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Simulation of a Process Unit for the Recovery of Light Ends from Natural Gas Mixture

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Abstract: Simulation of a process unit for the recovery of light ends from natural gas was carried out in this study by considering a three stage process column. The three stage process column was designed and simulated for the recovery of methane, ethane and propane from natural gas mixture respectively. The unit operations adopted in achieving these separations were de-methanizer column for absorption of methane and distillation unit using de-ethanizer column for ethane and de-propanizer column for propane recovery respectively. The process was imulated using Aspen Hysys and the result obtained showed 98% recovery of methane from de-methanizer column, 97.7% of ethane from de-ethanizer column and 94.7% of propane obtained from de-propanizer column respectively. Functional parameters effects such as variations of temperature, pressure, molecular weight and flow were investigated in the three stage separator (De-methanizer, De-ethanizer and De-propanizer). In addition, methane was obtained from de-methanizer column at temperature of -92.69°C, pressure of 2275KPa, flow rate of 1322Kgmole/h and molecular weight of 16.37g/mole, ethane was obtained from de-ethanizer column at temperature of 5.299°C, pressure of 2725KPa, flow rate of 320Kgmole/h and molecular weight of 30.37g/mole and propane was obtained from de-propanizer column at temperature of 46.49°C, pressure of 1585KPa and molecular weight of 43.91g/mole respectively.

Keywords: Natural Gas Mixture, Light Ends, De-Methanizer, De-Ethanizer, De-Propanizer, Aspen Hysys

1. Introduction

Natural gas is a naturally occurring hydrocarbon gas mixture consisting of mainly methane, ethane, propane and other higher alkanes compounds with traces of inorganic substances as impuritie [1] Nigeria has abundant natural gas reserves, and recent developments in drilling technology have made it possible to extract this gas in large quantities. The Nigeria's natural gas reserves are presently estimated at 182TCF (trillion cubic feet) with a predictable growth rate of over 70% by 2025, the nation's natural gas sector has shown to have the potential of being a key player in the emergent global natural gas market [2]. Unfortunately, even with this huge natural gas reserve, much has not been accomplished with respect to the effective exploitation and utilization of this abundant natural gas reserve. It will be of interest to know that some of this natural gas reserves are termed stranded, whose volume and location are often considered as non-commercial and difficult to exploit [3]. In addition, most of the nation's natural gas produced has been flared or re-injected to enhance greater crude oil recovery which is a huge waste of the inherent potentials and economy boost that can be achieved with efficient natural gas processing [4]. Considering the epileptic electric power generation and supply, high rate of unemployment, global climate change caused by green-house emissions from flare-out points, it has become expedient to find improved ways to exploit and utilize the nation's natural gas reserves and translate it to the improvement of our dear nation's economy [5]. One of the ways of utilizing the bounded potentials in natural gas is by processing the gas to remove impurities and to recover the light ends (methane, ethane and propane). These light ends have enormous applications as industrial chemicals and as a

source of energy for transportation and electricity [6].

Methane is an important source of energy, hydrogen and some organic chemicals. Methane reacts with steam at high temperatures to yield carbon monoxide and hydrogen; which is used in the manufacture of ammonia for fertilizers and explosives [7]. Ethane is mainly used to produce ethylene, which is then used by the petrochemical industry to produce a range of intermediate products, most of which are converted into plastics [8]. Propane is used as a fuel in domestic and industrial applications and in low-emissions public transportation. Propane is cracked to propylene which is an unsaturated organic compound having the chemical formula C_3H_6 [9]. It has one double bond and is the second simplest member of the alkene group of hydrocarbons after ethylene. Propylene is used for heating and cutting due to its superior combustion performance, also widely used as a fuel gas for high velocity oxygen fuel processes [10]. Furthermore, the chemical and plastics industries rely on propylene for its manufacture processes and the decrease in the availability and affordability of petrochemical products has propelled a renewed interest in the production of propylene, which is a major starting material (precursor) for the production of most petrochemical products [11]. Effective utilization of natural gas reserves in Nigeria demands need for technological improvement in the area of natural gas processing and storage. The absence of this technological improvement has led to the flaring of natural gas for so many years [12]. Flaring is a waste of resources and also a threat to the environment as it causes pollution of the environment [13] However, natural gas cannot be used as a mixture; hence, it is of great importance to recovery or separate natural gas mixture into its different constituents such as methane, ethane, propane etc [14].

