decrease in temperature. Obviously 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-Thompson coefficient ^[8].

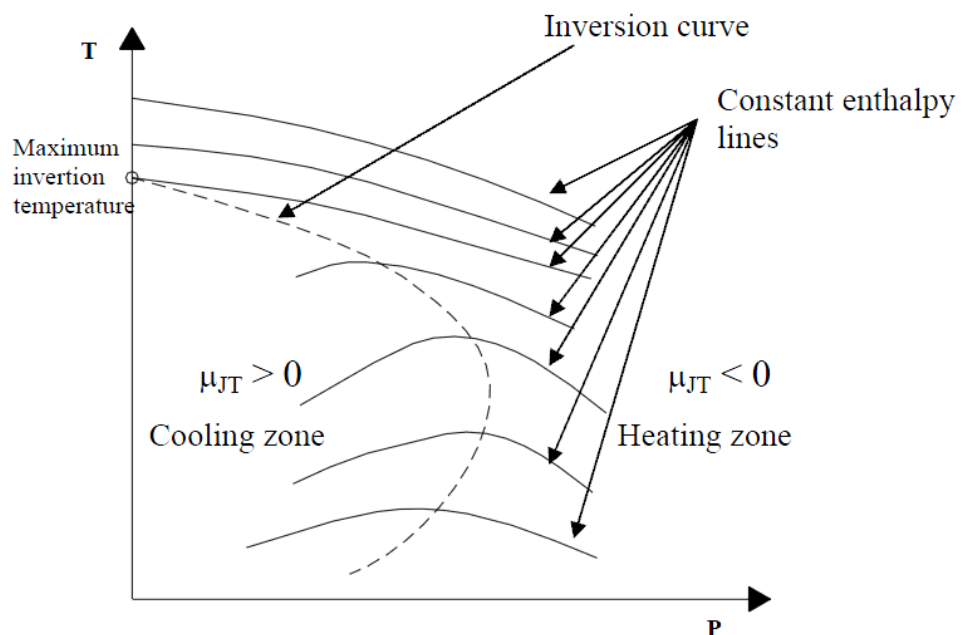


Figure1.3. Isenthalpic expansion of a real gas

1.5.2 Adiabatic expansion

The second method of producing low temperatures is the adiabatic expansion of the gas through a work producing device, such as an expansion engine. In the ideal case, the expansion would be reversible and adiabatic and therefore isentropic. In this case we can define the isentropic coefficient which expresses the temperature change due to a pressure change at constant entropy^[8].

1.6 OBJECTIVE

The objective of this project work is to design and simulate the liquefiers for nitrogen and helium and investigate the effects of different operating parameter on the output of liquefaction process efficiency using ASPEN PLUS simulator.

1.7 CHAPTER LAYOUT

In the following chapters the cycle thermodynamics of liquefaction of nitrogen and helium and the working of ASPEN PLUS simulator is discussed thoroughly. The results obtained from the simulation work are discussed thereafter.

Chapter2. Cycle Thermodynamics

Chapter3. ASPPEN PLUS simulator

Chapter4. Results and Discussions

Chapter5. Conclusion and Future Recommendation

Chapter – 02

THERMODYNAMICS OF GAS LIQUEFACTION

CYCLE THERMODYNAMICS

2.1 LINDE-HAMPSON SYSTEM FOR NITROGEN LIQUEFACTION

The Linde-Hampson system was the second among all the liquefaction systems which were used to liquefy gases (the cascade system was the first) although it is the simplest of all the liquefaction system. The Linde system is shown in figure 2.1 and the liquefaction cycle (T-S plot) of Linde system is shown in in figure2.2.

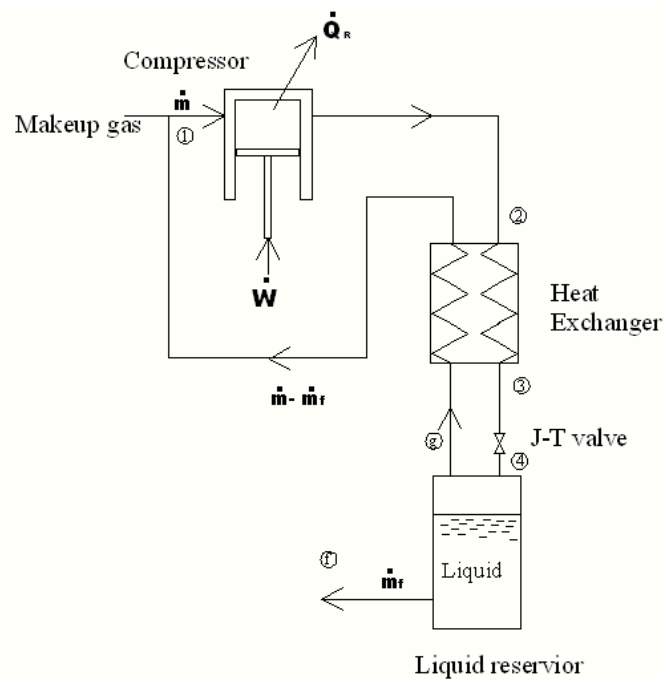


Figure2.1. Linde-Hampson liquefaction system

A basic differentiation between the various refrigeration cycles lies in the expansion device. This may be either an expansion engine like expansion turbine or reciprocating expansion engine or a throttling valve like JT valve. The expansion engine approaches an isentropic process whereas the valve approaches an isenthalpic process. Isentropic expansion implies an adiabatic reversible process while isenthalpic expansions are irreversible. In the Linde system, the basic principle of isenthalpic expansion by Joule-Thompson valve is incorporated [8].

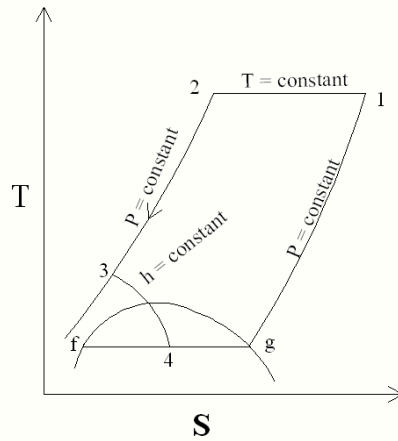


Figure2.2. Linde-Hampson liquefaction cycle (T-S plot)

2.1.1 Working principle

The gas enters the compressor through a pump which forced into compressor and compressed thereby being heated. The heat is subsequently removed with the help of a cooling device such as an air cooler or a water cooler and the compressed gas finally reach to ambient temperature. Then it passes through a counter flow heat exchanger where its temperature decreases below the inversion temperature of working fluid. The gas therefore reaches the J-T valve and it expands through the valve, so that the temperature decreases constantly, reaches at lower and lower temperature and eventually the critical temperature of the liquid gas is reached and liquefied gas begins to collect in chamber ^[8].

2.1.2 Performance of system

In order to analyse the performance of the system, let us assume ideal condition, i.e., no irreversible pressure drops (except for the expansion valve), no heat in-leak from ambient conditions, and 100 per cent effective heat exchanger. Applying the first law for steady flow to the combine heat exchanger, expansion valve, and liquid receiver, we obtain

$$0 = (m - m_f) h_1 + m_f h_f - m h_2 \quad (2.1)$$

Solving for the fraction of the gas flow that is liquefied

$$y = \frac{m_f}{m} = \frac{(h_1 - h_2)}{(h_1 - h_f)} \quad (2.2)$$

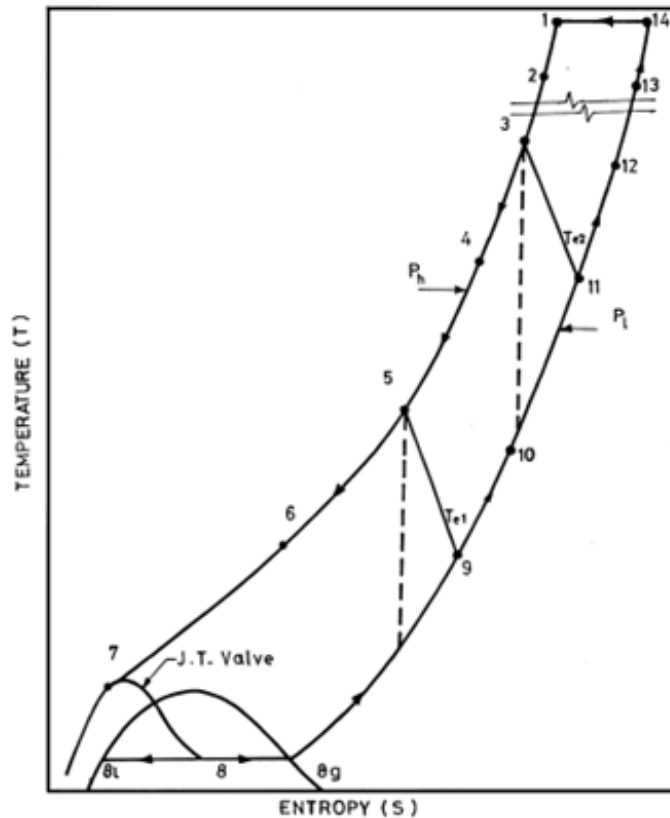


Figure 2.4. T-S diagram of Collins Helium Liquefaction Cycle

2.2.1 Assumptions in Collins Helium Liquefaction system

- The maximum pressure (P_h) in the system is 15 bar and the minimum pressure (P_l) is 1 bar.
- The temperature of the gas after compression is 300 K which is the ambient temperature and the return stream temperature of the helium gas after liquefaction is at its boiling point, i.e. 4.21 K.
- The pressure drop in the heat exchangers is negligible.
- The J-T expansion is a perfect isenthalpic expansion process.
- Heat in-leak in the system is negligible.
- Effectiveness of heat exchangers and efficiencies of expanders are assumed to be constant and their dependence on pressure, temperature and mass flow rate is ignored.

