Simulation and Improved Recovery of Liquified Petroleum Gas from Flare System (Case Study: Niger Delta, Nigeria)

Ukatu M. Godwin, Joel F. Ogbonna, Kinigoma S. Boma

Abstract—: Liquified Petroleum Gas(LPG) has been a good source of fuel in country of the world because of its environmental friendliness and economic factors. The price of LPG in the global market has increased in the last few years because of increase in the demand for the product as the world continues to seek alternative fuel with less CO2 emission. This research is concerned with the simulation and improved recovery of an LPG plant that produces LPG and valuable by-products like methane, ethane, and natural gasoline, from stranded natural gas stream (that is usually flared at the flare stack in Niger Delta area of Nigeria) using Aspen hysys V8.6. The development of a simple model and plotting of chart was done on Microsoft excel 2016. During optimization, it was observed that a depropanizer of 24 trays with the feed inlet located at the 14th tray yield 98.80% propane as the overhead product of the column, this is an improvement when compared with a convectional design that has a yield of 97.77% propane. It was also observed that relocating the feed inlet of the debutanizer of 23 trays yield 96.43% butane as the overhead product from the pretreated and conditioned stranded natural gas stream. A model for estimating the optimum feed location of the depropanizer and debutanizer given the total number of trays as well as predicting the maximum amount propane and butane (LPG) recoverable from depropanizer and debutanizer was developed respectively.

Index Terms— Flare system, Improved recovery, liquified petroleum gas, Niger delta, Nigeria, Optimun LPG Recovery, Simulation.

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1 INTRODUCTION

Nigeria is a country that is blessed with huge deposit of natural gas and commercial deposit of crude oil with dissolved gas (associated gas). This natural gas dissolved in crude oil is produce alongside the crude oil is known as Associated Gas (AG). Unfortunately, the Nigerian petroleum Industry was designed to Indiscriminately dispose this associated natural by burning it at the flare stack since it was considered to be of less economic valve as against the oil at that time the Nigerian petroleum Industry infrastructure was designed and constructed. Over the years, the world has realised the importance and the economic value of natural gas whether associated (produced alongside oil) or non-associated natural gas (produced from a gas well without oil) but the Nigeria state has continually wasted this bountiful Natural resource of great economic value in such a manner that does only poses economic issues but also poses harmful environmental degradation, causes global warming and climate change.

However, this natural resource that is wasted by flaring could help in the social economic development and help improve standard of living of state men, women and children, most especially in Nigeria which has an economy that is not so good. The economic worth of the gas burned in Nigeria via flaring is approximated to be around 2.5billion US$ per annum to the economy, amounting to 50 billion US$ over 20 years (Unicef,2010).

According to Lukman (2014), full processing and commercialization of stranded natural gas will not only help in areas of economic development but also will help to reduce the bad environmental consequences of pollutant released into the environment when gas is flared. Information released from the Nigerian National Petroleum Corporation (NNPC) show that about 244.84MMM Scf of natural gas has been lost to flaring in 2016 alone and the economic worth of these volume of natural gas is about N217 billion. The latest monthly report from the NNPC showed that 22.32 billion Scf of gas was flared in January; 20.38 billion Scf in February; 20.11 billion Scf in March; 18.7 billion Scf in April; 15.8 billion Scf in May, and 14.8 billion Scf in June. (punchng,2017). In the second half of the year, the country recorded the highest volume of gas flared in November at 24.54 billion Scf, up from 22.60 billion Scf in October; 21.5 billion Scf in September; 21.14 billion Scf in August, and 21.79 billion Scf in July. According to sundiatapost, the loss arising from volume of gas flared by oil companies in Nigeria has been put to $63.345 million (about N23.438 billion). The companies reportedly flared 20.50 billion standard cubic feet, SCF, of gas in April 2017.

Gas flaring contributes to climate change resulting in deleterious effects to the environment. The emission of carbon dioxide, burning of fossil fuel, mainly coal, oil and gas have led to global warming with more serious implications for developing countries, especially Africa which is highly vulnerable with limited ability to adapt. Another notable effect of gas flaring is acid rain. The primary causes of acid rain are emissions of sulphur dioxide (SO2) and nitrogen oxides (NO) which combine with atmospheric moisture to form sulfuric acid and nitric acid respectively (Uwem and Enobong, 2017).

