

# **SIMULATION OF AIR LIQUEFACTION USING ASPEN PLUS**

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**IN**

**CHEMICAL ENGINEERING**

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## **CERTIFICATE**

This is to certify that the report entitled “SIMULATION OF AIR LIQUEFACTION USING ASPEN PLUS” submitted by **ARUNIM BOSE (ROLL NO: 108CH051)** in the partial fulfillment of the requirement for the degree of the B.Tech in Chemical Engineering, National Institute Of Technology, Rourkela is an authentic work carried out by him under my super vision. To the best of my knowledge the matter embodied in the report has not been submitted to any other university/institute for any degree.

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## **ABSTRACT**

Air is a mixture of various gases. Each of these gases have got some kind of uses. As such, separation of air into its constituent gases becomes very necessary from commercial point of view. For separation of air into its constituent gases, it is necessary to liquefy the same. In this project, simulation of liquefaction of air, followed by its separation was done using Aspen Plus simulating tool. The model under consideration was Linde single-column system. Also, the effect of various process conditions on the yield and purity of final product were analyzed. It was found that by using Linde single-column system, oxygen of almost 98-99% purity could be obtained. However, the purity of nitrogen obtained was only about 90%.

Keywords: Aspen Plus, Linde single-column system.

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# CHAPTER 1

## INTRODUCTION AND LITERATURE REVIEW

# **1. INTRODUCTION AND LITERATURE REVIEW**

## **1.1 AIR LIQUEFACTION AND SEPARATION**

Air is a mixture of various types of gases. Atmospheric air has 78.084% nitrogen, 20.946% oxygen, 0.934% argon 0.03768% other gases by volume (on dry basis) <sup>[1]</sup>. Separation of atmospheric air is done in an air separation plant basically to obtain nitrogen and oxygen, and sometimes also argon and rarely other inert gases. There are various technologies for separation process, the most common being cryogenic distillation. In addition to the cryogenic method, there are other methods such as Membrane, Pressure Swing Adsorption (PSA) and Vacuum Pressure Swing Adsorption (VPSA), which are typically used to separate a single component.

## **1.2 CRYOGENIC GAS LIQUEFACTION SYSTEMS**

Of the various gas liquefaction techniques developed by various cryogenic experts <sup>[2]-[5]</sup>, some of them are listed below:-

- 1: Simple Linde Hampson system
- 2: Precooled Linde Hampson system
- 3: Linde dual- pressure system
- 4: Cascade system
- 5: Claude system
- 6: Kaptiza system

Liquefaction of gases is used to convert a gas into a liquid state. Many gases can be put into a liquid state at normal atmospheric pressure by simple cooling; a few, such as carbon dioxide, require pressurization as well.

Liquid oxygen is provided to hospitals for conversion to gas for patients suffering from breathing problems, and liquid nitrogen is used in the medical field for cryosurgery, and by inseminators to freeze semen <sup>[6]</sup>.

Liquid air is air that has been cooled to very low temperatures so that it has condensed to a pale blue mobile liquid. It is often used for condensing other substances into liquid and/or solidifying them, and as an industrial source of nitrogen, oxygen, argon, and other inert gases. Nowadays, liquid air is also replacing liquid nitrogen for theatrical smoke and fog effects <sup>[7]</sup>.

## 1.2.1 PRODUCTION OF LOW TEMPERATURES

### 1.2.1.1 Joule-Thomson Effect

Most of the practical liquefaction systems utilize an expansion valve or a Joule Thomson valve to produce low temperatures. 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 results in a decrease in temperature. It is made sure that the expansion valve is operated in the region where a net decrease in temperature occurs. The curve that separates two regions is called the inversion curve <sup>[2]</sup>.

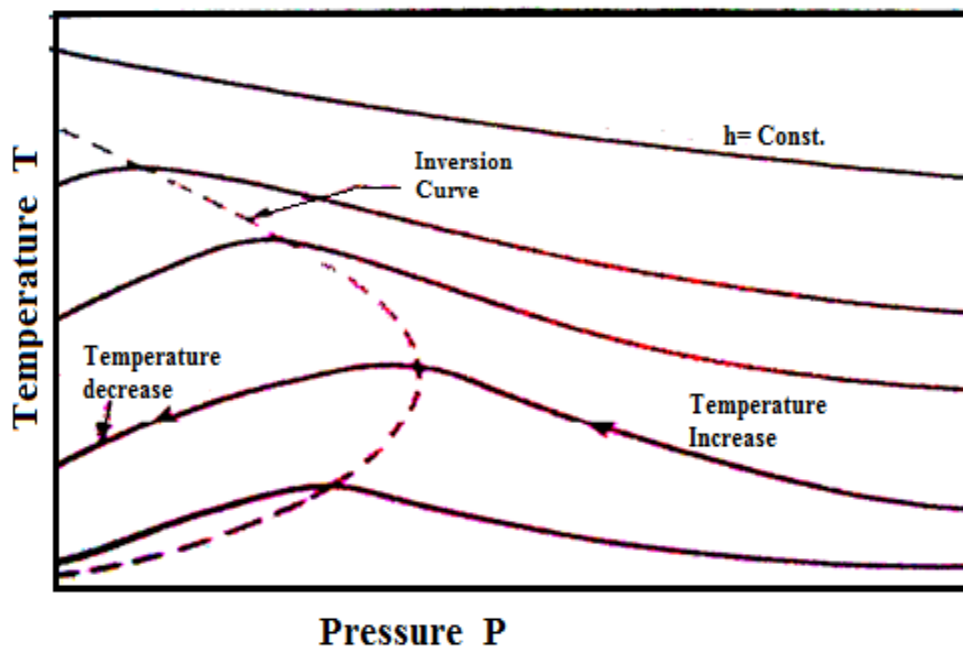


Figure 1.1 Isenthalpic expansion of a real gas.

### 1.2.1.2 Adiabatic Expansion

The second method of lowering temperature 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 hence isentropic <sup>[2]</sup>.

## **1.3 CRYOGENIC SEPARATION SYSTEMS**

In many cases, the separation of mixtures at cryogenic temperatures is the most economical method of all <sup>[2]</sup>. Almost all the commercially produced oxygen, nitrogen, argon, neon, krypton, and xenon are obtained through the rectification of liquid air. The effectiveness of other separation methods, such as physical adsorption and refrigeration purification, are increased as the temperature is lowered into the cryogenic range.

Some common air separation systems developed by cryogenic engineers <sup>[2]-[5]</sup> are listed below:

- 1: Linde single-column system
- 2: Linde double-column system
- 3: Linde-Frankl system
- 4: Heylandt system
- 5: Linde-Bronn system
- 6: L'Air liquide system

### **1.3.1 PRINCIPLES OF GAS SEPARATION**

#### **1.3.1.1 Simple Condensation or Evaporation**

Separation of some mixtures can be attained by partial condensation. Mixtures with widely different boiling points usually can be separated effectively by partial condensation, whereas the separation is usually less effective for substances having boiling points close together <sup>[2]</sup>.

It is not possible to separate air into practically pure components by a single condensation. Some separation can be achieved, but not enough for most practical purposes. On the other hand, nitrogen-helium mixtures, ammonia-hydrogen mixtures, and so on, can be separated fairly effectively by a single partial condensation.

### **1.3.1.2 Rectification**

Rectification is the cascading of several evaporations and condensations carried out in counterflow. As the mixture to be purified is heated, its vapors rise to the fractionating column. As it rises, it cools, condensing on the condenser walls and the surfaces of the packing material. Here, the condensate continues to be heated by the rising hot vapors; it vaporizes once more. However, the composition of the fresh vapors is determined once again by Raoult's law. Each vaporization-condensation cycle (called a theoretical plate) will yield a purer solution of the more volatile component. This method has been used successfully for separation of air mixture into its various constituents like nitrogen, oxygen, argon, neon etc.