2.2.2 Analysis and Performance of the system

The thermo physical properties of the helium gas, at different temperatures and pressures, are taken from Van Sciver ^[16]. For any intermediate temperatures, the values for enthalpy, entropy, etc. are linearly interpolated. Applying the first law of thermodynamics to the system, excepting the compressor, for the steady state condition, the ratio of liquid yield to the total mass flow rate, y , is given as follows:

$$y = \frac{\dot{m}_f}{\dot{m}} = \frac{h_{14} - h_1}{h_{14} - h_f} + x_1 \frac{\Delta h_{e1}}{h_{14} - h_f} + x_2 \frac{\Delta h_{e2}}{h_{14} - h_f}$$

where, $x_1 = m_{e1} / m$ and $x_2 = m_{e2} / m$. Δh_{e1} and Δh_{e2} are the net enthalpy changes in helium occurring in EX1 and EX2 respectively. h represents enthalpy at the respective points.

The results obtained from “Thermodynamic analysis of Collins helium liquefaction cycle” by M.D. Atrey ^[15] suggests that different parameters like heat exchanger effectiveness (ϵ), expander efficiencies (η_1 and η_2), temperatures of gas before expansion, total mass flow rate (m), mass flow fraction through expanders ($m_{e1} + m_{e2}$) etc. affect the performance of the liquefier. The cold produced in the expanders is directly proportional to the mass flow rate diverted through them and the liquefaction yield is proportional to the remaining mass flow rate that passes through the J-T valve.

From the result work of M.D. Atrey ^[15],s analysis it is known that, for $x_1=0.45$ and $x_2=0.35$ the output in terms of liquefaction quantity is maximum. The liquefied output is maximum where x_1 and x_2 together constitute about 80–81% of the total mass flow rate while the remaining 19–20% of the total mass flow rate goes through the J-T valve. It is also seen that as the $(x_1 + x_2)$ value is below 79–79.5% there is no liquefaction indicated by the divergence of the program ^[15]. This is due to the fact that in these cases, the point of the isenthalpic line after J-T expansion translates into the gaseous region, i.e. outside the dome so the the gas would never attain a low enough temperature for liquefaction due to insufficient refrigeration effect, and instead the machine would act as a refrigerator. As the values of $(x_1 + x_2)$ exceed an optimum value there is a decrease in the percentage of liquefied output value essentially due to the fact that effectively less mass flows through the J-T valve and this decreases the values of y in these cases.

Chapter – 03

ASPEN PLUS SIMULATOR

3.1 INTRODUCTION

Aspen ONE is Aspen-Tech’s comprehensive set of software solutions and professional services designed to help process companies achieve their operational excellence objectives. It leverages the value of simulation models to help process companies increase operational efficiency and profitability across their global enterprise. Aspen-one cover four major field as shown in figure 3.1 , Chemical , Energy , Polymer , Pharmaceuticals ^[13].

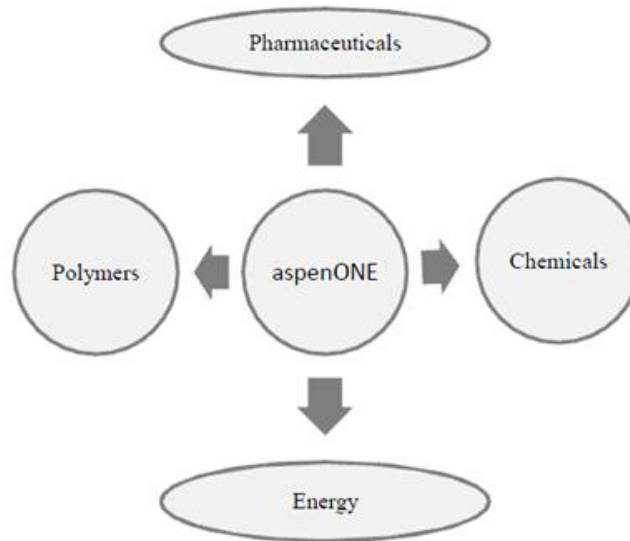


Figure3.1.Industries and business areas of Aspen ONE

3.2 ASPEN-ONE ENGINEERING

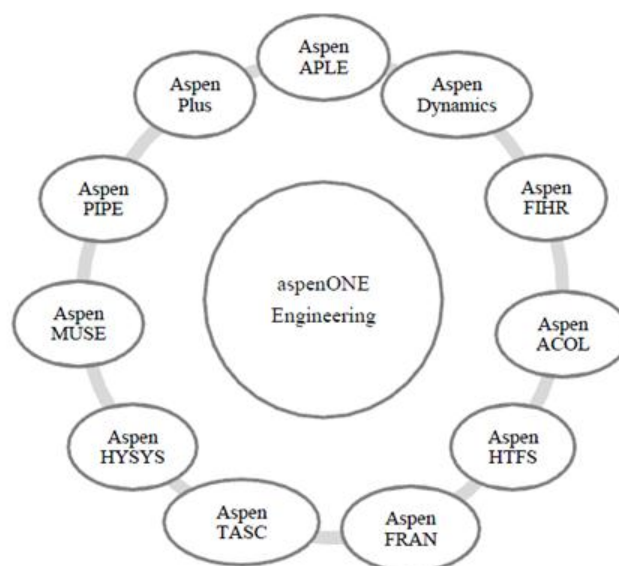


Fig 3.2 Aspen ONE engineering classification

3.3 INTRODUCTION TO ASPEN PLUS

Aspen Plus is a market-leading process modelling tool for conceptual design, optimization, and performance monitoring for the chemical, polymer, specialty chemical, metals and minerals, and coal power industries. Aspen plus is a software package designed to allow a user to build a process model and then simulate the model without tedious calculations.

3.4 EQUATION OF STATE

In physics and thermodynamics, an equation of state is a relation between intensive and extensive state of the system. More specifically, an equation of state is a thermodynamic equation describing the state of matter under a given set of physical conditions. It is a constitutive equation which provides a mathematical relationship between two or more state functions associated with the matter, such as its temperature, pressure, volume, or internal energy. Equations of state are useful in describing the properties of fluids, mixtures of fluids.

Aspen Plus contains various property packages, but for nitrogen and helium liquefaction cycle Peng-Robinson equation of state is used ^[13].

3.4.1 Peng-Robinson:

Peng-Robinson is a Cubic equation of state given as below.

$$P = \frac{RT}{V_m - b} - \frac{a\alpha}{V_m^2 + 2bV_m - b^2} \quad (3.1)$$

$$a = \frac{0.45724 R^2 T_c^2}{P_c} \quad (3.2)$$

$$b = \frac{0.07780 RT_c}{P_c} \quad (3.3)$$

$$\alpha = (1 + (0.37464 + 1.54226\omega - 0.26992\omega^2)(1 - T_r^{0.5}))^2 \quad (3.4)$$

$$T_r = \frac{T}{T_c} \quad (3.5)$$

In Polynomial form

$$A = \frac{a\alpha P}{R^2 T^2} \quad (3.6)$$

$$B = \frac{bP}{RT} \quad (3.7)$$

$$Z^3 - (1 - B)Z^2 + (A - 3B^2 - 2B)Z - (AB - B^2 - B^3) = 0 \quad (3.8)$$

Where ω is the acentric factor of the species and R is the universal gas constant.

The Peng-Robinson equation was developed in 1976 in order to satisfy the following goals.

1. The parameters should be expressible in terms of the critical properties and the acentric factor.
2. The model should provide reasonable accuracy near the critical point, particularly for calculations of the compressibility factor and liquid density.
3. The mixing rules should not employ more than a single binary interaction parameter, which should be independent of temperature pressure and composition
4. The equation should be applicable to all calculations of all fluid properties in natural gas processes ^[13].

For the most part the Peng-Robinson equation exhibits performance similar to the Soave equation, although it is generally superior in predicting the liquid densities of many materials, especially nonpolar ones ^[13].

3.5 SIMULATION ENVIRONMENT

The Simulation environment contains the main flow sheet where we do the majority of our work (installing and defining streams, unit operations, columns and sub-flow sheets). Before entering the simulation environment, we must have a fluid package with selected components in the component list and a property package.