The unavailability and insufficiency of necessary natural processing Infrastructure is the major reason for underutilization of natural gas in Nigeria which have resulted to immense flaring of natural gas (a high value economic commodity in

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developed countries) and causing a hazardous environmental contamination. In Nigeria, large volume of stranded natural gas is flared every day and the environment no longer has the ability to contain the amount of greenhouse gases that is produced as a result of gas flaring, this has led to global warming and climate change. LPG is cheaper, burns cleaner and poses environmental threats when compared to other mostly used alternatives in Nigeria such as firewood, and Kerosene.

The objectives of this research work are:

i. To simulate the recovery of LPG from stranded associated gas stream in the flare system

ii. To improve the LPG recovery, and minimize environmental pollution

2 METHODOLOGY

2.1 Simulation, Optimization and Modelling Tool

The simulation and optimization of LPG recovery from flare system was done using Aspen HysisV8.6 process simulation software. And the fluid package used for the simulation of the plant is Peng-Robinson. The development of the various models in this work, as well as various graphical presentation of results generated from sensitivity analysis of the simulated LPG recovery plant was done using Microsoft office excel spreadsheet 2016.

2.2 Inlet Feed Parameter

The components of the natural gas feed together with the feed conditions and composition are as follows

2.2.1 inlet Feed Components List

The components of natural gas feed stream used in this work was selected from Aspen HysisV8.6 library and the chosen components are: Nitrogen, CO2, Methane, Ethane, Propane, Isobutane, normal butane, I-pentane, n-pentane, hexane, n-heptane, n-octane.

2.2.2 Feed Condition

The inlet Natural gas feed is modelled according the following inlet condition.

Table 2.1 Natural gas feed Condition

Pressure [kPa]	22275
Temperature [c]	-95
MolarFlow [kgmole/h]	1620

Table 2.2 Natural gas feed molar composition

Component	Molar composition
Nitrogen	0.0025
Carbon dioxide	0.0048
Methane	0.7041
Ethane	0.1921
Propane	0.0706
Isobutane	0.0112
normal butane	0.0085
i-pentane	0.0036
n-pentane	0.0020
Hexane	0.0003
n-heptane	0.0002
n-Octane	0.0001

2.3 Process Description

The pre-treated feed gas stream from the gas recovery section of a gas flare system is fed into the plant to produce Six different final product streams of methane, ethane, propane, isobutane, normal butane and Natural gasoline (C5+) but for the scope of this process, we are only concentrating on maximum recovery of 2 product stream namely propane, butane, which are the fundamental components of LPG.

Five conventional columns are used in this simulation, the first one in the methane recovery system(Demethanizer) and remaining four in NGL fractionation (Deethanizer, Depropanizer, Debutanizer and butane splitter).

The feed gas is first charged into a methane recovery system where methane is separated as top product and Natural gas liquids (NGL) as bottom product. The next stage is to charge the NGL from the methane recovery system into a deethanizer. In this column, residual methane (minor) and ethane (major) are separated at the top most part of the distillation column as vapour. The heavier hydrocarbons (C3+) flow at the bottom in liquid phase and are then sent into the next column called a Depropanizer.

In order to obtain pure specified propane product, propane and heavier hydrocarbon are separated in Depropanizer Column. Propane goes to the top while the C4+ to the bottom. In the debutanizer, butane is separated as top products from natural gas liquid (C5+) which flows at the bottom.

Then finally, butane is charged into the butane splitter where normal butane and isobutane are separated as overhead and bottom product respectively to specified products.

2.4 Description of simulation Environment

Computer aided Modelling and simulating the LPG production plant is not as easy as the description, especially when it comes to converging the distillation column with Aspen Hysys V8.6

2.4.1 Demethanizer

Modelling the demethanizer is quite simple and complex if one don't have the required data, and skills. Generally, in modelling a demethanizer in HYSYS, a "Reboiled absorber column" is used in contrast to the distillation column.