Several case studies for the separation of various hydrocarbon mixtures using different techniques such as classical column train and enhanced distillation (extractive and reactive) using the computer algebra Mathematica solver and simulation results were compared to those obtained using the flow-sheeting software Aspen Hysys [15]. Furthermore, researchers have developed a technical and economic study to compare between traditional glycol absorption plants and an innovative system using polymer membranes. The results showed that the membrane system is more cost effective for low feed gas flow rates and more friendly environmental [16]. Also, a design analysis study was performed for dehydration of one million standard cubic meter of natural gas per day using a liquid desiccant, triethylene glycol (TEG) in bubble cap tray towers [17]. Therefore, this research study seeks to simulate a process unit consisting of three stage recovery unit such as de-methanizer, de-ethanizer and de-propanizer columns for the recovery of valuable light ends from natural gas mixture. This study is achieved by studying and analyzing recovery process of light ends from natural gas, identification of unit operation for the recovery of methane, ethane and propane into individual component, and simulate the recovery process units using Aspen Hysys with operating parameters and feedstock composition analysed.

2. Materials and Methods

The materials applied in performing this study include natural gas mixture, de-methanizer column, de-ethanizer column, de-propanizer column, Aspen Hysys, operating parameters etc.

2.1. Aspen Hysys Recovery Process

The simulation of light ends recovery process from natural gas mixture using Aspen Hysys is shown in Figure 1. The flow diagram of the simulated natural gas recovery processing units consists of three main columns namely: de-methanizer, de-ethanizer and depropanizer for the recovery of valuable light ends from natural gas mixture.

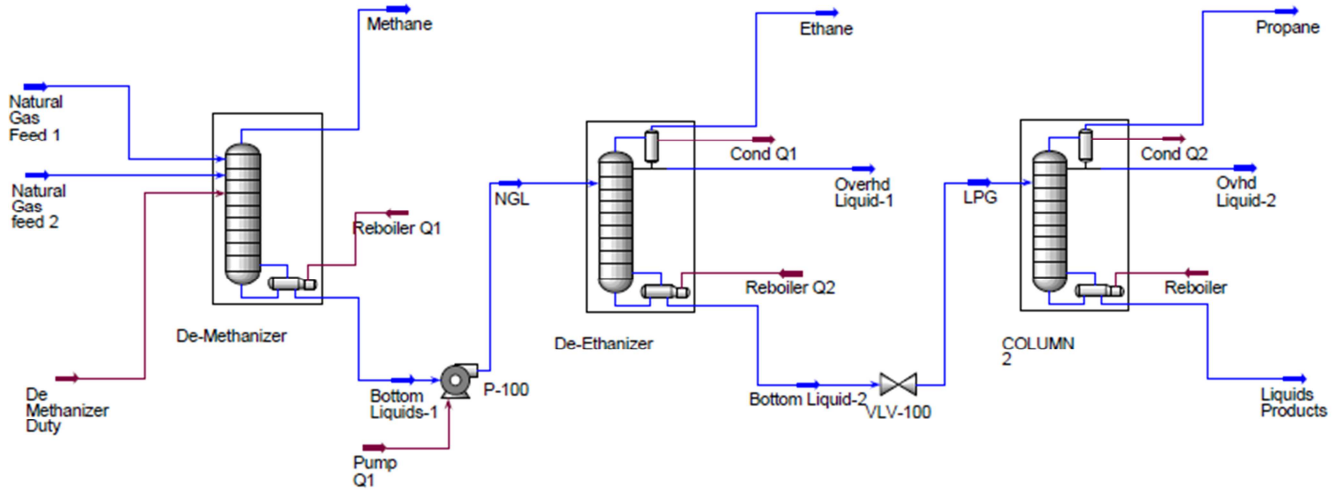

Figure 1. *Light Ends Recovery Process.*

2.2. De-Methanizer Column

The de-methanizer column is an absorption column used for recovery of product from the natural gas mixture. The molecular weight of natural gas mixture (M_G) was determined as

$$M_G = \sum_i^n y_i m_i \quad (1)$$

Also, the viscosity of the natural gas mixture is determined by applying Pavlov correlation [18].

$$\mu_G = \frac{M_G}{\sum_{i=1}^{n} \frac{y_i m_i}{\mu_i}} \quad (2)$$

The diameter of the de-methanizer column is evaluated [19].