# CHAPTER 2

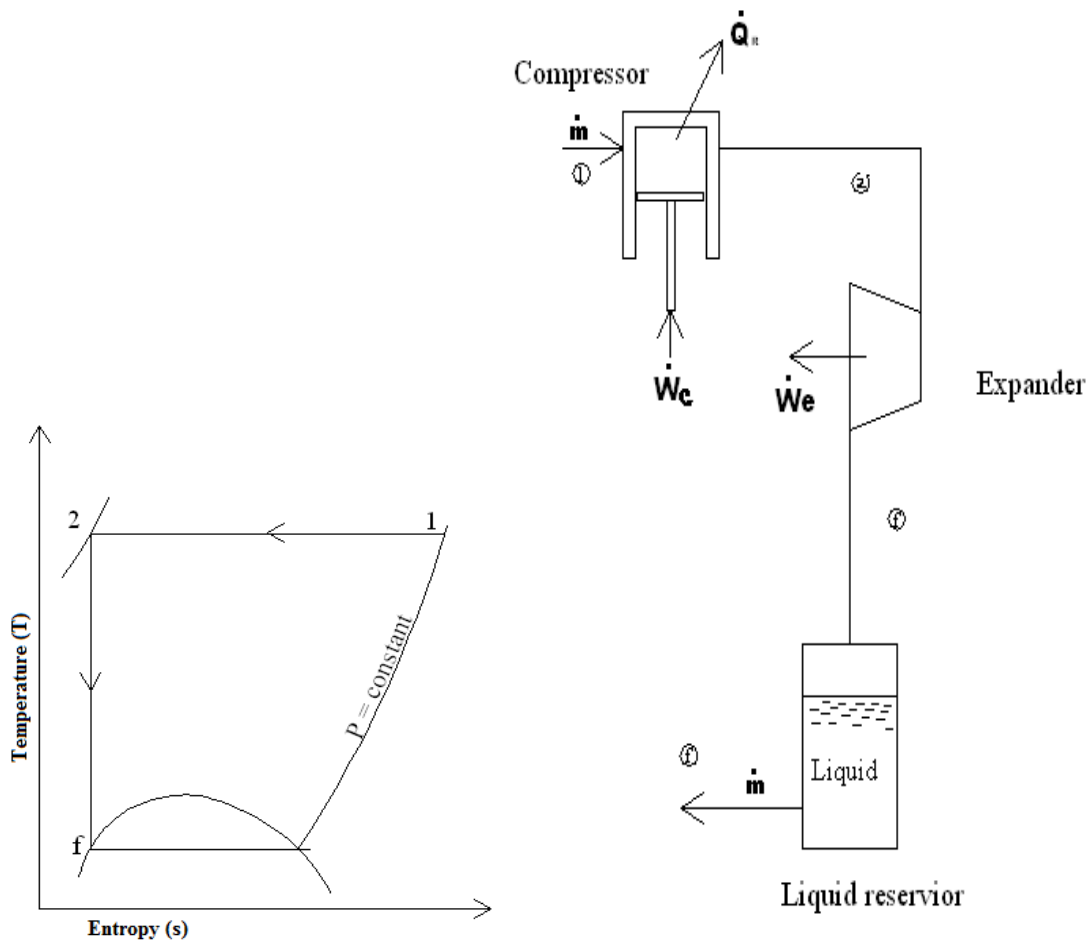
## THERMODYNAMIC ASPECT

## 2. THERMODYNAMIC ASPECT

### 2.1 CRYOGENIC GAS LIQUEFACTION SYSTEMS

#### 2.1.1 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, the first two processes in the Carnot cycle are chosen; a reversible isothermal compression followed by a reversible isentropic expansion [2].



(a) Thermodynamic cycle T-S plane (b) Apparatus setup

Figure 2.1 The thermodynamically ideal liquefaction system



### 2.1.1.1 Working Principle

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 70GPa or 80GPa ( $10^7$  psia) for nitrogen [2]. It is highly impracticable to attain this pressure in a liquefaction system, which is the reason it is not an ideal process for a practical system.

### 2.1.2 SIMPLE LINDE-HAMPSON SYSTEM

The Linde-Hampson system was the second used to liquefy gases (the cascade system was the first), although it is the simplest of all the liquefaction systems. A basic differentiation between the various refrigeration cycles lies in the expansion device. The expansion engine approaches an isentropic process and the valve 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 is also incorporated [2].

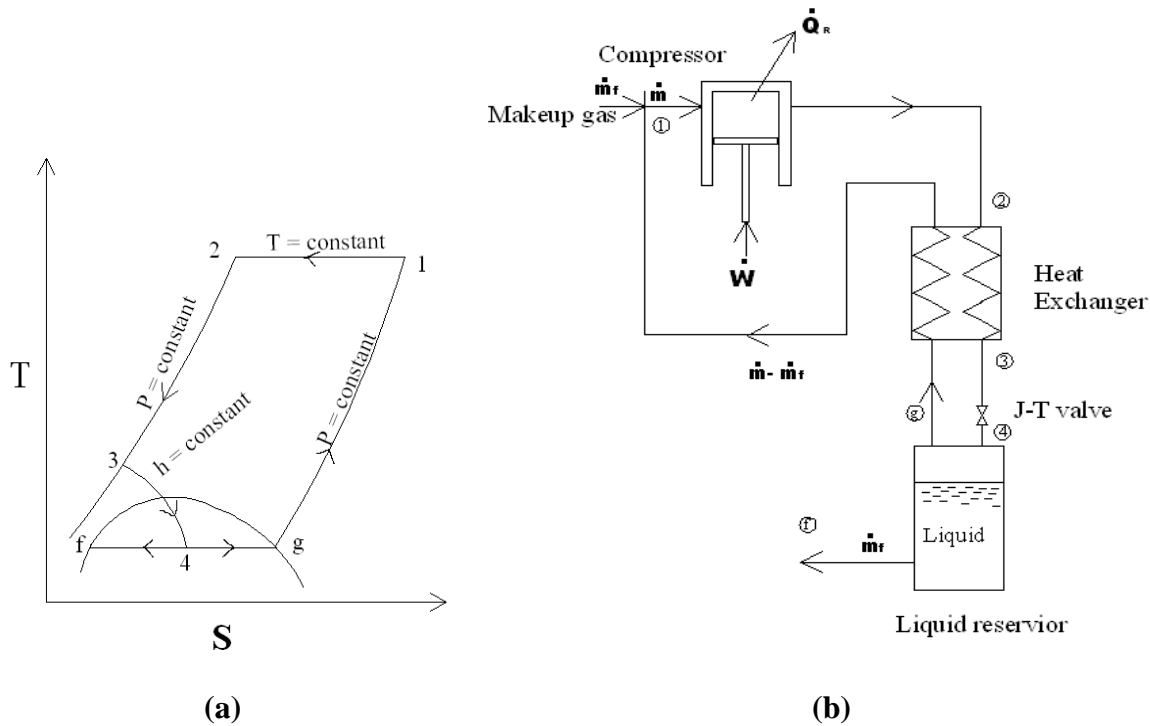


Figure 2.2 Linde-Hampson liquefaction system

(a) Linde-Hampson cycle (b) Apparatus setup

### 2.1.2.1 Working Principle

The gas is first compressed from ambient conditions at point 1 reversibly and isothermally to point 2. In a real system, process 1 to 2 would actually be two processes: an irreversible adiabatic or polytropic compression followed by an aftercooling to lower the gas temperature back to within a few degrees of ambient temperature. The gas next passes through a constant-pressure heat exchanger (ideally) in which it exchanges energy with the outgoing low-pressure steam to point 3. From point 3 to point 4, the gas expands through an expansion valve to  $p_4=p_1$ . At point 4, some of the gas stream is in the liquid state and is withdrawn at condition f (saturated-liquid condition), and the rest of the gas leaves the liquid receiver at condition g (saturated-vapor condition). This cold gas is finally warmed to the initial temperature by absorbing energy at constant pressure (ideally) from the incoming high-pressure stream <sup>[2]</sup>.