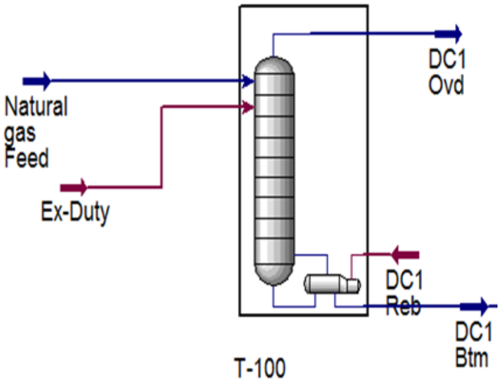

Figure 2.1 simulation of Demethanizer

2.4.2 Dethanizer

2.4.2 Dethanizer

Dethanizer is modelled as distillation column with reboiler at the bottom and a total refluxed condenser at the top. After selecting the feed conditioning process, the next step is to define the process conditions in the Dethanizer column as well as converging the column. Ethane and residual methane will be separated from the stream in gaseous form as top product while propane together with other heavier hydrocarbons flow as the bottom product. Overhead vapour rate, distillate rate and C2/C3 ratio are used to reach convergence.

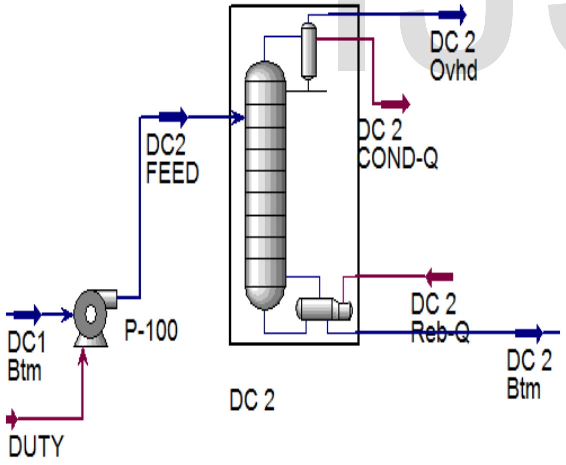

Figure 2.2 simulation of Dethanizer

2.4.3 Depropanizer

Depropanizer in Aspen hysys V8.6 is modelled as a distillation column just as the deethanizer but this time with a reboiler at the bottom and a total condenser at the top. Depropanizer is used next in order to separate propane as overhead product front heavier hydrocarbons (C4 +) which flow down the column as bottom products. The column specification used is Components recovery. Selecting operating pressure and number of stages are also inputted based on available data

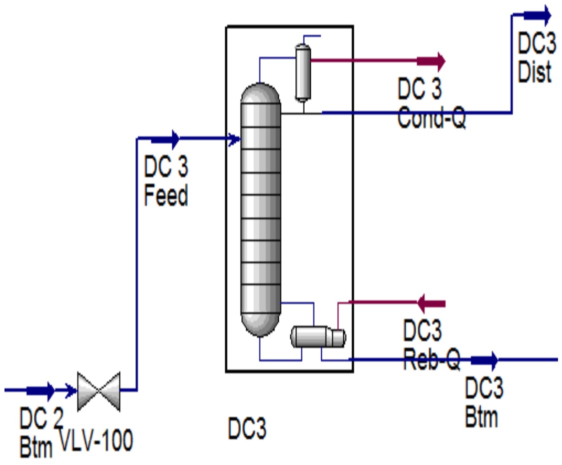

Figure 2.3 Simulation of Depropanizer

2.4.4 Debutanizer

Debutanizer is modelled as a distillation column in Aspen HysysV8.6 just as the depropanizer with a reboiler at the bottom and a total condenser at the top.

Debutanizer is used to separate butane and lighter hydrocarbons at the top from natural gasoline (C5+) at the bottom. In, modelling the debutanizer by hysys, a condenser along with a reboiler is used. Basically, the steps in modelling the debutanizer column are almost the same like modelling the depropanizer. Since a condenser alongside a reboiler are used, there are 2 column specifications to be defined in order to converge the column.