$$D = \left[\frac{4\left(\frac{Q_G}{3600}\right)}{v_G \pi}\right]^{0.5} \quad (3)$$

The amount of methane absorbed in the de-methanizer column is estimated as

$$m_{m(abs)} = \left(\frac{Q_G \cdot \rho_G}{M_G}\right) . y_m . \%R . M_m \quad (4)$$

Hence, the overall gas pressure drop per meter of packing height (ΔP/Z) was determined as [19].

$$\frac{\Delta P}{Z} = \frac{\Delta P_0}{Z}\left[\left(\frac{\varepsilon}{\varepsilon - h_L}\right)^{1.5} \exp\left(\frac{Re_L}{200}\right)\right] \quad (5)$$

2.3. De-Ethanizer and De-Propanizer Recovery Column

De-ethanizer and de-propanizer columns are fractionation or distillation columns applied in this study for the recovery of ethane and propane from natural gas mixture respectively.

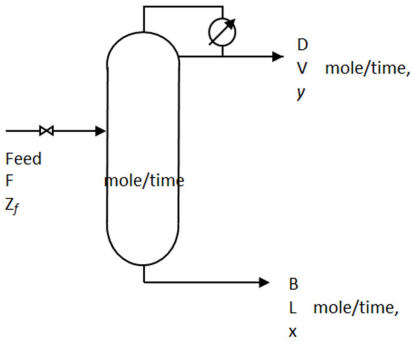

Figure 2. *Distillation Column.*

2.3.1. Operating Line Equations

The operating line equations for the rectifying section, which consist of the condenser and all the plate above the feed plate is expressed as

$$y_i = \frac{(1 + {}^{L}/_{V}) Z_{fi}}{(V + {}^{L}/_{k_i})} \quad (6)$$

Similarly, the operating line equations for the stripping section, which consist of the feed plate, all the plate below the feed plate and re-boiler is expressed as

$$x_i = \frac{(1 + \emptyset) Z_{fi}}{(1 + {}^{\emptyset}/_{k_i})} \quad (7)$$

2.3.2. Number of Column Trays, Minimum Reflux Ratio and Feed Point

The Fenske equation is applied in calculating the minimum number of ideal tray at total reflux.

$$N_{min} = \frac{\ln\left(\frac{x_{Di} x_{bi}}{x_{Dj} x_{Di}}\right)}{\ln \propto_{ij}} \quad (8)$$

$$\propto_{ij} = \left[\propto_{ij} \propto_{ij}\right]^{\frac{1}{2}}$$

Also, the minimum reflux ratio for multi-component distillation column is expressed using Colburn and Underwood equation.

$$\sum \frac{\alpha_i X_{id}}{\alpha_i - \theta} = R_{min} + 1 \quad (9)$$

The root of the equation is estimated as

$$\sum \frac{\alpha_i X_{xf}}{\alpha_i - \theta} = 1 - q$$

The value of θ must lie between the values of relative volatility of the light heavy keys and is found by trial and error. For most distillation the guideline is useful.

$$1.3R_m \leq R \leq 1.5R_m$$

The feed point or location in the column is deduced by applying empirical equation given by Kirkbride [20] (Nasri & Binous, 2007).

$$\log\left[\frac{N_r}{N_s}\right] = 0.206 \log\left[\left(\frac{B}{D}\right)\left(\frac{X_{f.HK}}{X_{f.LK}}\right)\left(\frac{X_{b.LK}}{X_{d.HK}}\right)^2\right] \quad (10)$$

2.3.3. Feed Specification

The feed conditions, its compositions and the columns operating parameters are shown in Tables 1, 2 and 3 respectively.

Table 1. *De-Methanizer Feed Conditions.*

Parameters	De-Methanizer Feed	
	Natural Gas Feed 1	Natural Gas Feed 2
Vapour/Phase Fraction	1.0000	0.4344
Temperature [°C]	-95.00	-85
Pressure [kPa]	2275	2300
Molar Flow [kgmole/h]	1620	215
Mass flow [kg/h]	13.7423	5198
Std ideal liquid Vol. flow [m^3/h]	102.4	13.81
Molar Enthalpy [kJ/kmole]	-9.625e+004	-9.670e+004
Molar Entropy [kJ/kmole]		112.1
Heat flow [kJ/h]	100.1	-2.079e+007