## 2.2 CRYOGENIC SEPARATION SYSTEMS

### 2.2.1 IDEAL SEPARATION SYSTEM

An ideal system would be the one in which all the processes are reversible. Mixing two gases together is ordinarily an irreversible process because the gases would not unmix themselves without some external assistance. There is one method, however, we could imagine that allows reversible mixing and separation. This method employs semipermeable membranes- that is, membranes that allow the complete free passage of one gas but completely block the passage of all other gases. Using these devices, the gases could be mixed while work is obtained, and the same amount of work would be expended to unmix the gases. Hence, the process may be imagined to be reversible <sup>[2]</sup>.

The idea of semipermeable membranes is not a completely theoretical concept because materials do exist in nature that are permeable to certain gases. For example, a thin sheet of palladium allows molecules of hydrogen to pass through it, but does not allow other gases to pass through. Since we are concerned with an idealized reversible system, it does not matter whether such membranes may or may not physically exist <sup>[2]</sup>.

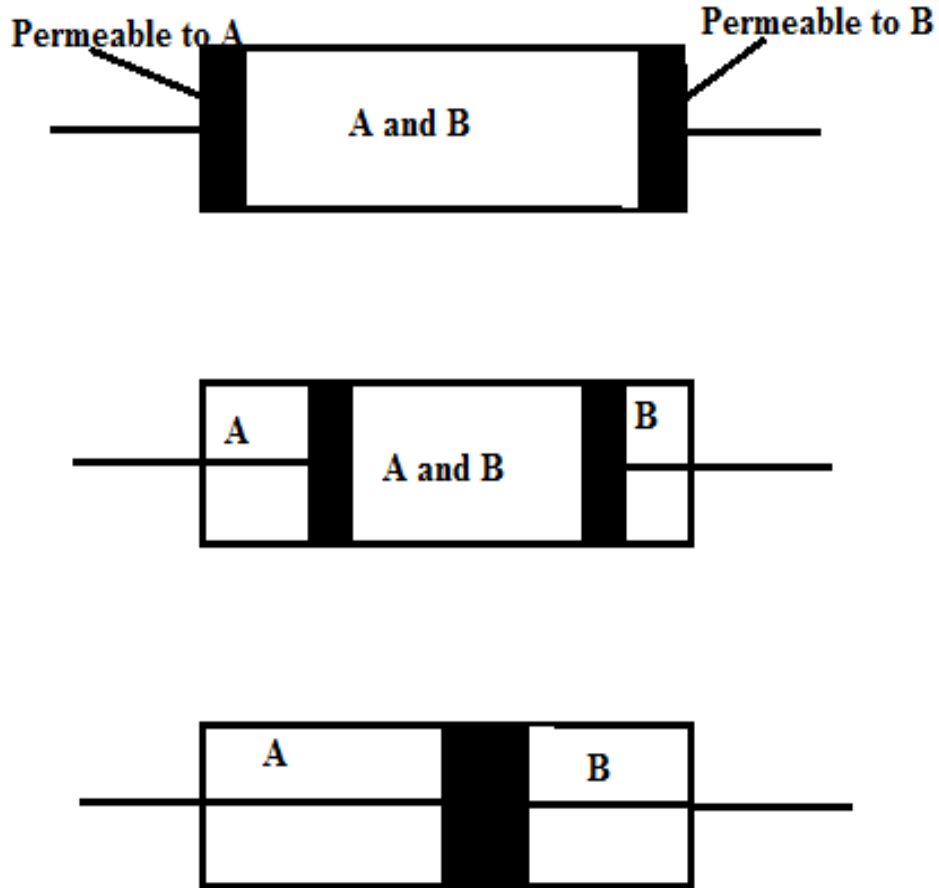


Figure 2.3 Thermodynamically ideal gas-separation system

### 2.2.1.1 Working Principle

Let us consider the separation of a mixture of two gases in the double-cylinder arrangement shown in Fig. 2.3. The left-hand piston is permeable to gas A but not to gas B, and the right-hand piston is permeable to gas B but not to gas A. By moving the two pistons together, the mixture of A and B can be separated reversibly into pure A and pure B <sup>[2]</sup>.

## 2.2.2 LINDE SINGLE-COLUMN SYSTEM

One of the most simple air-separation systems is the Linde single-column system shown in Fig. 2.4. This system was first operated by Linde in 1902 [2].

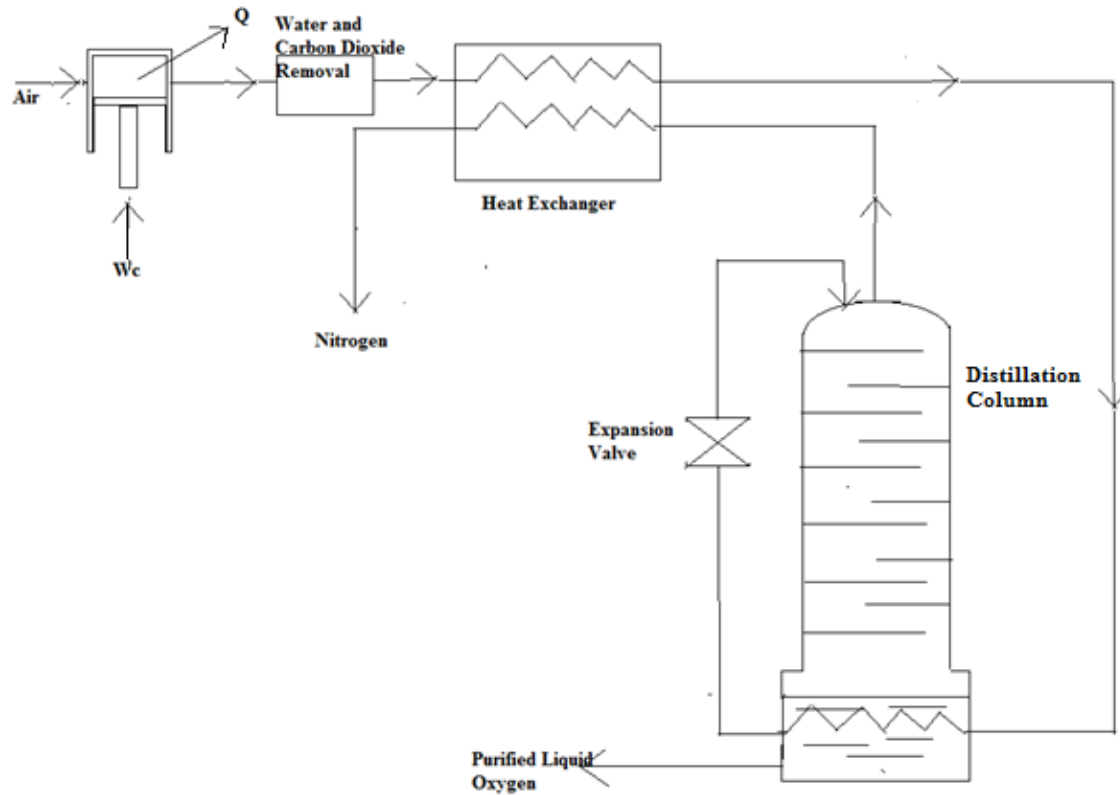


Figure 2.4 Linde single-column gas-separation system

### 2.2.2.1 Working Principle

The entering gas is compressed, the water vapor and carbon dioxide are removed, and the air is passed through a heat exchanger in which the incoming gas is cooled. If the oxygen is desired as a liquid, the heat exchanger is a two-channel type, as shown in the figure. The cold oxygen gas is used to help cool down the incoming air. The liquid oxygen is then withdrawn from the lower section of the column (called the *kettle*, in the terminology of the petroleum industry).