2.5 Assumptions

1. It is assumed that the feed gas has been pre-treated for removal of contaminants such as acid gases, Sulphur compounds and water.
2. It is assumed that after treatment feed gas has been conditioned for inlet into Demethanizer.

3 RESULTS

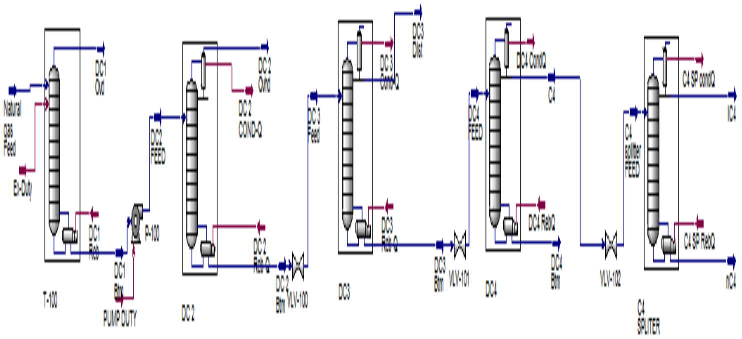

Figure 3.1 Completed Simulation of LPG recovery process

from flare system

Table 3.1 Effect of feed position on Propane Recovery (10 tray Depropanizer)

Feed Location	**Propane Recovery %**
1	89.49%
2	90.89%
3	91.27%
4	90.88%
5	89.80%
6	88.05%
7	85.43%
8	82.49%
9	79.48%
10	76.80%

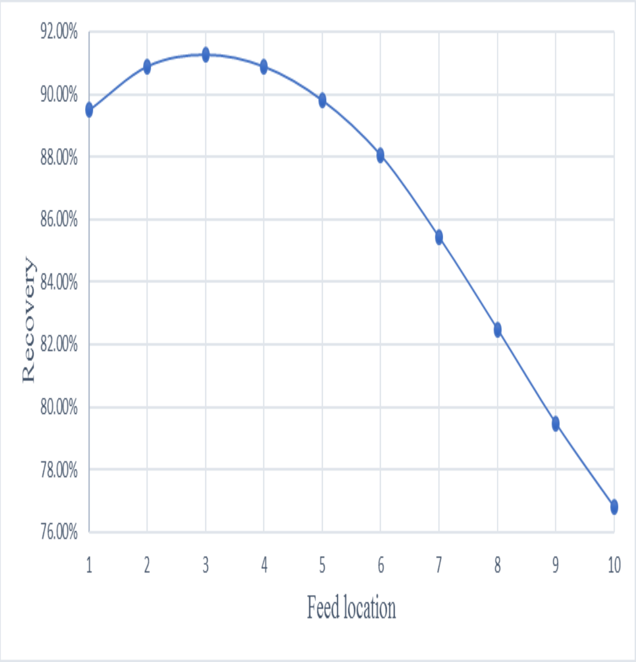

Figure 3.2 graphical presentation of the effect of feed position on Propane Recovery (10 tray Depropanizer)

Table 3.2: Effect of feed position on Propane Recovery for 12 tray depropanizer

Feed Location	**Propane Recovery**
1	90.888%
2	92.848%
3	93.776%
4	**94.057%**
5	93.818%
6	93.016%
7	91.492%
8	89.134%
9	86.104%
10	82.818%
11	79.596%
12	96.918%