Table 2. *Hysys De-Methanizer Feed Compositions.*

Constituents	Natural Gas Feed 1	Natural Gas Feed 2
	Mole Fraction	0.005680
NO_2	0.0025	0.002890
CO_2	0.0048	0.720108
Methane	0.7041	0.117178
Ethane	0.1921	0.074731
Propane	0.0706	0.023914
i-Butane	0.0112	0.019629
n-Butane	0.0085	0.014647
i-Pentane	0.0035	0.010163
n-Pentane	0.0020	0.003687
n-Hexane	0.0030	0.004683
n-Heptane	0.0020	0.002690
n-Octane	0.0020	0.005680

Table 3. *Three Stage Column Operating Conditions.*

	De-Methanizer	De-Ethanizer	De-Propanizer
No of Stage/Trays	10	14	24
Reflux ratio	4	4.9	1.797
Reflux rate	1321.81	1591 kgmole/h	240.2 kgmole/h
Overhead Vapour Rate	1321.81 kgmole/h	320.0 kgmole/h	1.934e-006 kgmole/h
Distillate Rate		5.132e-006 kgmole/h	133.7 kgmole/h
Bottom Products Rate	513.19 kgmole/h	193.2 kgmole/h	59.51 kgmole/h
Tower operating pressure at the condenser	2275 kPa	2725 kPa	1585 kPa
Pressure drop at the condenser	3.889kPa	35 kPa	35.00 kPa
Tower operating pressure at the reboiler	2310 kPa	2792 kPa	1655 kPa
Pressure drop at the reboiler	0.000	0.0000	0.000
Tray diameter [m]	1.500	1.500	1.500
Tray Volume [m^3]	0.8836	0.9719	0.9719
Weir Height (m)	5.000e-002	5.000e-002	5.000e-002
Weir Length (m)	1.200	1.200	1.200
State Equations	Peng Robinson	Peng Robinson	Peng Robinson

3. Results

The products composition from the Aspen Hysys recovery process of light ends from natural gas mixture are shown below. Methane, ethane and propane gases are produced form de-methanizer, de-ethanizer and de-propanizer columns respectively. The respective mole composition of the recovered light ends showed 98% methane from de-methanizer, 97.8% ethane from de-ethanizer and 94.9% propane from de-propanizer column respectively.

Table 4. *Composition of Product from the Aspen Hysys.*

Chemical Compounds	Methane	Ethane	Propane	Bottom Product
	Mole Fraction	Mole Fraction	Mole Fraction	Mole Fraction
NO_2	0.0000	0.0000	0.0188	0.0249
CO_2	0.0024	0.0165	0.0000	0.0000
Methane	0.9800	0.0003	0.0000	0.0000
Ethane	0.0168	0.9778	0.0238	0.0000
Propane	0.0008	0.0054	0.9491	0.0200
i-Butane	0.0000	0.0000	0.0078	0.3570
n-Butane	0.0000	0.0000	0.0004	0.2998
i-Pentane	0.0000	0.0000	0.0000	0.1482
n-Pentane	0.0000	0.0000	0.0000	0.0912
n-Hexane	0.0000	0.0000	0.0000	0.0215
n-Heptane	0.0000	0.0000	0.0000	0.0224
n-Octane	0.0000	0.0000	0.0000	0.0152

3.1. De-methanizer Column

The de-methanizer column is an absorption column used in recovery methane from the natural gas mixture. The composition of recovered product mainly methane (98%) from the natural gas mixture is shown in Figure 3.

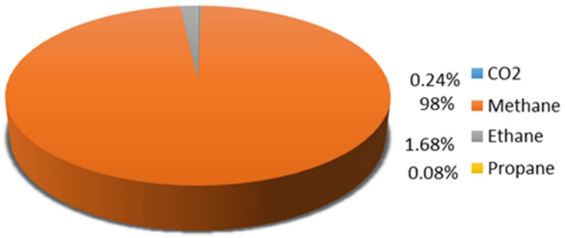

Figure 3. *Composition of Products from De-Methanize.*

Also, the composition profile of the de-methanizer column along the column tray, which shows rapid decrease of methane composition in the de-methanizer column due to its recovery, thus little or no methane product present at the bottom of the column (reboiler). Therefore, the bottom product is sent to de-ethanizer column for further recovery process.