The cool air is further cooled and partially condensed by exchanging energy with the liquid in the kettle. This accomplishes two purposes:

1. The incoming air is further cooled, which allows a greater liquid yield, and

2. The heat is made available to boil some of the liquid in the kettle to furnish the upward-flowing vapor in the column without the addition of heat from ambient temperatures.

The cold air is expanded through a Joule-Thomson valve, after which some liquid is formed. This liquid is then passed to the top of the column, where it begins to travel down the column across the plates. As the liquid flows down the column over the plates, it is enriched in oxygen by exchange with the upward-flowing vapor. When the liquid reaches the bottom of the column, a portion is evaporated by the incoming air. This vapor flows up the column, bubbling through the liquid layers and picking up nitrogen on its way. The gas at the top of the column is removed and passed through the heat exchanger to help cool the incoming air <sup>[2]</sup>.

When the oxygen is desired as a gas, the air need to be compressed only to pressure on the order of 3 MPa to 6 MPa (30 atm to 60 atm); however, if liquid oxygen is desired, the air must be compressed to approximately 20 MPa (200 atm) for effective operation. The pressure within the column itself is usually on the order of 130 kPa to 200 kPa (1.3 atm to 2 atm) <sup>[2]</sup>.

# CHAPTER 3

## DESCRIPTION OF SIMULATING TOOL

### 3. DESCRIPTION OF SIMULATING TOOL

#### 3.1 ASPEN TECHNOLOGY

##### 3.1.1 INTRODUCTION

Aspen Technology, Inc. is a provider of software and services for the process industries. Headquartered in Burlington, Massachusetts, USA, Aspentech is having 34 offices in 27 countries, spanning 6 continents.

Founded in 1981, Aspentech was born out as a joint research project between the *Massachusetts Institute of Technology (MIT)* and US Department of Energy—an *Advanced System for Process Engineering (ASPEN)* Project [8].

##### 3.1.2 ASPEN ONE

aspenONE is AspenTech’s comprehensive set of software solutions and professional services designed for helping process companies to 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 covers four major fields: Chemical, Energy, Polymer and Pharmaceuticals [9].

##### 3.1.2.1 AspenONE Engineering

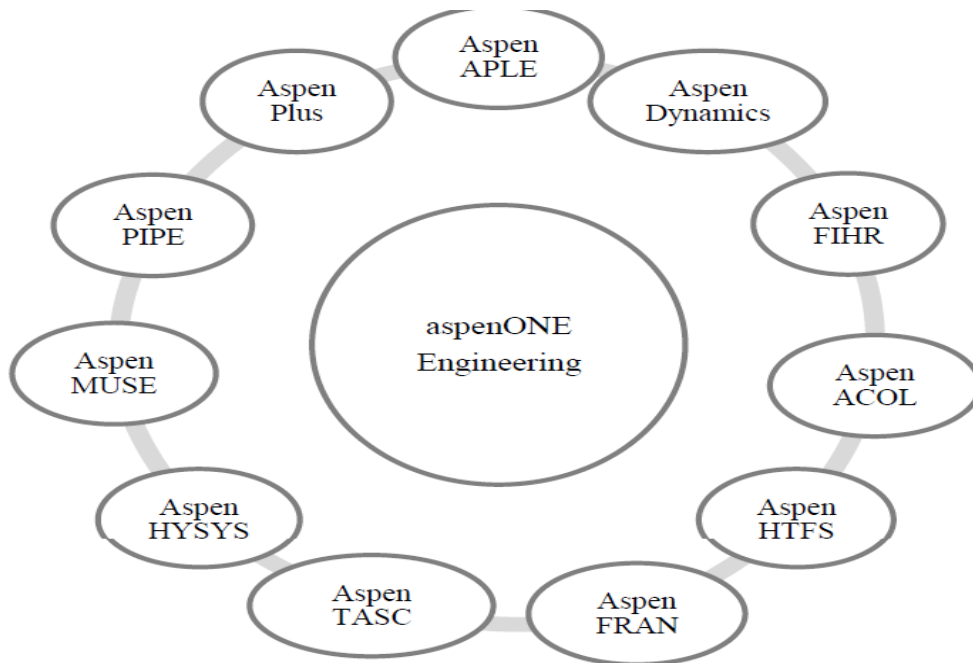


Figure 3.1 aspenONE engineering classification

## 3.2 ASPEN PLUS

### 3.2.1 INTRODUCTION

Aspen Plus is a process modeling tool for conceptual design, optimization, and performance monitoring for the chemical, polymer, specialty chemical, metals and minerals, and coal power industries. Aspen Plus is one of the core elements of AspenTech's aspenONE® Engineering applications <sup>[10]</sup>.

### 3.2.2 FEATURES <sup>[10]</sup>

1. *Best-in-class physical properties methods and data.* Aspen Plus includes the world's largest database of pure component and phase equilibrium data for conventional chemicals, electrolytes, solids, and polymers. Regularly updated data from the U.S. National Institute of Standards and Technology (NIST) ensures easy access to the best available experimental property data, enabling process engineers to save months of effort when developing chemical process models.
2. *Aspen Properties Mobile* provides access to rigorous physical property calculations and data when and where you need it – at a customer site, in a conference room, from home, on the road – anywhere you can remotely access your corporate network.
3. *Improved conceptual design workflow.* Aspen Plus has been tightly integrated with AspenTech's industry-leading cost analysis software and heat exchanger design software. Process engineers can rapidly estimate the relative costs of proposed designs and make decisions based on capital and operating cost estimates using proven cost modeling technology. Key equipment such as heat exchangers and distillation columns can be rigorously sized or rated from within the simulation environment. The tight integration of design and costing software with process simulation eliminates costly manual iterations and promotes more optimal designs based on rigorous cost estimates.
4. *Scalability for large and complex processes.* Aspen Plus's unique Equation Oriented (EO) modeling capability and hierarchical flow sheeting lets you simulate even the most large scale and complex processes; even highly integrated processes with multiple recycles. Customers can build models spanning entire sites to find the globally optimal operating conditions.
5. *State of the art column internals calculations for flooding and pressure drop.* Aspen Plus includes a library of more than 300 packings and 5 different tray types with parameters fitted for calculation of tray internals.
6. Aspen Plus provides users with *rate-based distillation technology* which enables distillation calculations while accounting for rigorous mass transfer on trays or on packings.



7. *Greenhouse gas emissions report* of carbon equivalents generated in the process or by consumption of process utilities. Annual carbon tax can also be calculated.
8. Aspen Plus also enables users to model batch distillation in a rigorous manner.
9. Additionally, Aspen Plus also enables users to identify azeotropes and residue curves which can help users to design and synthesize non-ideal distillation columns.
10. Aspen Plus also provides users with a complete set of polymer thermodynamics methods and data, rate-based polymerization reaction models, and a library of industrial process models.
11. *Online deployment of models* as part of an open-loop operator advisory system or in closed-loop, real-time optimization/advanced process control applications when used with Aspen Online Deployment™ and Aspen Simulation Workbook™.
12. *Workflow automation*. Aspen Plus models can be linked to Microsoft Excel® using Aspen Simulation Workbook or Visual Basic® and used to automate the engineering workflow and deploy the model to a wider range of end users in the field.
13. *Aspen Plus Dynamics®* is used for safety and controllability studies, sizing relief valves, optimizing transition, startup, and shutdown policies.
14. *Links to third-party tools*. Aspen Plus includes links to several well-known tools including the OLI's electrolyte package and Technip's SPYRO ethylene cracker models.