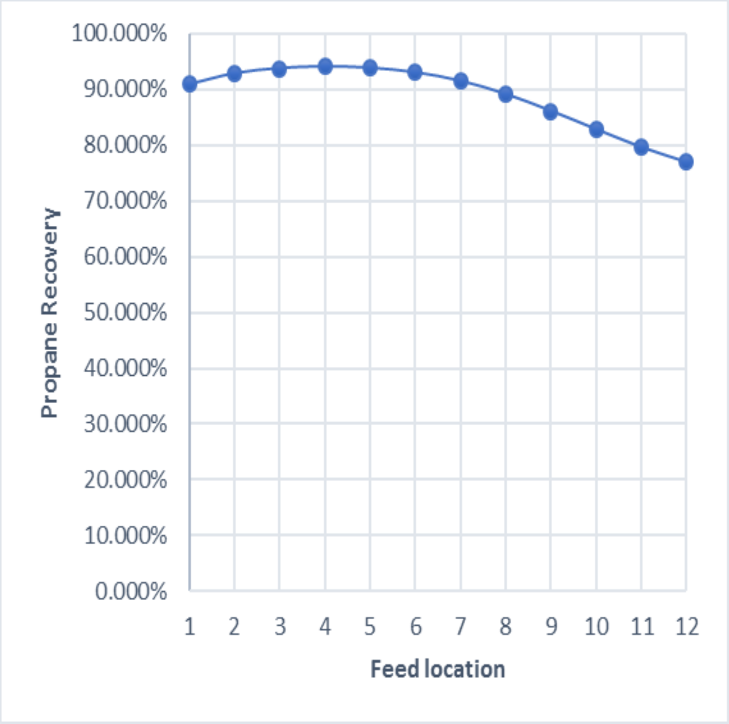

Figure 3.3 graphical presentation of the effect of feed position on Propane Recovery (12 tray Depropanizer).

Table 3.3: Effect of feed position on Propane Recovery (14 tray depropanizer)

Feed Location	Propane Recovery
1	91.48%
2	93.71%
3	94.96%
4	95.64%
5	95.92%
6	95.86%
7	95.42%
8	94.40%
9	92.54%
10	89.78%
11	86.46%
12	82.99%
13	79.65%
14	76.97%

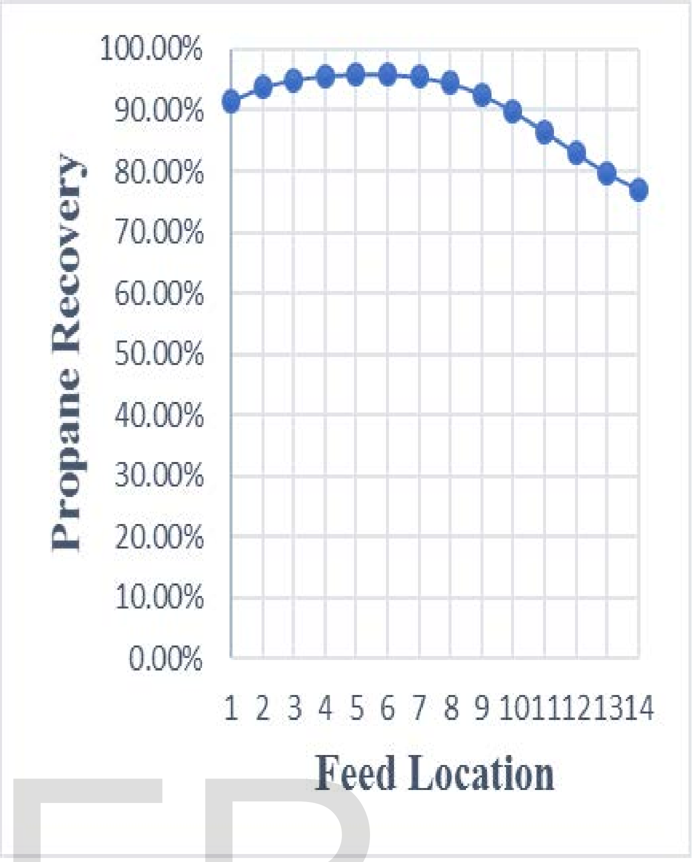

Figure 3.4 graphical presentation of the effect of feed position on Propane Recovery (14 tray depropanizer)

Table 3.4 Effect of feed position on Propane Recovery (16 tray depropanizer).