3.5.1 The User Interface

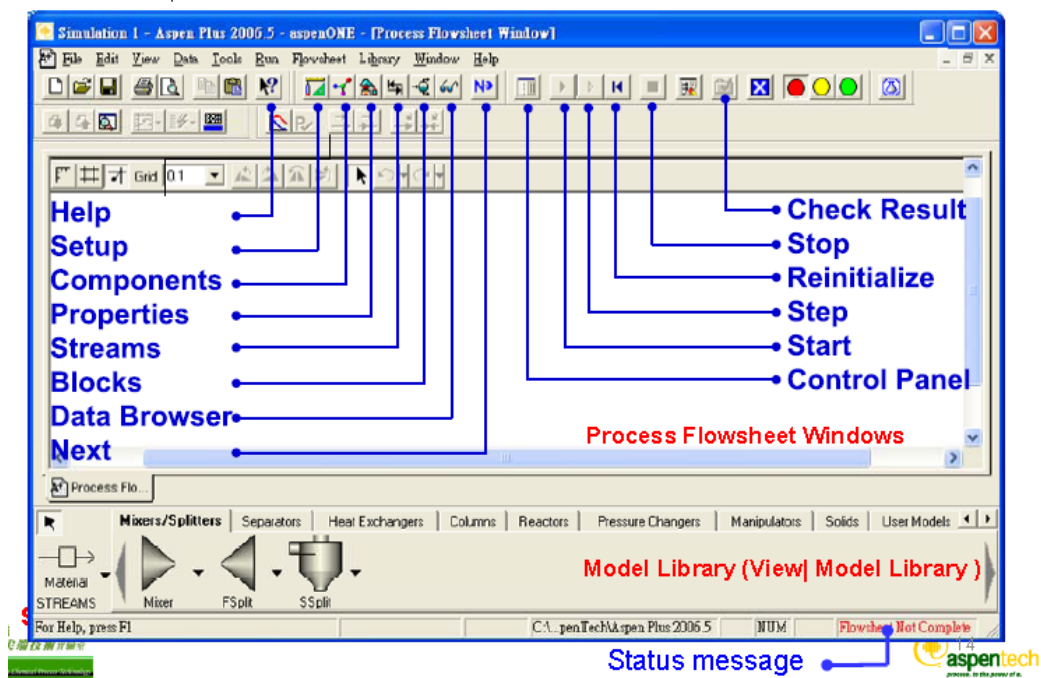


Figure 3.3. The user interface

3.5.1.1 Features of the User Interface

- Menus: are used to specify program options and commands.
- Toolbar: allows direct access to commonly-used functions.
- Data Browser: is used to navigate folders, forms, and sheets.
- Sheets make up forms and forms make up folders (a sheet in a form in a folder).
- Folders are the root items in the Data browser.
- Forms: are located in folders and are used to enter data and view simulation results.
- Sheets: are contained in folders and are selected using tabs at the top of each sheet.

3.5.2 The Data Browser

The Data Browser is a sheet and form viewer with a hierarchical tree view of the available simulation input, results, and objects that have been defined.

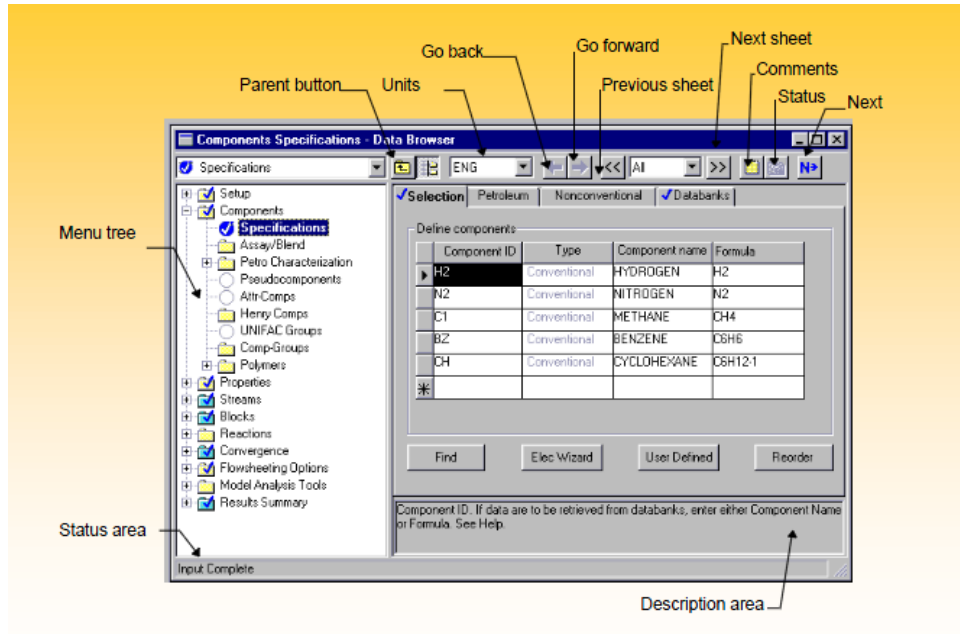


Figure 3.4. The data browser

The Data Browser is used to

- Display forms and sheets and manipulate objects.
- View multiple forms and sheets without returning to the Data menu, for example, when checking

Properties Parameters input

- Edit the sheets that define the input for the flow sheet simulation
- Check the status and contents of a run
- See what results are available

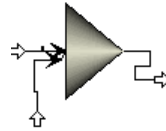
In addition to drawing the flow sheet, we need to provide data for five main folders:

- Setup: This folder is used to specify information on the simulation, units, etc.
- Components: Describes the various chemical species involved in the process.
- Properties: Allows us to choose the thermodynamic model(s) for estimating properties.
- Stream: This folder is where we enter stream data.
- Blocks: Folder for providing data on the process equipment.

3.6 THE COMPONENTS OR THE BLOCKS OR THE EQUIPMENTS

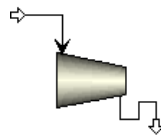
The description of the various components and the conditions at which they operate are described subsequently.

A) Mixer



Mixer is used to combine streams into one stream. Mixer models mixing tees or other types of mixing operations. Mixer combines material streams (or heat streams or work streams) into one stream. Heat (Q) and Work (W) Mixer icons are selected from the Model Library for heat and work streams respectively. A single Mixer block cannot mix streams of different types (material, heat, work) ^[17].

B) Compr or Compressor

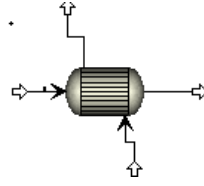


It is a pressure changer. The different type of pressure changers available in Aspen plus are poly-tropic centrifugal compressor, poly-tropic positive displacement compressor, isentropic compressor. The Compressor is used to change stream pressure when energy-related information, such as power requirement, is needed or known ^[17].

C) Heater or Cooler

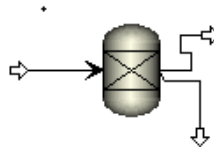


We can use heater to represent Heaters, Coolers, Valves, Pumps (whenever work-related results are not needed), and Compressors (whenever work-related results are not needed). The Cooler operations are one-sided heat exchangers. When we specify the outlet conditions, Heater (Cooler) determines the thermal and phase conditions of a mixture with one or more inlet streams ^[17].



D) HeatX or Heat Exchanger

HeatX can perform a full zone analysis with heat transfer coefficient and pressure drop estimation for single- and two-phase streams. For rigorous heat transfer and pressure drop calculations, you must supply the exchanger geometry. If exchanger geometry is unknown or unimportant, HeatX can perform simplified shortcut rating calculations. For example, you may want to perform only heat and material balance calculations ^[17].



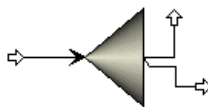
E) Sep or Separator

Sep combines streams and separates the result into two or more streams according to splits specified for each component. When the details of the separation are unknown or unimportant, but the splits for each component are known, we can use Sep in place of a rigorous separation model to save computation time ^[17].



F) Valve or Joule-Thompson Valve

Valve models control valves and pressure changers. Valve relates the pressure drop across a valve to the valve flow coefficient. Valve assumes the flow is adiabatic, and determines the thermal and phase condition of the stream at the valve outlet ^[17].



G) FSplit or Splitter

Splitter or FSplit combines streams of the same type (material, heat, or work streams) and divides the resulting stream into two or more streams of the same type. All outlet streams have the same composition and conditions as the mixed inlet ^[17].

Chapter – 04

RESULTS AND DISCUSSIONS

4.1 SIMULATION OF LINDE CYCLE FOR NITROGEN LIQUEFACTION

Problem Specification 1:

To solve Linde cycle of Nitrogen liquefaction (**Without HX**), using Aspen Plus as simulation tool.

Given condition:

$$T_{\text{ambient}} = 300\text{K} \quad P_{\text{ambient}} = 1 \text{ atm} \quad P_{\text{max}} = 25 \text{ atm}$$

Pressure drop (except valve) is zero.