### 3.2.3 SIMULATION ENVIRONMENT

The Simulation environment contains the main flow sheet area where the majority of the work (installing and defining streams, unit operations, columns and sub flow sheets) is done.

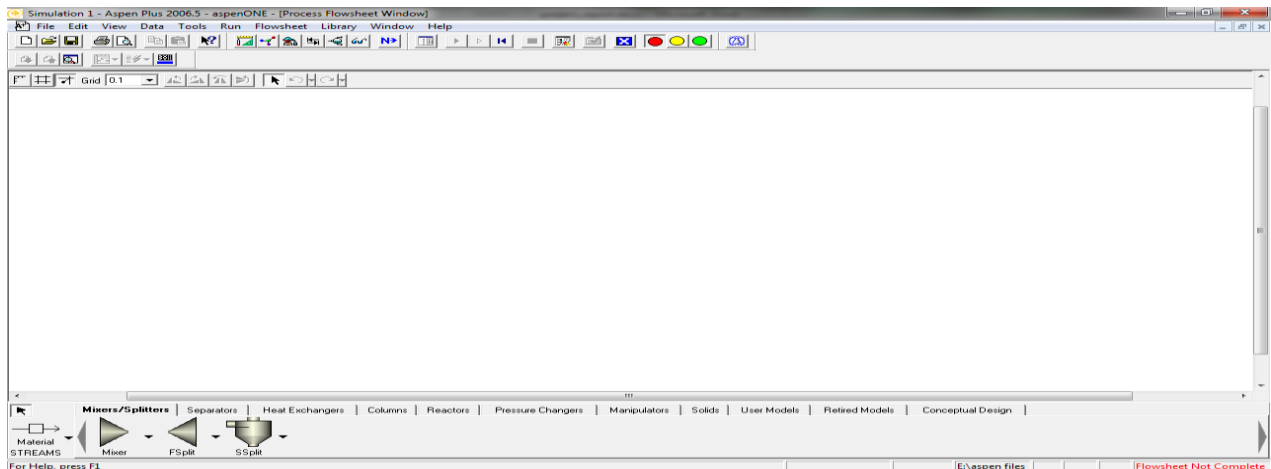


Figure 3.2 Simulation Environment of Aspen Plus

The flow sheet area in Aspen Plus shows the various components needed to draw a flowsheet and henceforth, simulate the process.

### 3.2.4 EQUATION OF STATE USED FOR SIMULATION

An equation of state is a relation between state variables. More specifically, an equation of state is basically a thermodynamic equation describing the state of matter under a given set of physical conditions.

For simulation of air liquefaction, Peng-Robinson equation of state was used. Peng-Robinson is a Cubic equation of state<sup>[9]</sup> and is stated as follows:

$$p = \frac{RT}{V_m - b} - \frac{a\alpha}{V_m^2 + 2bV_m - b^2}$$

$$a = 0.457235R^2T_c^2/p_c$$

$$b = 0.077796RT_c/p_c$$

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

$$T_r = T/T_c$$

In polynomial form,

$$A = (a\alpha p)/(R^2T^2)$$

$$B = (bp)/(RT)$$

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

where,  $\omega$  is the acentric factor of the species,  $R$  is the universal gas constant and  $Z = PV/(RT)$  is compressibility factor.

# CHAPTER 4

## RESULTS AND DISCUSSIONS

## 4. RESULTS AND DISCUSSIONS

### 4.1 SIMULATION OF AIR LIQUEFACTION AND SEPARATION

Given Conditions:

Ambient Temperature = 298K, Ambient Pressure = 1atm, Maximum Pressure for Compression = 200atm, Molar Flow Rate = 200moles/sec, Approach of Heat Exchanger = 5K, Temperature of Stream after passing through kettle section = 91K, Pressure within Distillation Column = 1atm, Reflux Ratio = 7.502, Distillate to feed mole ratio = 0.875, Number of stages = 7 (100% efficient).

Assumptions:

1. Air is a mixture of nitrogen and oxygen only, with nitrogen accounting for 79% and oxygen accounting for 21% by volume (on dry basis).
2. There is no pressure drop across the compressor, cooler and heat exchanger.

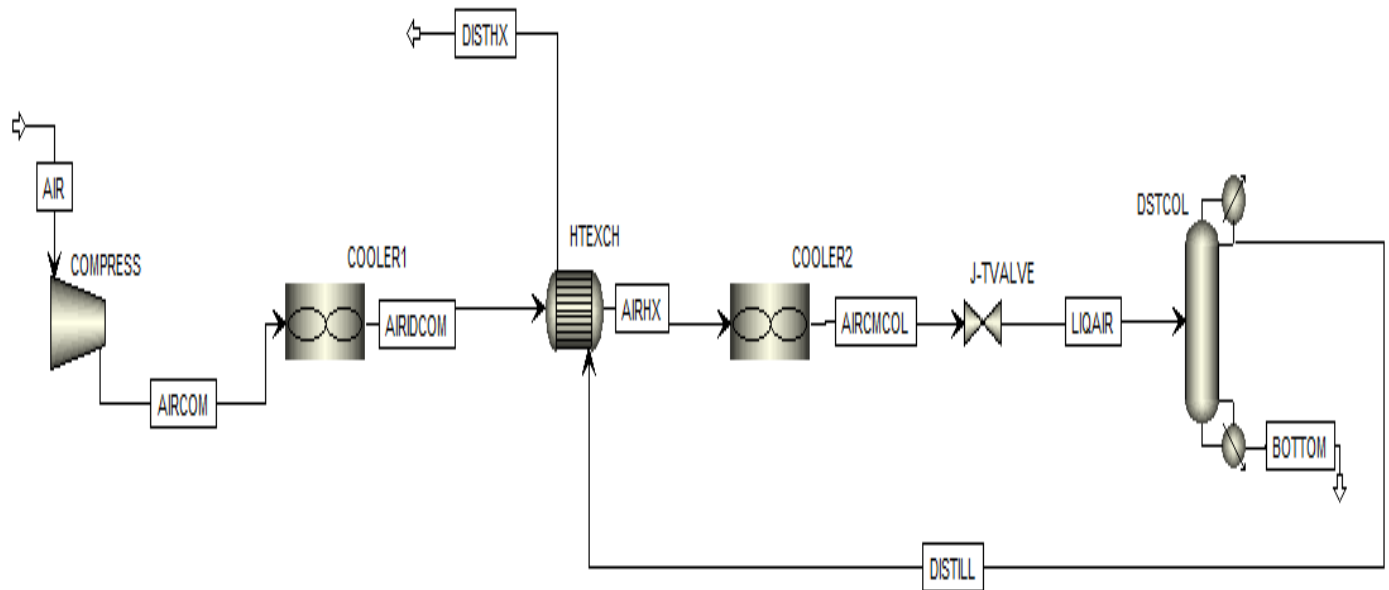


Figure 4.1: Process Flow Diagram for Linde single column gas separation system.