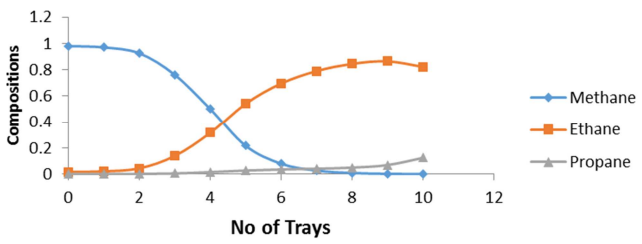

Figure 4. *De-Methanizer Tray Composition.*

3.2. Temperature and Pressure Effects in De-Methanizer

The temperature in the column varies appreciably from the bottom to the top of the column as shown in Figure 5, which showed an increase in temperature from the top of the column to the bottom as the number of trays increases.

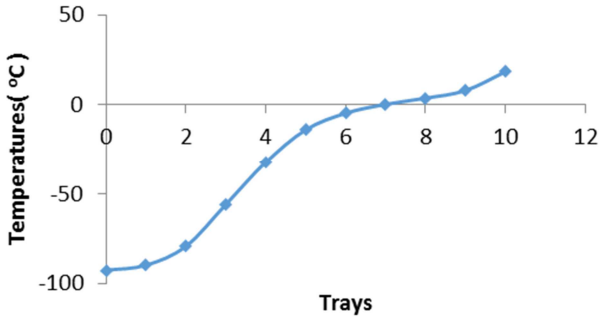

Figure 5. *Temperature against Tray Position.*

Also, pressure variation in de-methanizer column is depicted in Figure 6. There is an increase in pressure as the recovery process continue till the tenth tray, after which there is pressure stability to the reboiler, where there is no change in pressure. The feed entered the column at 2275kPa and leaves the reboiler at 2310kPa. Therefore, the removal of methane lead to an increase in pressure.

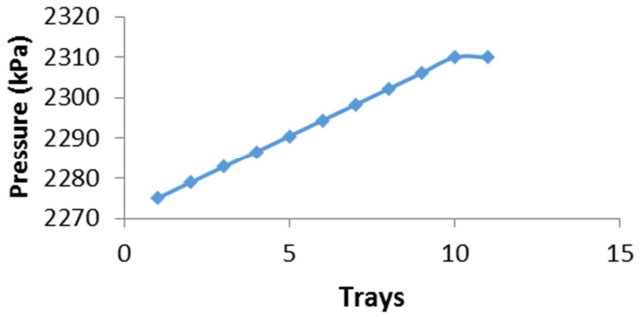

Figure 6. *Pressure against Tray Position.*

3.3. De-Ethanizer Column

De-ethanizer column is a fractionation column for recovery of ethane from liquid product from the de-methanizer column. The vapour phase (recovered ethane) of de-ethanizer column is made up of 97% ethane with other impurities such as little percentage of propane and carbon dioxide as outlined below.

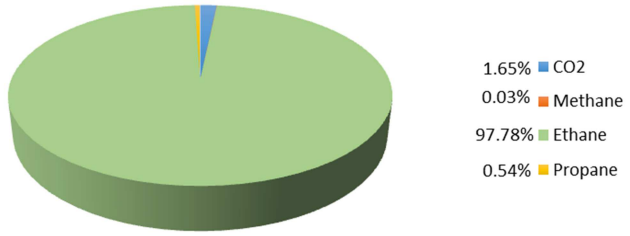

Figure 7. *Composition of Ethane Gas Product.*

In addition, the composition profile of the de-ethanizer column where there is ethane recovery, thereby leading to rapid decrease of ethane product from the column. Therefore, there is neither methane nor ethane present at the bottom (reboiler) of the de-ethanizer column, as propane is the most abundant component. Thus, the bottom product is sent to de-propanizer column for the recovery of propane.

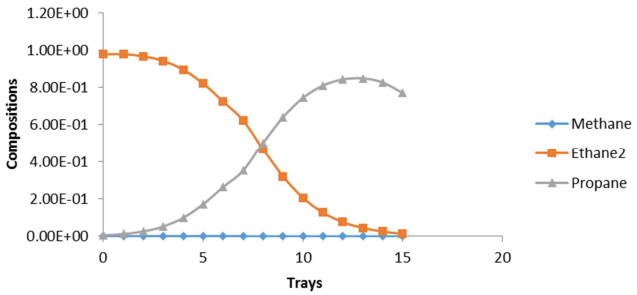

Figure 8. *Tray Composition of De-Ethanizer Column.*

3.4. Temperature and Pressure Variations in the De-Ethanizer Column

The temperature in the de-ethanizer column varies appreciably from the top of the column to the bottom as shown in Figure 9. The graphical representation shows the temperature behaviour in the column thus, there is increase in temperature as the number of trays increases from the top of the column to the bottom.