Fluid package = Peng-Robinson

Fluid = Pure Nitrogen

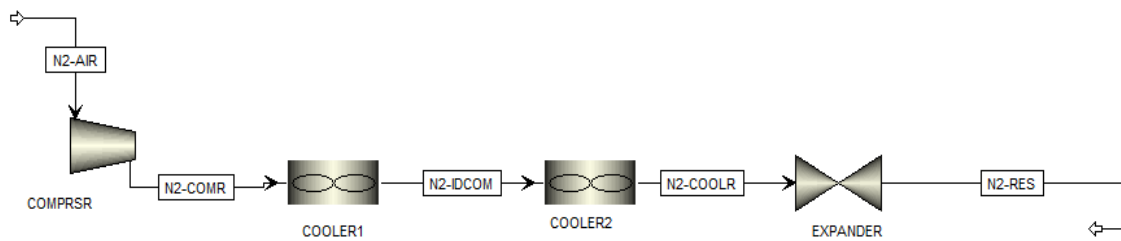


Figure4.1. PED of Nitrogen Liquefaction using Linde cycle (without HX)

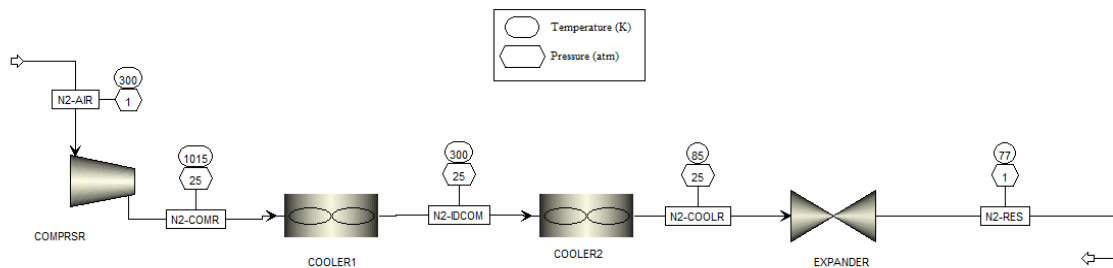


Figure4.2. Result Flow Sheet of Nitrogen liquefaction using Linde cycle (without HX)

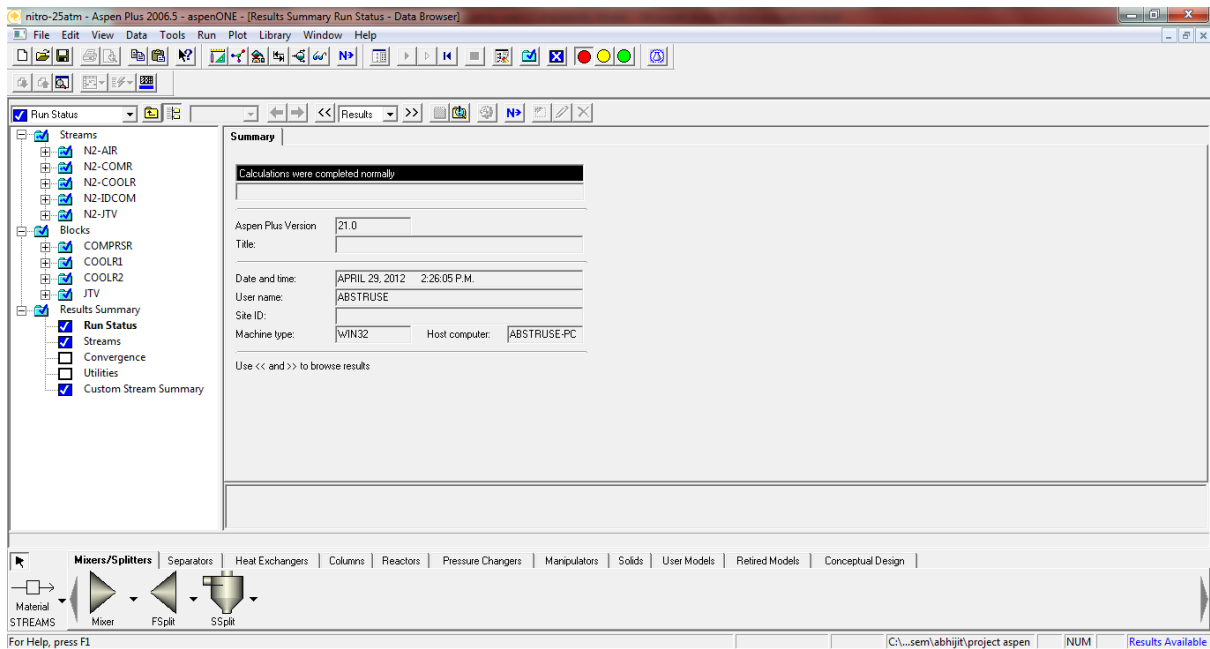


Figure4.3. Success Report of Simulation

Table4.1 Stream table for nitrogen liquefaction without HX

Heat and Material Balance Table						
Stream ID		N2-AIR	N2-COMR	N2-COOLR	N2-IDCOM	N2-RES
From			COMPRSR	COOLER2	COOLER1	EXPANDER
To		COMPRSR	COOLER1	EXPANDER	COOLER2	
Phase		VAPOR	VAPOR	LIQUID	VAPOR	MIXED
Substream: MIXED						
Mole Flow	kmol/hr					
NITROGEN		35.69710	35.69710	35.69710	35.69710	35.69710
Total Flow	kmol/hr	35.69710	35.69710	35.69710	35.69710	35.69710
Total Flow	kg/hr	1000.000	1000.000	1000.000	1000.000	1000.000
Total Flow	l/min	14639.78	1996.222	21.66542	581.0086	313.5230
Temperature	K	300.0000	1015.102	85.00000	300.0000	77.47918
Pressure	atm	1.000000	25.00000	25.00000	25.00000	1.000000
Vapor Frac		1.000000	1.000000	0.0	1.000000	.0811815
Liquid Frac		0.0	0.0	1.000000	0.0	.9188185
Solid Frac		0.0	0.0	0.0	0.0	0.0
Enthalpy	cal/mol	11.04851	5255.538	-2776.132	-30.83913	-2776.132
Enthalpy	cal/gm	.3943996	187.6075	-99.09986	-1.100868	-99.09986
Enthalpy	cal/sec	109.5554	52113.19	-27527.74	-305.7965	-27527.74
Entropy	cal/mol-K	.0377836	2.454721	-25.60575	-6.476357	-25.31812
Entropy	cal/gm-K	1.34877E-3	.0876264	-.9140509	-.2311872	-.9037834
Density	mol/cc	4.06394E-5	2.98039E-4	.0274608	1.02400E-3	1.89763E-3
Density	gm/cc	1.13845E-3	8.34911E-3	.7692752	.0286857	.0531593
Average MW		28.01348	28.01348	28.01348	28.01348	28.01348
Liq Vol 60F	l/min	31.86430	31.86430	31.86430	31.86430	31.86430

Problem Specification 2:

To solve Linde cycle of Nitrogen liquefaction (**Without Recycle Stream**), using Aspen Plus as simulation tool.

Given condition:

$$T_{\text{ambient}} = 300 \text{ K} \quad P_{\text{ambient}} = 1 \text{ atm} \quad P_{\text{max}} = 25 \text{ atm}$$

Pressure drop (except valve) is zero.

Fluid package = Peng-Robinson

Fluid = Pure Nitrogen

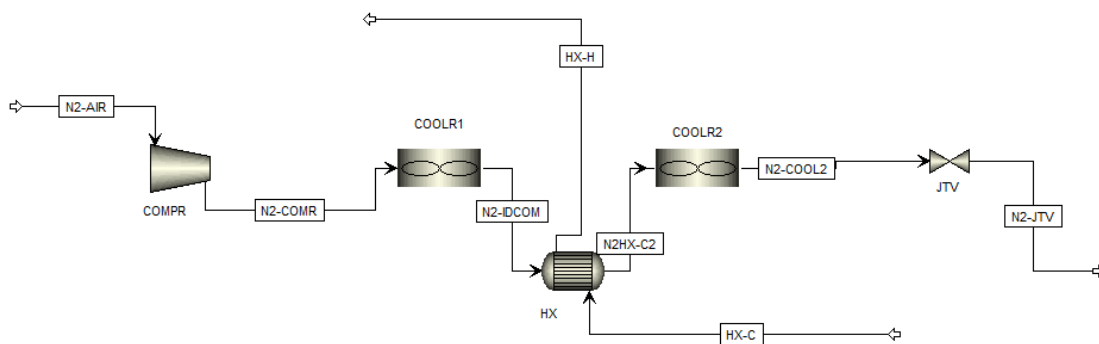


Figure4.4.PFD of Nitrogen liquefaction using Linde cycle (without Recycle)

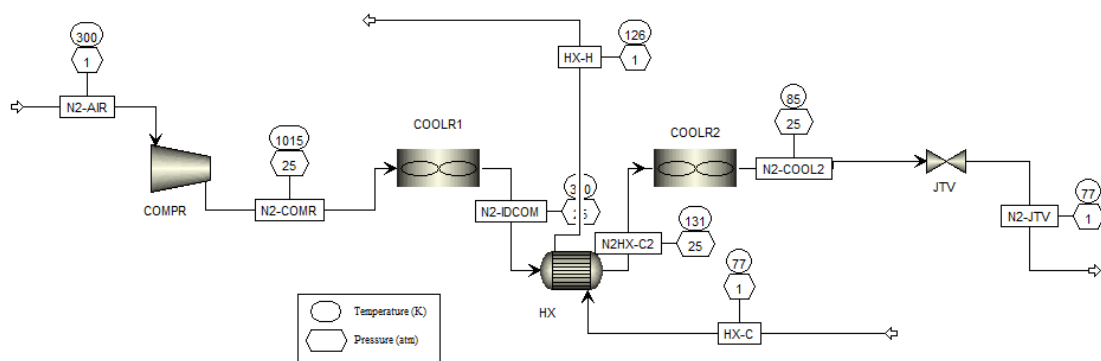


Figure4.5. Result Flow Sheet of Nitrogen liquefaction using Linde cycle (without Recycle)