## Explanation:

The first step in Linde single column gas separation system is isothermal compression. Block COMPRESS takes care of the compression. In order to make sure that we have an isothermal compression, a cooler is added after block COMPRESS and is named as block COOLER1. After that, cooling of the stream is done by using heat exchanger, which is taken care by the block HTEXCH. After that, further cooling takes place in the kettle section of the distillation column, which is taken care of by the block COOLER2. After that, the expansion valve (block J-TVALVE) releases the pressure to obtain liquid air. Separation of the liquid air into nitrogen and oxygen occurs in block DSTCOL.

## Simulation Result:

The simulation was performed successfully and results were obtained without any error.

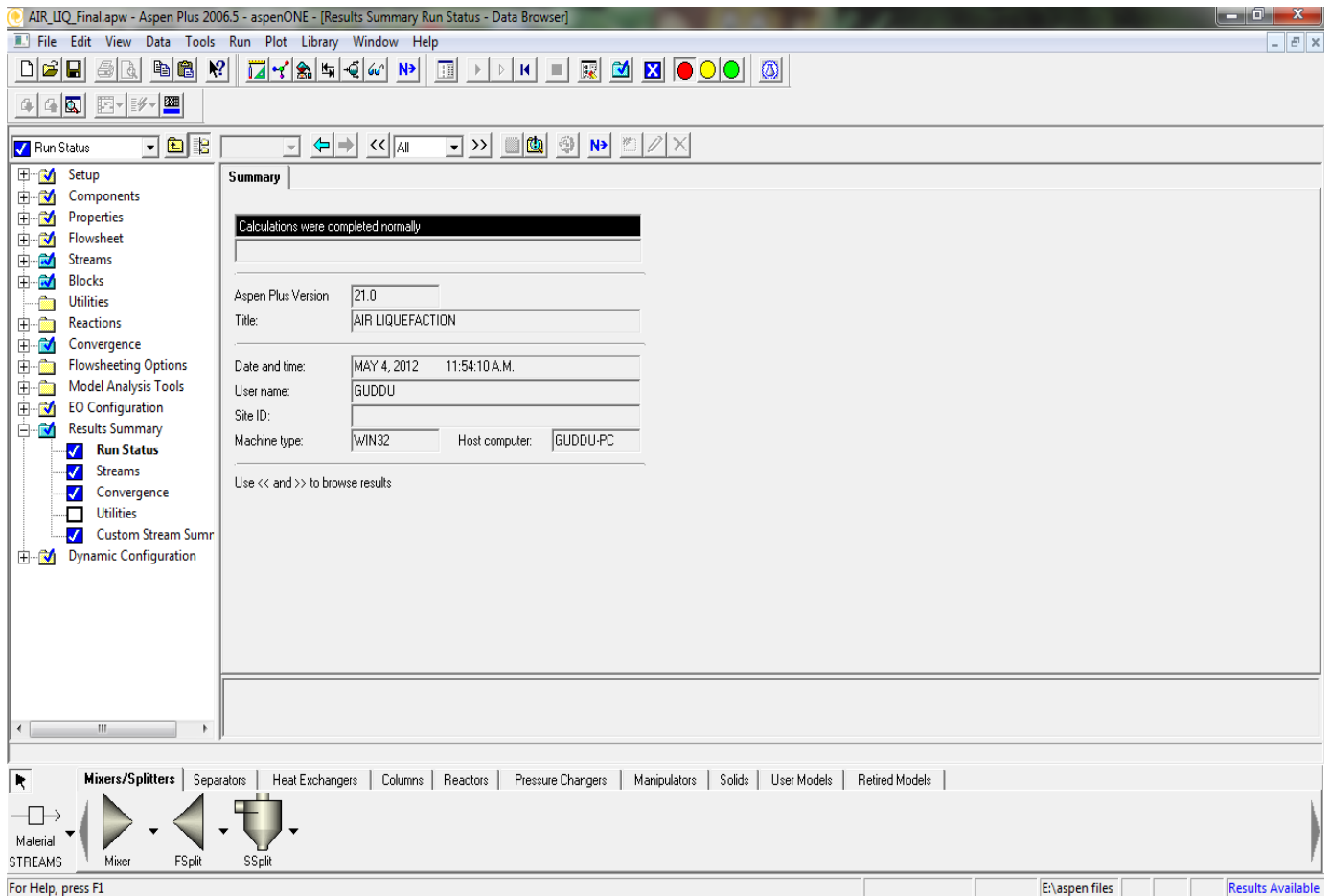


Figure 4.2: Success report of simulation

AIR LIQUEFACTION										
Stream ID		AIR	AIRCMCOL	AIRCOM	AIRHX	AIRIDCOM	BOTTOM	DISTHX	DISTILL	LIQAIR
From			COOLER2	COMPRESS	HTEXCH	COOLER1	DSTCOL	HTEXCH	DSTCOL	J-TVALVE
To		COMPRESS	J-TVALVE	COOLER1	COOLER2	HTEXCH			HTEXCH	DSTCOL
Phase		VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	LIQUID	VAPOR	LIQUID	MIXED
Substream: MIXED										
Mole Flow	kmol/hr									
N2		568.8000	568.8000	568.8000	568.8000	568.8000	1.348183	567.4511	567.4511	568.8000
O2		151.2000	151.2000	151.2000	151.2000	151.2000	88.65182	62.54887	62.54887	151.2000
AR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mole Frac										
N2		.7900000	.7900000	.7900000	.7900000	.7900000	.0149798	.9007161	.9007161	.7900000
O2		.2100000	.2100000	.2100000	.2100000	.2100000	.9850202	.0992839	.0992839	.2100000
AR		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Flow	kmol/hr	720.0000	720.0000	720.0000	720.0000	720.0000	90.00000	630.0000	630.0000	720.0000
Total Flow	kg/hr	20772.29	20772.29	20772.29	20772.29	20772.29	2874.519	17897.77	17897.77	20772.29
Total Flow	cum/hr	17596.38	178.5891	307.6470	31.86832	88.89968	2.529825	7596.630	21.48120	3848.753
Temperature	C	24.85000	-182.1500	714.0076	-120.1048	24.85000	-183.6121	-125.1079	-195.0077	-192.3062
Pressure	bar	1.013250	202.6500	202.6500	202.6500	202.6500	1.013250	1.013250	1.013250	1.013250
Vapor Frac		1.000000	1.000000	1.000000	1.000000	1.000000	0.0	1.000000	0.0	.8363141
Liquid Frac		0.0	0.0	0.0	0.0	0.0	1.000000	0.0	1.000000	.1636859
Solid Frac		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Enthalpy	J/kmol	-12530.55	-7.3901E+6	2.16325E+7	-7.9439E+6	-1.1355E+6	-1.2880E+7	-4.3967E+6	-1.2178E+7	-7.3901E+6
Enthalpy	J/kg	-434.3284	-2.5615E+5	7.49817E+5	-2.7535E+5	-39357.75	-4.0327E+5	-1.5476E+5	-4.2865E+5	-2.5615E+5
Enthalpy	MMBtu/hr	-8.5512E-3	-5.043244	14.76264	-5.421118	-.7748883	-1.098716	-2.625363	-7.271593	-5.043244
Entropy	J/kmol-K	4235.690	-61756.17	-3370.596	-75407.22	-43209.06	-1.0990E+5	-17808.39	-1.0938E+5	-46506.74
Entropy	J/kg-K	146.8157	-2140.566	-116.8301	-2613.733	-1497.694	-3440.796	-626.8537	-3850.014	-1611.996
Density	kmol/cum	.0409175	4.031602	2.340345	22.59297	8.099016	35.57558	.0829315	29.32798	.1870736
Density	kg/cum	1.180486	116.3133	67.51987	651.8162	233.6598	1136.252	2.356014	833.1831	5.397146
Average MW		28.85040	28.85040	28.85040	28.85040	28.85040	31.93910	28.40916	28.40916	28.85040
Liq Vol 60F	cum/hr	38.56162	38.56162	38.56162	38.56162	38.56162	4.820202	33.74141	33.74141	38.56162

Table 4.1: Stream Table for simulation of Linde single column gas separation system

From the generated stream table, it is seen that the liquid fraction in LIQAIR stream is nearly 0.1637, which implies that the liquefaction of air has taken place under the given conditions.