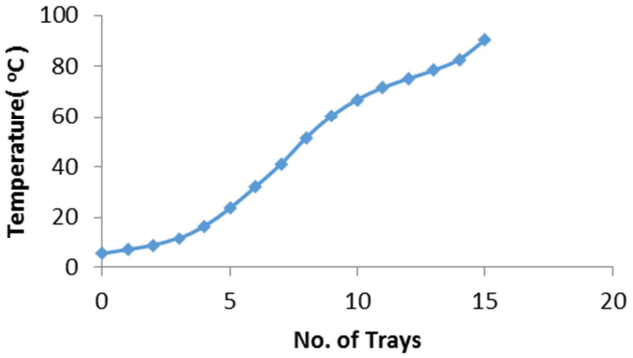

Figure 9. *Temperatures Profile of De-Ethnaizer Column.*

Also, there is a sharp increase in pressure between the condenser stage and tray one. However, pressure continues to increase at a steady state from stage two until the fourteenth tray and attains stability to the reboiler, where there is no change in pressure. Thus, there is rapid increase in pressure notable between condenser and tray one, after which the pressure increases at a constant rate.

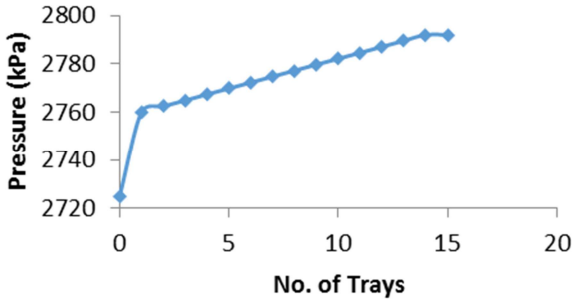

Figure 10. *Pressure Profile of De-Ethanizer Column.*

3.5. De-Propanizer Column

De-propanizer column is used for recovery of propane from the natural gas mixture. In this column, 94.9% of

propane is recovered with the bottom stream product of the column constituting the remaining percentage value. Thus, the product composition from de-propanizer column is shown below.

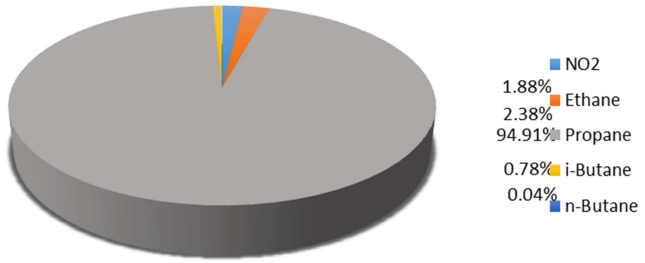

Figure 11. *Composition of Propane Recovered from De-Propanizer.*

The composition profile of the de-propanizer showed a rapid decrease of propane in the column rectifying section while bottom product contains butane and higher hydrocarbons.

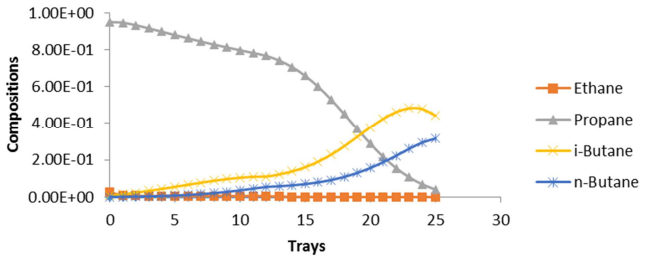

Figure 12. *Composition Profile in De-propanizer Column.*

The bottom product from de-propanizer column is made up of 2.49% of nitrogen dioxide, 2% of propane, 35.7% of iso-butane, 29.98% of normal butane and 29.85% of other heavy hydrocarbons as shown in Figure 13. Thus, the bottom product can further be processed through other treatment technique.