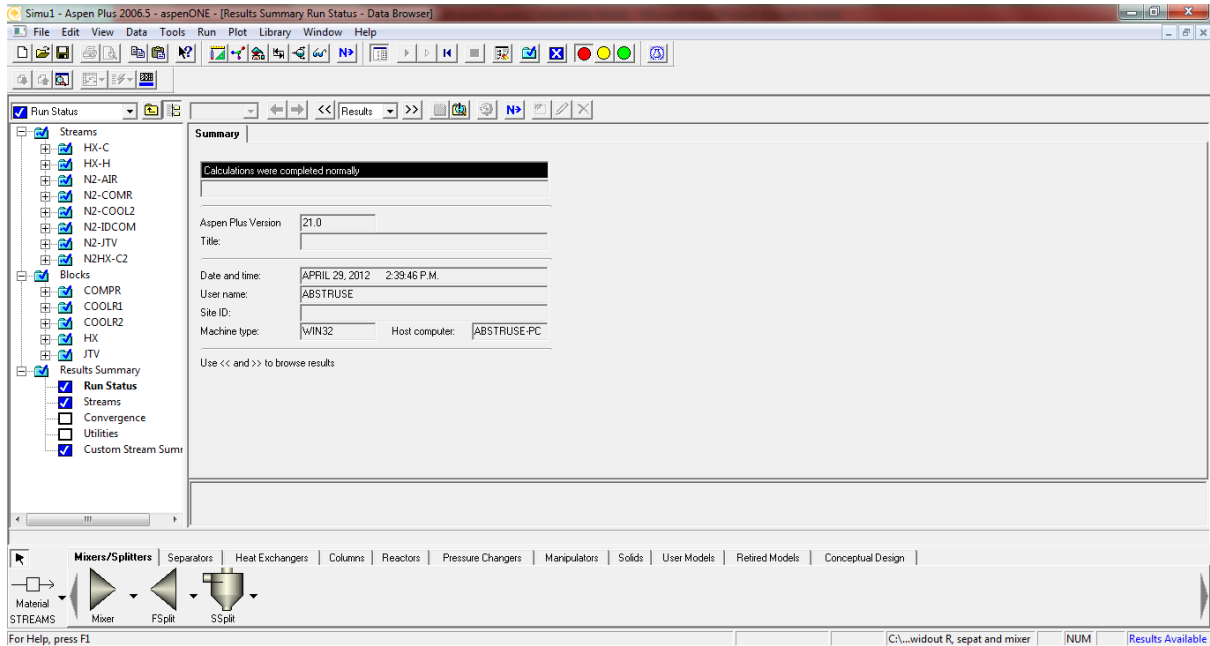


Figure 4.6. Success Report of Simulation

Table 4.2 Stream table for nitrogen liquefaction without recycle stream

Stream ID		HX-C	HX-H	N2-AIR	N2-COMR	N2-COOL2	N2-IDCOM	N2-JTV	N2HX-C2
From			HX		COMPR	COOLR2	COOLR1	JTV	HX
To		HX		COMPR	COOLR1	JTV	HX		COOLR2
Phase		LIQUID	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	MIXED	VAPOR
Substream: MIXED									
Mole Flow	kmol/hr								
NITROGEN		28.91465	28.91465	35.69710	35.69710	35.69710	35.69710	35.69710	35.69710
Total Flow	kmol/hr	28.91465	28.91465	35.69710	35.69710	35.69710	35.69710	35.69710	35.69710
Total Flow	kg/hr	810.0000	810.0000	1000.000	1000.000	1000.000	1000.000	1000.000	1000.000
Total Flow	l/min	16.74726	4923.305	14639.78	1996.222	150.7932	581.0086	2946.039	179.4489
Temperature	K	77.00000	125.9437	300.0000	1015.102	85.00000	300.0000	77.47918	130.9513
Pressure	atm	1.000000	1.000000	1.000000	25.00000	25.00000	25.00000	1.000000	25.00000
Vapor Frac		0.0	1.000000	1.000000	1.000000	1.000000	1.000000	.8110893	1.000000
Liquid Frac		1.000000	0.0	0.0	0.0	0.0	0.0	.1889107	0.0
Solid Frac		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Enthalpy	cal/mol	-2890.769	-1205.142	11.04851	5255.538	-1801.819	-30.83913	-1801.819	-1396.198
Enthalpy	cal/gm	-103.1921	-43.02006	.3943996	187.6075	-64.31973	-1.100868	-64.31973	-49.84021
Enthalpy	cal/sec	-23218.22	-9679.514	109.5554	52113.19	-17866.59	-305.7965	-17866.59	-13844.50
Entropy	cal/mol-K	-26.79801	-6.031001	.0377836	2.454721	-16.09801	-6.476357	-12.74270	-13.35405
Entropy	cal/gm-K	-.9566112	-.2152892	1.34877E-3	.0876264	-.5746523	-.2311872	-.4548776	-.4767008
Density	mol/cc	.0287755	9.78836E-5	4.06394E-5	2.98039E-4	3.94548E-3	1.02400E-3	2.01950E-4	3.31544E-3
Density	gm/cc	.8061018	2.74206E-3	1.13845E-3	8.34911E-3	.1105267	.0286857	5.65731E-3	.0928769
Average MW		28.01348	28.01348	28.01348	28.01348	28.01348	28.01348	28.01348	28.01348
Liq Vol 60F	l/min	25.81008	25.81008	31.86430	31.86430	31.86430	31.86430	31.86430	31.86430

Problem Specification 3:

To solve Linde cycle of Nitrogen liquefaction (**With Recycle Stream**), using Aspen Plus as simulation tool.

Given condition:

$$T_{\text{ambient}} = 300 \text{ K} \quad P_{\text{ambient}} = 1 \text{ atm} \quad P_{\text{max}} = 25 \text{ atm}$$

Pressure drop (except valve) is zero.

Fluid package = Peng-Robinson

Fluid = Pure Nitrogen

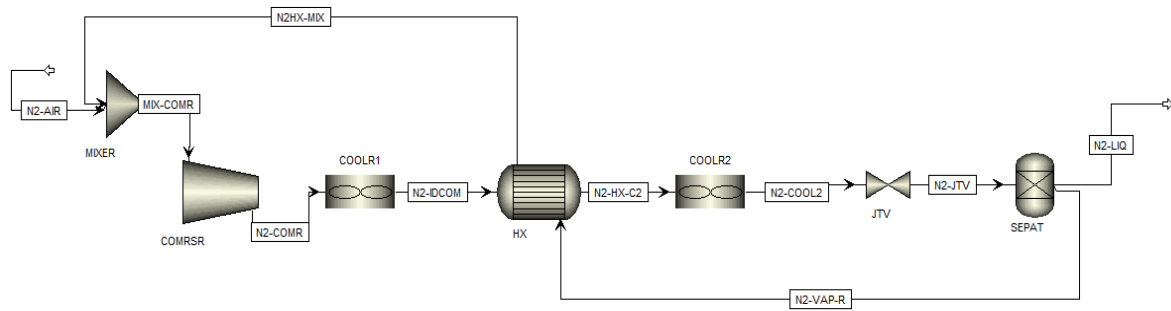


Figure4.7.PFD of Nitrogen liquefaction using Linde cycle (with Recycle stream)

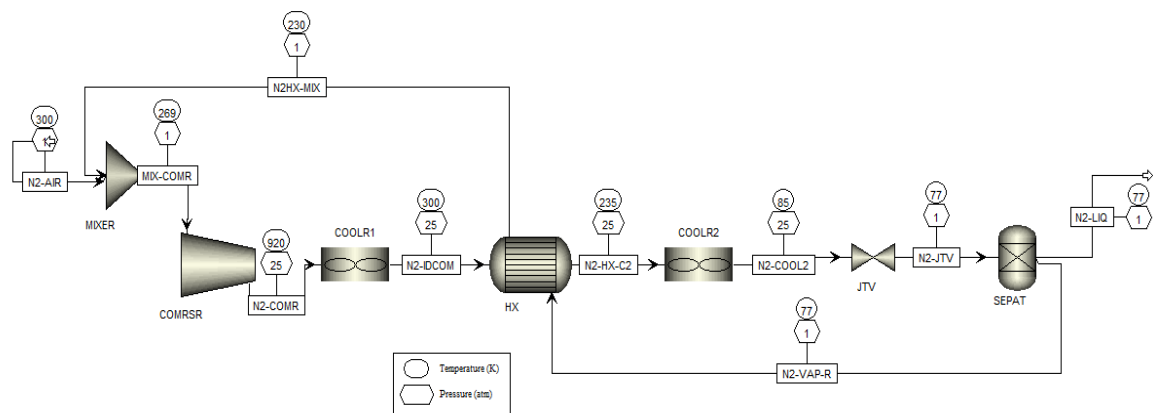


Figure4.8. Result Flow Sheet of Nitrogen liquefaction (with Recycle stream)