Also, the BOTTOM stream has 0.985 mole fraction of oxygen and 0.015 mole fraction of nitrogen. The DISTILL stream has 0.901 mole fraction of nitrogen and 0.099 mole fraction of oxygen. Hence, the separation of liquefied air into oxygen and nitrogen has been achieved and the purity of oxygen and nitrogen obtained from bottom and top of distillation column are nearly 98% and 90%, respectively.

## 4.2 EFFECT OF CHANGE IN VARIOUS PROCESS CONDITIONS

### 4.2.1 VARIATION OF LIQUID FRACTION WITH PRESSURE OF COMPRESSION

<b>Pressure (atm)</b>	100	150	200	250	300	350	400
<b>Liquid Fraction</b>	0.1617945	0.1630618	0.1636859	0.1640575	0.1643040	0.1644795	0.1646108
<b>Pressure (atm)</b>	450	500	550	600	650	700	
<b>Liquid Fraction</b>	0.1647128	0.1647942	0.1648607	0.1649162	0.1649630	0.1650031	

Table 4.2: Table for variation of liquid fraction with pressure of compression

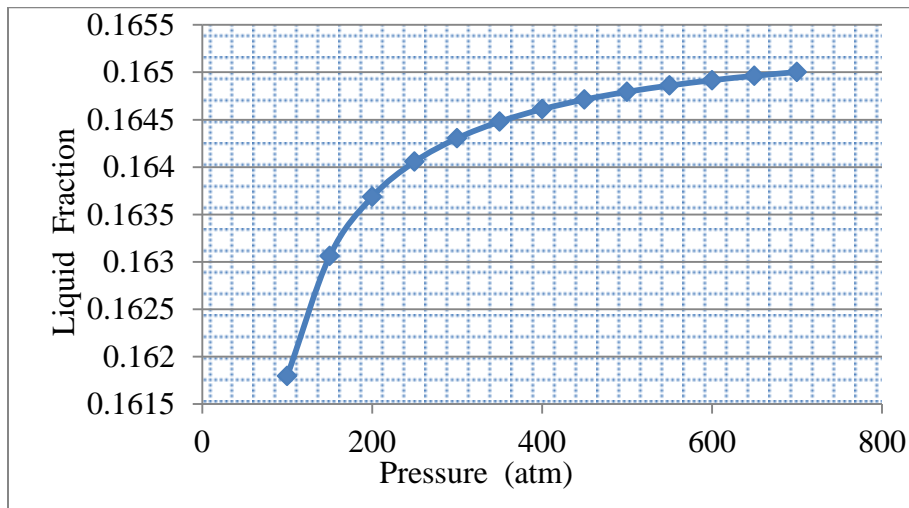


Figure 4.3: Plot of liquid fraction vs pressure of compression.

The above figure shows that the liquid fraction obtained increases with increase in pressure of compression. However, for increase of compression pressure, the work requirement increases, thereby increasing the overall cost of production. For most industrial situations, a compression pressure of 200atm is used, when oxygen is the desirable product in liquid form <sup>[2]</sup>.

#### 4.2.2 VARIATION OF LIQUID FRACTION WITH MOLAR FLOW RATE

<b>Molar Flow Rate(moles/sec)</b>	150	200	250	300	350
<b>Liquid Fraction</b>	0.1636859	0.1636859	0.1636859	0.1636859	0.1636859

Table 4.3: Table for variation of liquid fraction with molar flow rate

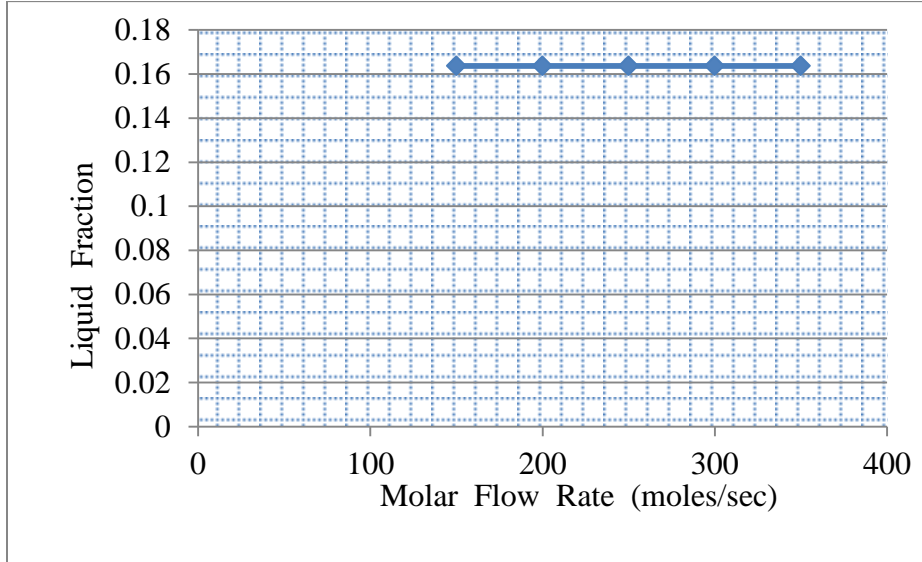


Figure 4.4: Plot for liquid fraction vs molar flow rate.

The above plot shows that the liquid fraction is independent of the molar flow rate of air. Hence, the flow rate has no contribution in determining the fraction of air liquefied. The current project considers the simulation of a plant with a molar flow rate of 200moles/sec, which corresponds to nearly 498 tonnes/day.

#### 4.2.3 VARIATION OF LIQUID FRACTION WITH THE EXTENT OF COOLING IN KETTLE SECTION OF DISTILLATION COLUMN

<b>Temperature before entering expansion valve (K)</b>	91	95	100	105	110
<b>Liquid Fraction</b>	0.1636859	0.1581833	0.1522229	0.1474877	0.1442894

Table 4.4: Table for variation of liquid fraction with the extent of cooling in kettle section of distillation column.



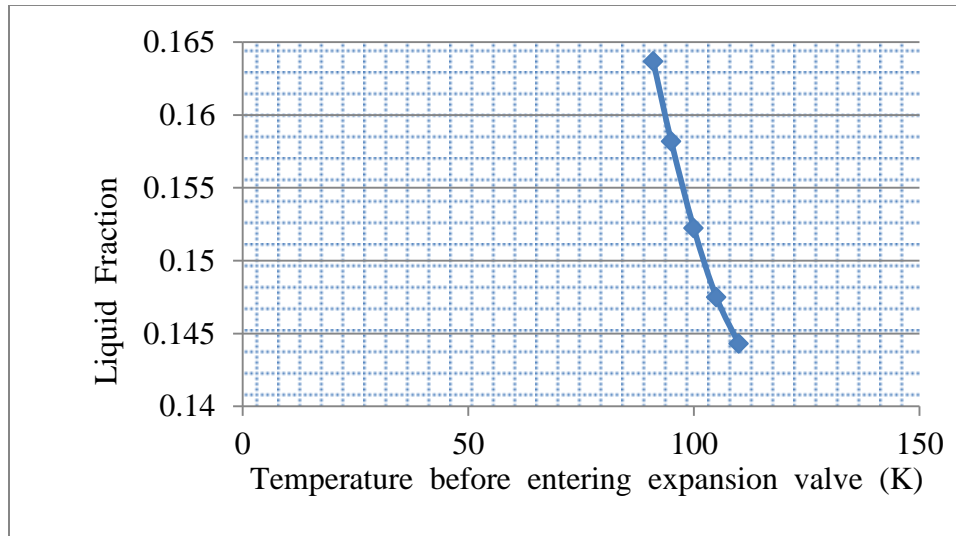


Figure 4.5: Plot for liquid fraction vs temperature of stream before entering expansion valve.