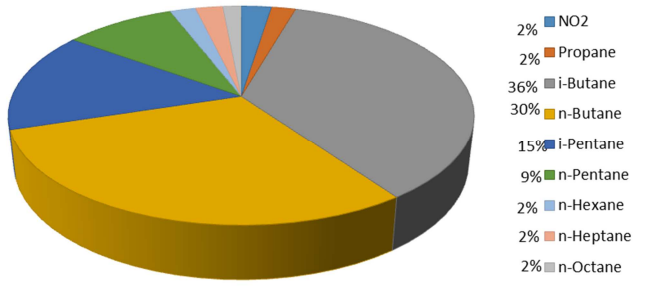

Figure 13. *Bottom Product Composition from De-Propanizer Column.*

3.6. Temperature and Pressure Variations in the De-Propanizer Column

The temperature in the de-propanizer column varies appreciably from the bottom of the column to the top. Figure 14 showed the temperature behaviour or variation in the column, which depicts temperature increase from the top of the column to the bottom, thus increase in temperature as the number of trays increase.

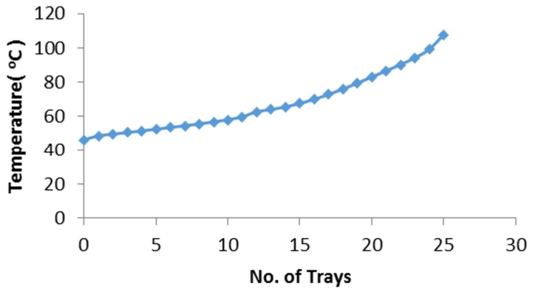

Figure 14. *Temperatures Profile of De-Propanizer Column.*

In addition, variation of pressure in the de-propanizer column showed a sharp increase in pressure between the condenser stage and the first tray. However, pressure continues to increase at a steady state from tray two till the twenty fourth tray and attains stability to the re-boiler, where there is no change in pressure.

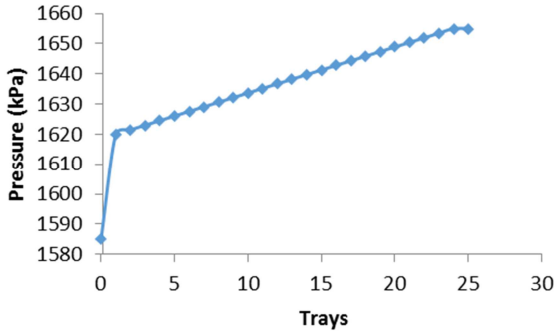

Figure 15. *Pressure Profile in De-Propanizer Column.*

4. Conclusion

The recovery of light end products from natural gas mixture was carried out in this study, which involved the absorption of methane from natural gas mixture in de-methanizer column and fractionation of ethane and propane in de-ethanizer and de-propanizer columns respectively. The three stage process columns were designed using Aspen Hysys and simulated for the recovery of methane, ethane, propane and bottom products. The composition of the products obtained showed 98% of methane from de-methanizer, 97.7% of ethane from de-ethanizer and 94.7% of propane from de-propanizer column respectively. Furthermore, effect of parameters such as temperature and pressure were investigated in the respective column, and the recovery of methane with molecular weight of 16.37g/mole from the de-methanizer column was achieved at temperature of -92.69°C, pressure of 2275KPa and flow rate of 1322Kgmole/h, ethane with molecular weight of 30.37g/mole was recovered from de-ethanizer column at temperature of 5.29°C, pressure of 2725KPa and flow rate of 320Kgmole/h, while the recovery of propane with molecular weight of 43.91g/mole from de-propanizer column was achieved at temperature of 46.49°C and pressure of 1585KPa. It is therefore recommended that more research can be carried out on recovery of more

components from the bottom product and also test the commercial value of the bottom product in terms of quantity and economics of the recovery process.

Nomenclature

μ_m is the viscosity of natural gas mixture
D is the diameter of column.
d is the top product
b is the bottom product
N_r is the number of stages at the rectifying section including any partial condenser
N_s is the number of stages at the stripping section, including the re-boiler
$X_{f.HK}$ is concentration of the heavy key in the feed
$X_{f.LK}$ is concentration of the light key in the feed
$X_{d.HK}$ is concentration of the heavy key in the top product
$X_{d.LK}$ is concentration of the light key in the bottom product.
α_i is relative volatility of component i with respect to reference component, usually the heavy key
R_{min} is minimum reflux ratio
$X_{i.d}$ is concentration of component i in the distillate at minimum reflux
θ_i is the root of the equation.
X_{xf} is the concentration of component i in the feed
q is thermal condition of the feed.
R is actual reflux ratio
R_m is minimum reflux ratio

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