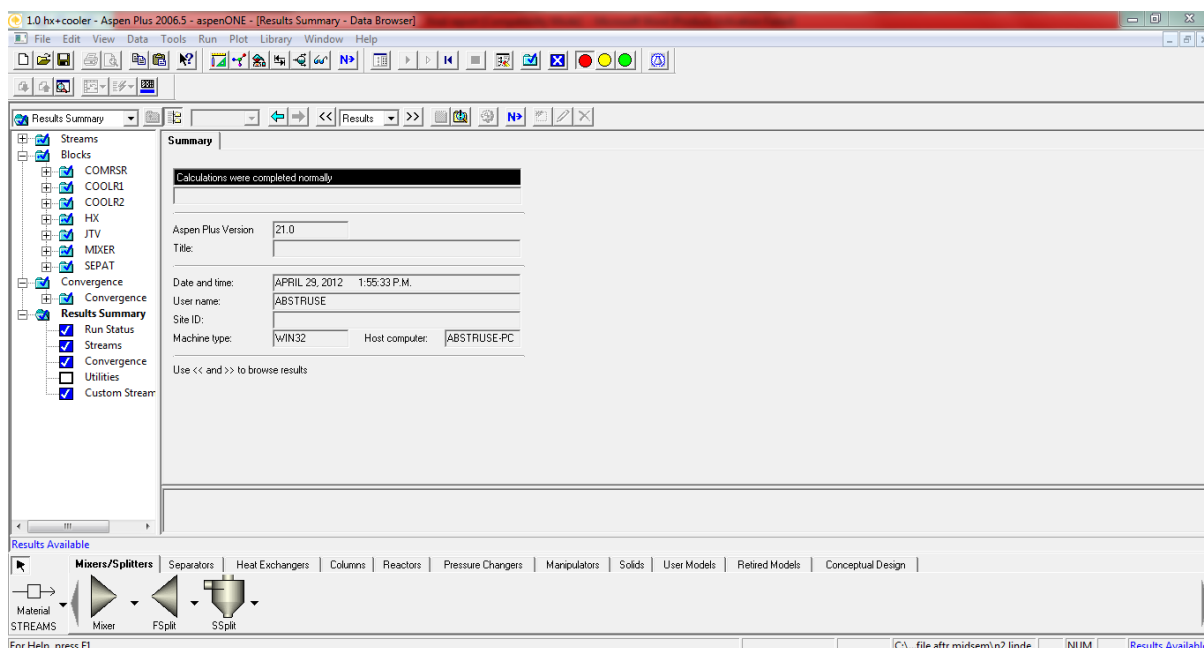


Figure 4.9. Success Report of Simulation

Table 4.3 Stream table for nitrogen liquefaction with recycle stream

Heat and Material Balance Table											
Stream ID		MIX-COMR	N2-AIR	N2-COMR	N2-COOL2	N2-HX-C2	N2-IDCOM	N2-JTV	N2-LIQ	N2-VAP-R	N2HX-MIX
From		MIXER		COMRSR	COOLR2	HX	COOLR1	JTV	SEPAT	SEPAT	HX
To		COMRSR	MIXER	COOLR1	JTV	COOLR2	HX	SEPAT		HX	MIXER
Phase		VAPOR	VAPOR	VAPOR	LIQUID	VAPOR	VAPOR	MIXED	LIQUID	VAPOR	VAPOR
Substream: MIXED											
Mole Flow	kmol/hr										
NITROGEN		64.61175	35.69710	64.61175	64.61175	64.61175	64.61175	64.61175	35.69710	28.91465	28.91465
Total Flow	kmol/hr	64.61175	35.69710	64.61175	64.61175	64.61175	64.61175	64.61175	35.69710	28.91465	28.91465
Total Flow	kg/hr	1810.000	1000.000	1810.000	1810.000	1810.000	1810.000	1810.000	1000.000	809.9998	809.9998
Total Flow	l/min	23720.09	14639.78	3277.349	39.21440	802.3804	1051.625	567.4766	20.73032	2938.171	9079.207
Temperature	K	268.6574	300.0000	920.2594	85.00000	234.9818	300.0000	77.47918	77.47918	77.47918	229.9788
Pressure	atm	1.000000	1.000000	25.00000	25.00000	25.00000	25.00000	1.000000	1.000000	1.000000	1.000000
Vapor Frac		1.000000	1.000000	1.000000	0.0	1.000000	1.000000	.0811815	0.0	1.000000	1.000000
Liquid Frac		0.0	0.0	0.0	1.000000	0.0	0.0	.9188185	1.000000	0.0	0.0
Solid Frac		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Enthalpy	cal/mol	-207.4044	11.04851	4517.586	-2776.132	-510.8218	-30.83913	-2776.132	-2884.495	-1549.653	-477.0995
Enthalpy	cal/gm	-7.403737	.3943996	161.2647	-99.09986	-18.23486	-1.100868	-99.09986	-102.9681	-55.31813	-17.03107
Enthalpy	cal/sec	-3722.434	109.5554	81080.32	-49825.20	-9168.079	-553.4917	-49825.20	-28602.25	-12446.58	-3831.990
Entropy	cal/mol-K	-.7313080	.0377836	1.691616	-25.60575	-8.280933	-6.476357	-25.31812	-26.71678	-9.488007	-1.815227
Entropy	cal/gm-K	-.0261055	1.34877E-3	.0603857	-.9140509	-.2956053	-.2311872	-.9037834	-.9537114	-.3386943	-.0647983
Density	mol/cc	4.53988E-5	4.06394E-5	3.28577E-4	.0274608	1.34209E-3	1.02400E-3	1.89763E-3	.0286995	1.64017E-4	5.30785E-5
Density	gm/cc	1.27178E-3	1.13845E-3	9.20459E-3	.7692752	.0375964	.0286857	.0531593	.8039755	4.59469E-3	1.48691E-3
Average MW		28.01348	28.01348	28.01348	28.01348	28.01348	28.01348	28.01348	28.01348	28.01348	28.01348
Liq Vol 60F	l/min	57.67438	31.86430	57.67438	57.67438	57.67438	57.67438	57.67438	31.86430	25.81008	25.81008

Table 4.4 Variation of liquid yield with maximum pressure inside liquefaction system

Pressure (atm)	Liquid yield (%)
10	92.23
15	92.12
20	92
25	91.88
30	91.75
35	91.63
50	91.23
75	90.53
100	89.79
125	89.01
150	88.21
175	87.38
200	86.52
225	85.66
250	84.77
275	83.87
300	82.95

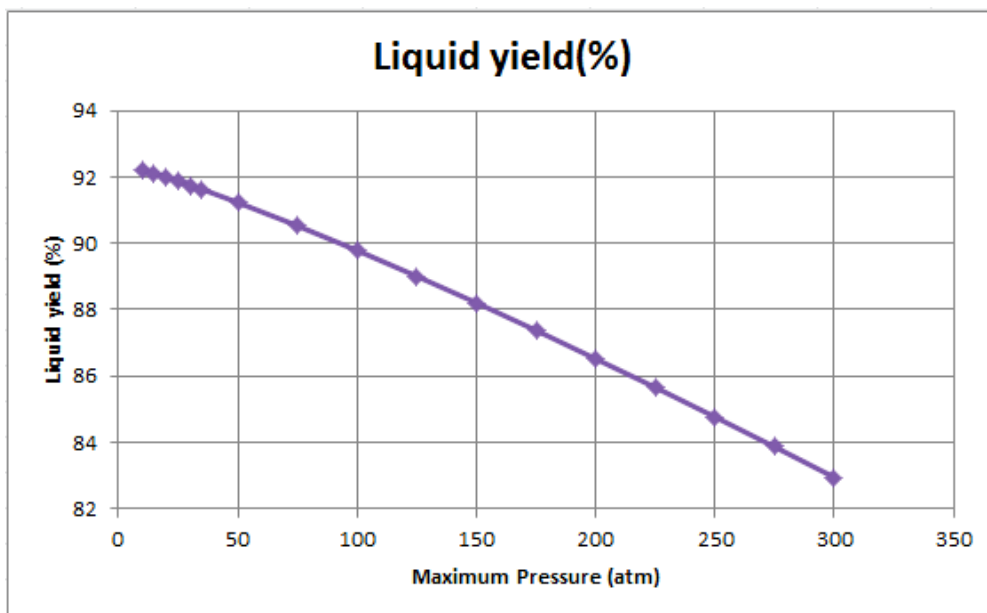


Figure 4.10. Liquid yield v/s Pressure plot for Linde system of nitrogen liquefaction

4.2 SIMULATION OF COLLINS CYCLE FOR HELIUM LIQUEFACTION

Problem Specification 1:

To solve Collins cycle of helium liquefaction using Aspen Plus as simulation tool.

Given condition:

$$T_{\text{ambient}} = 300 \text{ K} \quad P_{\text{ambient}} = 1 \text{ bar} \quad P_{\text{max}} = 15 \text{ bar}$$

Pressure drop (except valve) is zero.