The above figure shows that as the temperature of the stream before entering the expansion valve decreases, the fraction of liquid obtained increases. Hence, more the cooling in the kettle section of the distillation column, more is the yield of the liquid. For industrial purposes, usually it is taken care that the temperature of the stream before entering the expansion valve lies in the range of 90K to 100K.

#### 4.2.4 VARIATION OF HOT STREAM AND COLD STREAM OUTLET TEMPERATURE WITH APPROACH OF HEAT EXCHANGER

<b>Temperature Approach (K)</b>	1	3	5	7	9	11	13	15
<b>Hot Stream Outlet Temperature(K)</b>	152	152	153	154	154	155	156	156
<b>Cold Stream Outlet Temperature(K)</b>	151	149	148	147	145	144	142	141

Table 4.5: Table for variation of hot stream and cold stream outlet temperature with approach of heat exchanger.

The table shows that the effect of temperature approach on hot stream outlet temperature is less as compared to its effect on cold stream outlet temperature. When the temperature approach of heat exchanger changes from 1K to 15K, the cold stream outlet temperature changes from 151K to 141K, whereas, the hot stream outlet temperature changes only from 152K to 156K.

#### 4.2.5 VARIATION OF PURITY OF BOTTOM AND TOP PRODUCTS WITH CHANGE IN NUMBER OF STAGES IN DISTILLATION COLUMN

Number of stages	7	10	15	20	25	30
% purity of nitrogen in top	90.07161	90.15386	90.17717	90.18547	90.18953	90.19185
% purity of oxygen in bottom	98.50202	99.07744	99.24645	99.30468	99.33285	99.34905

Table 4.6: Table for variation of purity of bottom and top products with change in number of stages in distillation column.

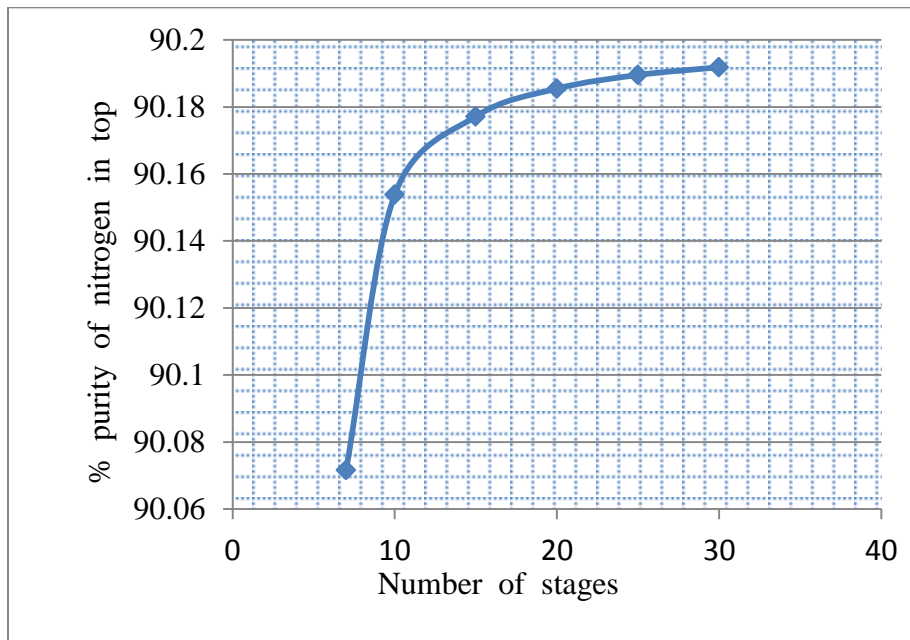


Figure 4.6: Plot for % purity of nitrogen in top vs number of stages in distillation column.

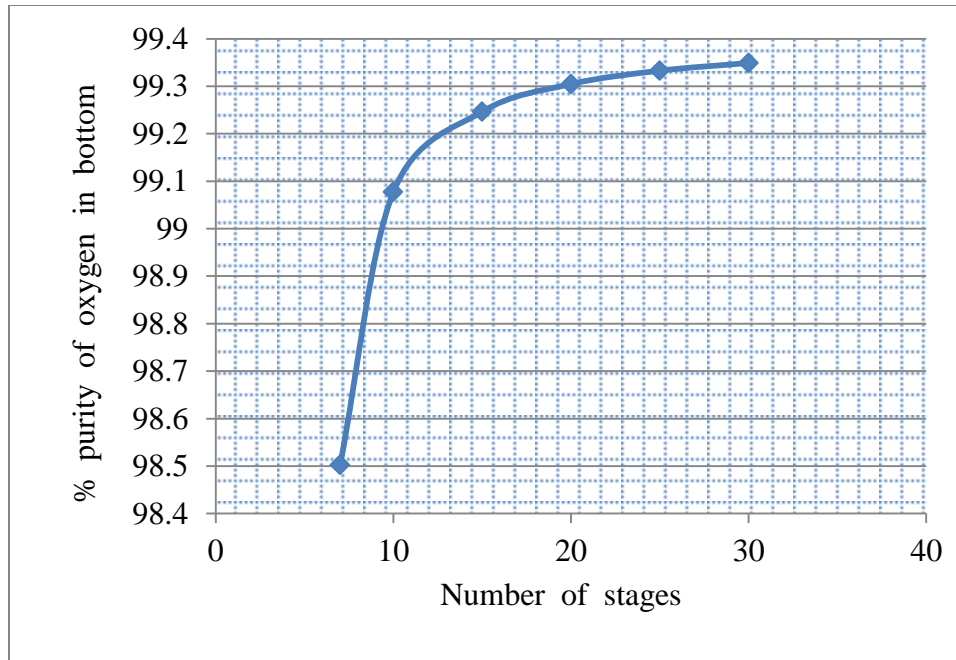


Figure 4.7: Plot for % purity of oxygen in bottom vs number of stages in distillation column.

The table 4.6 shows that with increase in number of stages, the purity of both nitrogen and oxygen in top and bottom, respectively increases, but the increase is marginal. So, this single column method is widely used where oxygen is desirable product since oxygen has almost 99% purity. But, when nitrogen is desirable product, this method is not preferred as its purity is only 90% and also huge amount of oxygen is wasted from the top stream of the distillation column.

# CHAPTER 5

## CONCLUSIONS AND FUTURE ASPECTS

## **5. CONCLUSIONS AND FUTURE ASPECTS**

Simulation of air liquefaction and its separation was done successfully using Aspen Plus simulating tool. The model under consideration was Linde single-column system. Also, the effect of variation of various process conditions on yield, purity of final product, and temperature were analyzed. Results obtained showed that by using Linde single-column system, oxygen of almost 98-99% purity could be obtained. However, the purity of nitrogen obtained was only about 90%. As such, Linde single-column system can be used when oxygen is the desirable product.

In the project, cost analysis of the processes were not considered. So, as a future recommendation, cost analysis can be done, leading to optimization of the entire process. Also, simulation of much complex liquefaction systems can be considered which produces argon, along with oxygen and nitrogen.

# CHAPTER 6

## REFERENCES

## 6. REFERENCES

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