Fluid package = Peng-Robinson

Fluid = Pure Helium

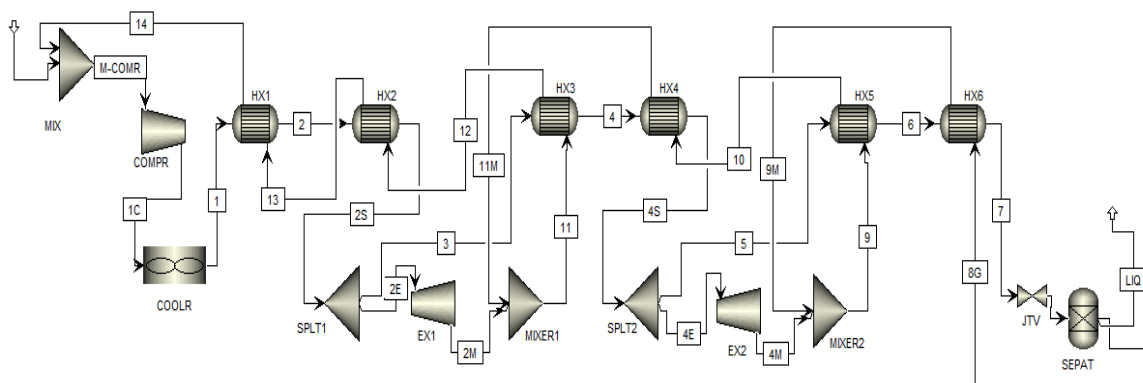


Figure4.11.PFD of Helium liquefaction using Collins cycle

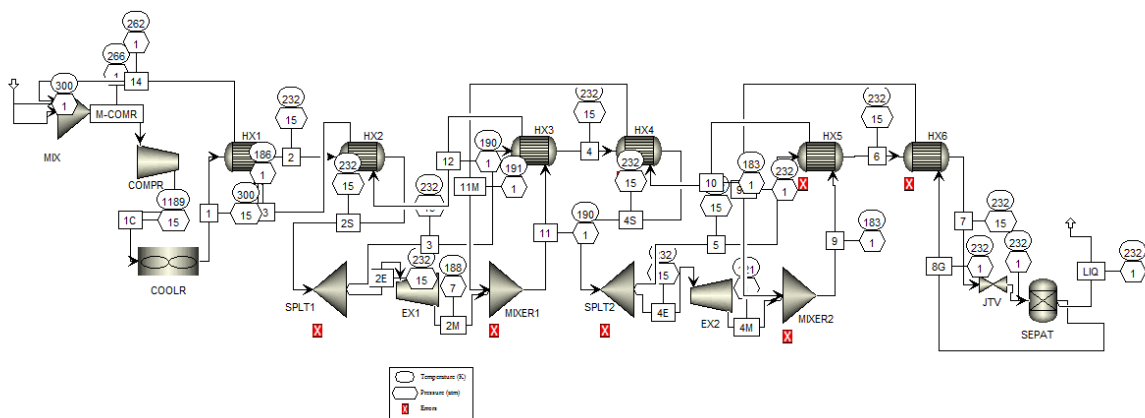


Figure4.12. Result flow sheet of Helium liquefaction using Collins cycle

From the result flow sheet of the helium liquefaction cycle (fig 4.12) , it was seen that Aspen plus simulator was showing error starting from HX 5 and 6. So in order to find the error, step by step simulaton was done. As the error was seen in only HX 5 and 6 so , the process upto HX 4 was simulated as shown below.

Problem Specification 2:

To solve up to 4 heat exchangers in Collins cycle of helium liquefaction using Aspen Plus.

Given condition:

$$T_{\text{ambient}} = 300 \text{ K} \quad P_{\text{ambient}} = 1 \text{ bar} \quad P_{\text{max}} = 15 \text{ bar}$$

Pressure drop (except valve) is zero.

Fluid package = Peng-Robinson

Fluid = Pure Helium

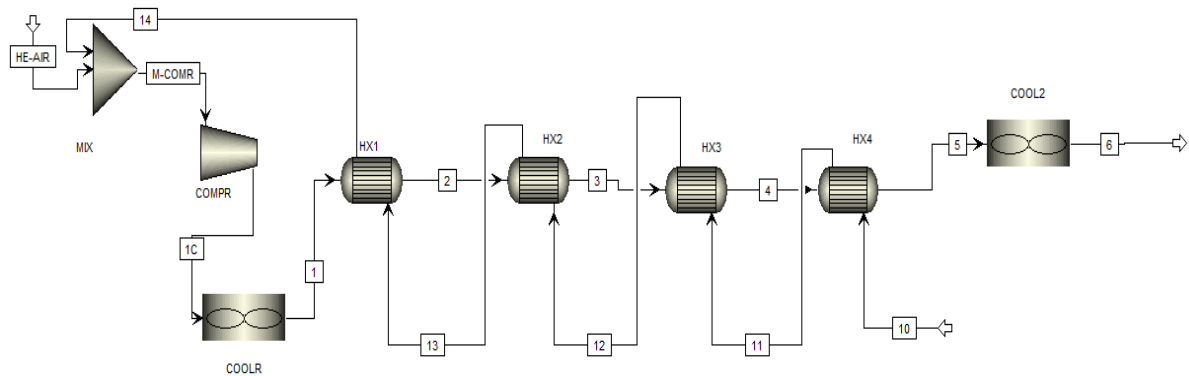


Figure4.13.PFD of Helium liquefaction using Collins cycle upto HX4

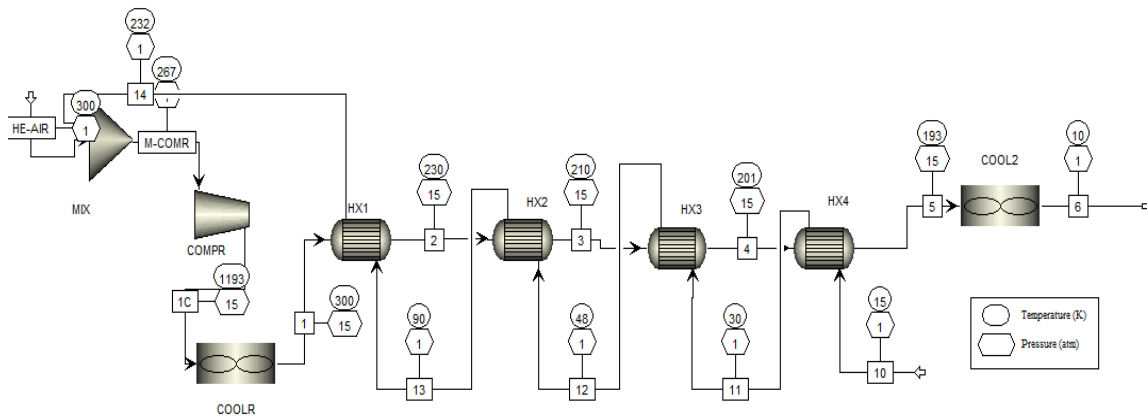


Figure4.14. Result flow sheet of Helium liquefaction using Collins cycle

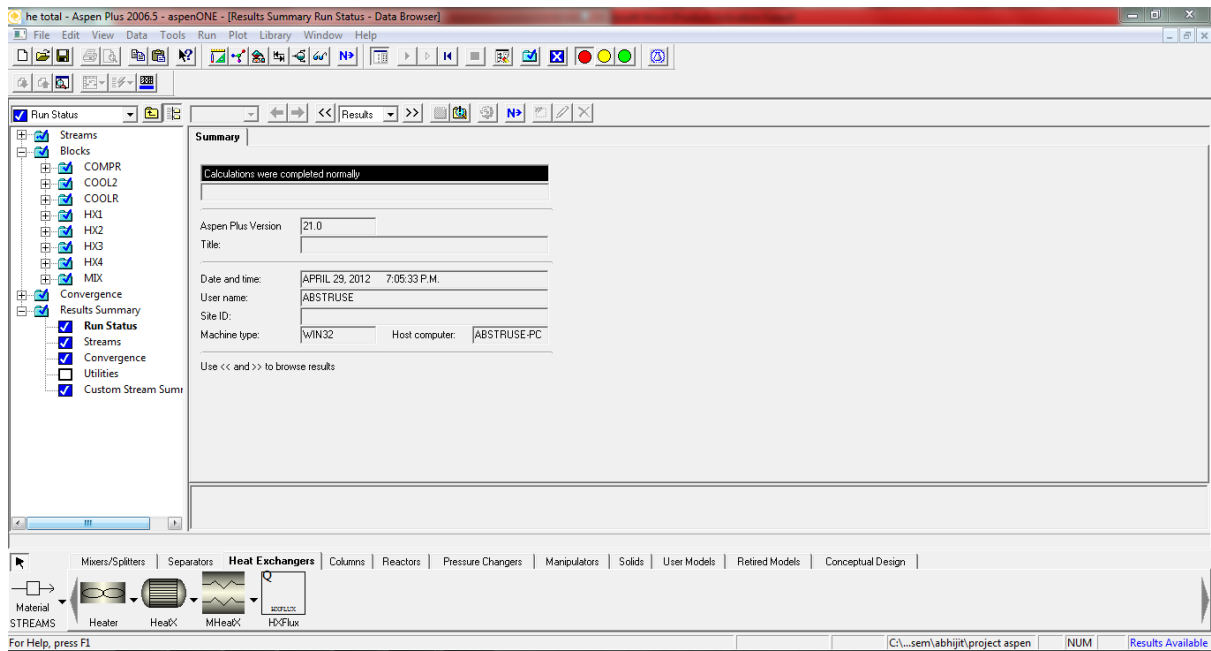


Figure 4.15. Success rate of simulation

Table 4.5 Stream table for helium liquefaction up to HX4

Heat and Material Balance Table															
Stream ID		1	1C	2	3	4	5	6	10	11	12	13	14	HE-AIR	M-COMR
From		COOLR	COMPR	HX1	HX2	HX3	HX4	COOL2		HX4	HX3	HX3	HX2	HX1	
To		HX1	COOLR	HX2	HX3	HX4	COOL2							MIX	COMPR
Phase		VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR
Substream: MIXED															
Mole Flow	kmol/hr														
HELIUM		489.6817	489.6817	489.6817	489.6817	489.6817	489.6817	489.6817	239.8441	239.8441	239.8441	239.8441	239.8441	249.8376	489.6817
Total Flow	kmol/hr	489.6817	489.6817	489.6817	489.6817	489.6817	489.6817	489.6817	239.8441	239.8441	239.8441	239.8441	239.8441	249.8376	489.6817
Total Flow	kg/hr	1960.000	1960.000	1960.000	1960.000	1960.000	1960.000	1960.000	960.0000	960.0000	960.0000	960.0000	960.0000	1000.000	1960.000
Total Flow	l/min	13423.00	54022.56	10308.74	9394.107	8989.633	8647.570	6785.731	4707.358	9917.286	16066.40	29963.06	77272.81	1.02517E+5	1.78779E+5
Temperature	K	300.0000	1193.088	230.3835	209.9505	200.9172	193.2792	10.46000	14.50000	30.00000	48.43000	90.18000	232.4700	300.0000	266.9233
Pressure	atm	15.00000	14.80385	15.00000	15.00000	15.00000	15.00000	9869233	9869233	9869233	9869233	9869233	9869233	1.000000	1.000000
Vapor Frac		1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
Liquid Frac		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solid Frac		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Enthalpy	cal/mol	9.388853	4444.784	-336.7046	-438.3318	-483.2707	-521.2734	-1430.057	-1409.541	-1331.952	-1240.202	-1032.713	-326.1058	9.190036	-155.0365
Enthalpy	cal/gm	2.345689	1110.474	-84.12148	-109.5118	-120.7392	-130.2337	-357.2820	-352.1564	-332.7718	-309.8491	-258.0106	-81.47348	2.296016	-38.73394
Enthalpy	cal/sec	1277.097	6.04592E+5	-45799.47	-59623.08	-65735.79	-70905.01	-1.9452E+5	-93908.37	-88739.15	-82626.44	-68802.83	-21726.26	637.7824	-21088.48
Entropy	cal/mol-K	-5.350507	1.532484	-6.663166	-7.125092	-7.343877	-7.536712	-16.68769	-15.02854	-11.38661	-9.002161	-5.912315	-1.209609	.0304650	-5495627
Entropy	cal/gm-K	-1.336758	.3828722	-1.664709	-1.780116	-1.834777	-1.882954	-4.169212	-3.754695	-2.844803	-2.249078	-1.477119	-.3022058	7.61132E-3	-.1373014
Density	mol/cc	6.08013E-4	1.51073E-4	7.91693E-4	8.68775E-4	9.07864E-4	9.43775E-4	1.20272E-3	8.49182E-4	4.03074E-4	2.48805E-4	1.33411E-4	5.17310E-5	4.06172E-5	4.56505E-5
Density	gm/cc	2.43363E-3	6.04686E-4	3.16883E-3	3.47736E-3	3.63382E-3	3.77755E-3	4.81402E-3	3.39893E-3	1.61335E-3	9.95867E-4	5.33991E-4	2.07059E-4	1.62575E-4	1.82721E-4
Average MW		4.002600	4.002600	4.002600	4.002600	4.002600	4.002600	4.002600	4.002600	4.002600	4.002600	4.002600	4.002600	4.002600	4.002600
Liq Vol 60F	l/min	437.1046	437.1046	437.1046	437.1046	437.1046	437.1046	437.1046	214.0920	214.0920	214.0920	214.0920	214.0920	223.0125	437.1046

It was seen from this simulation that the temperature was reduced to 10 K when 4 heat exchangers were used. But the boiling point of helium is 4.22 K. So the outlet temperature of HX6 should be in between 10 K and 4.22 K and this was where the error was shown in Aspen plus (Fig 4.12). So it is possible that Aspen plus simulator does not entertain temperature below 10 K. In order to reach at a conclusion, the last step of Collins helium liquefier (simulation at Joule Thompson valve) was simulated separately with the help of the data from “Thermodynamic analysis of Collins helium liquefaction cycle” by M.D. Atrey [15].

Problem Specification 3:

To solve the last stage of Collins cycle of helium liquefaction using Aspen Plus

Given condition:

$$T_{\text{ambient}} = 300 \text{ K} \quad P_{\text{ambient}} = 1 \text{ bar} \quad P_{\text{max}} = 15 \text{ bar}$$

Pressure drop (except valve) is zero.

Fluid package = Peng-Robinson

Fluid = Pure Helium

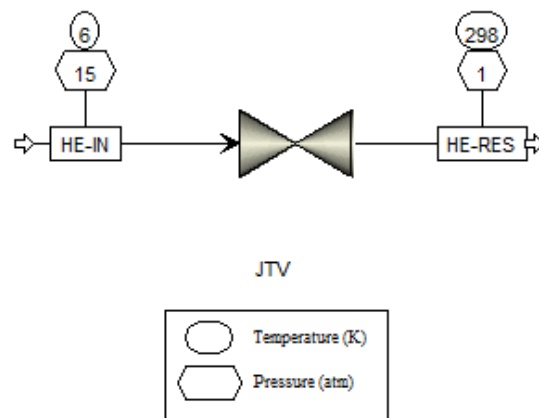


Figure4.16. PFD of last step of Helium liquefaction of Collins cycle after simulation

Specifications | Flash Options | PSD | Component Attr. | EO Options

Substream name: MIXED Ref Temperature

State variables

Temperature: 6.35 K

Pressure: 15 bar

Total flow: 1000 kg/hr (Mass)

Solvent:

Composition

Component	Value
HELIU-01	1

Total: 1

Figure4.17. Stream specifications of the last stage of Collins helium liquefaction cycle

Operation | Valve Parameters | Calculation Options | Pipe Fittings

Calculation type
 Adiabatic flash for specified outlet pressure (pressure changer)
 Calculate valve flow coefficient for specified outlet pressure (design)
 Calculate outlet pressure for specified valve (rating)

Pressure specification
 Outlet pressure: 1 bar
 Pressure drop: atm

Valve operating specification
 % Opening:
 Flow coef:

Flash options
 Valid phases: Vapor-Liquid
 Maximum iterations: 30
 Error tolerance: 0.0001

Figure4.18. Block specification for JTV in the last stage of Collins Helium liquefaction cycle

```

COMPUTATION ORDER FOR THE FLOWSHEET:
JTV
->Calculations begin ...

*** SEVERE ERROR WHILE PERFORMING INITIAL ENTHALPY CALCULATIONS FOR STREAM:
"HE-IN"
STREAM INITIALIZATION CALCULATIONS FOR STREAM HE-IN
BYPASSED DUE TO UNREASONABLE SPECIFICATIONS. SPECIFIED TEMPERATURE
IS      6.3500      SPECIFIED PRESSURE IS      0.15000E+07.

Block: JTV      Model: VALVE
->Simulation calculations completed ...
  
```

Figure4.19. Results Summary

From the results summary, it was clear that any temperature below 10 K is termed as unreasonable specifications in Aspen plus. So the coolers and the heat exchangers couldn't cool below 10 K in Aspen plus simulator. So liquefaction of Helium is outside the scope of Aspen plus simulator as any specified temperature below 10 K is termed as unreasonable specifications.

Chapter – 05

CONCLUSION

CONCLUSION AND SCOPE FOR FUTURE WORK

The above project work presents a cycle simulation for the Nitrogen and Helium liquefaction cycle with a compressor, cooler, heat exchangers, J-T valve and separator. It gives us the design data in terms of nodal temperature across the heat exchanger, compressor, cooler etc. and mass flow rates through all the equipment. The simulation can be adapted to bring about any changes in the configuration of the liquefaction cycle and can be successfully applied for other complicated cycle.

Using Linde-Hampson system, the maximum liquid yield obtained in the simulation process is 92.23% for maximum pressure of 10 atm inside the system. As we decrease the maximum pressure from 300 atm to 10 atm, liquid yield increases from 82.95% to 92.23%. This is due to the fact that in Joule-Thompson region, with decrease in pressure, temperature also decreases. So the rate of liquefaction increases i.e. liquid yield increases. But in the absence of recycle stream, the liquid yield drastically decreases to 18.89%. The liquefaction of Helium using Collins cycle is outside the scope of Aspen Plus simulator as the results showed that temperature below 10K was unreasonable specification for the simulator as the coolers and heat exchangers in Aspen could not cool beyond 10 K. In future, if the process data across all the blocks and streams of industrial helium liquefier are known then helium liquefier simulation can be done using Aspen Hysys simulator.

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