Feed Location	Propane Recovery
1	91.688%
2	94.042%
3	95.434%
4	96.287%
5	96.802%
6	97.076%
7	97.14%
8	96.987%
9	96.484%
10	95.333%
11	93.173%
12	90.138%
13	86.650%
14	83.081%
15	79.659%
16	76.980%

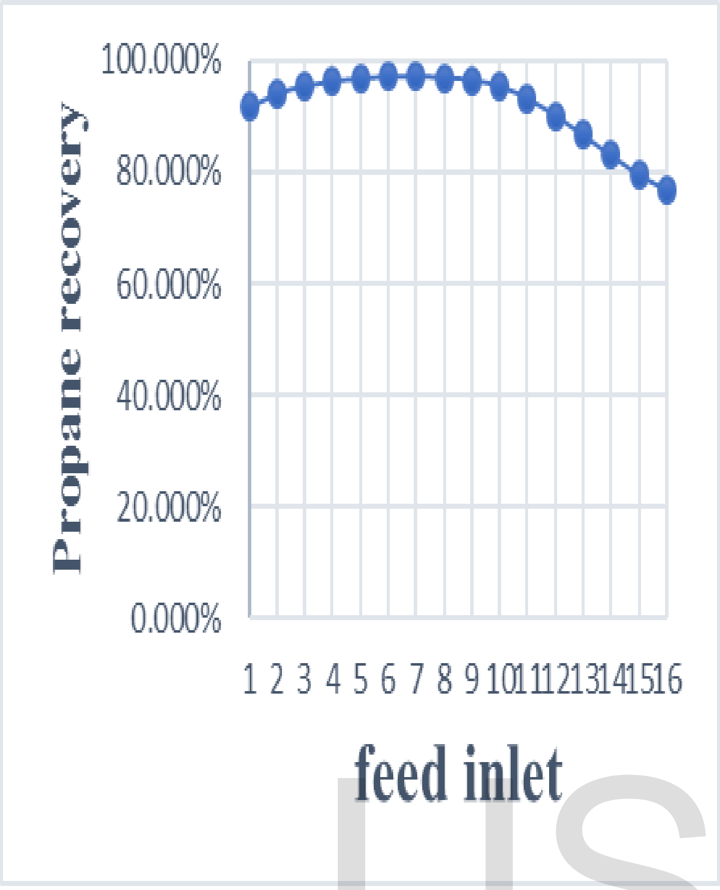

Figure 3.5: graphical presentation of the effect of feed position on Propane Recovery (16 tray Depropanizer)

Table 3.5: Effect of feed position on Propane Recovery (18 trays depropanizer)

Feed Location	Propane Recovery
1	91.759%
2	94.155%
3	95.605%
4	96.529%
5	97.137%
6	97.532%
7	97.774%
8	97.892%
9	97.889%
10	97.721%
11	97.229%
12	95.970%
13	93.536%
14	90.321%
15	86.790%
16	83.176%
17	79.708%
18	77.009%

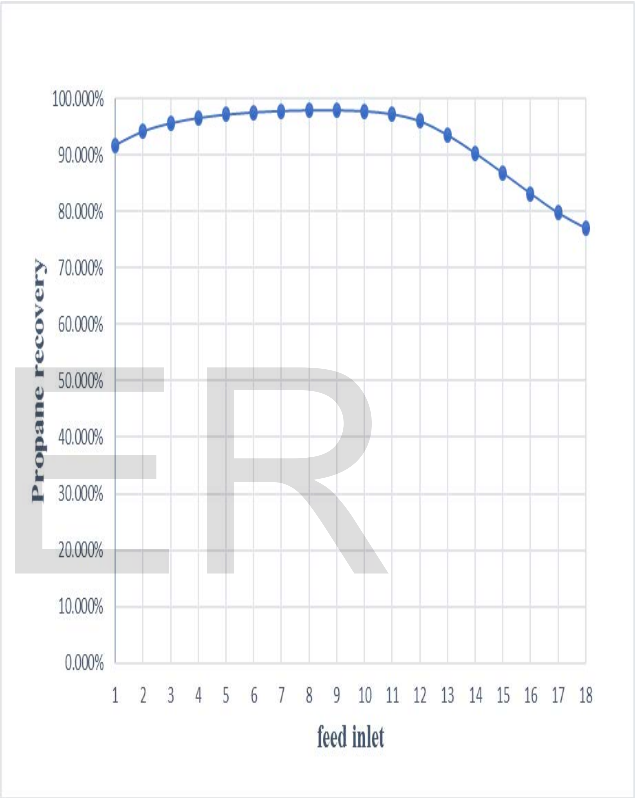

Figure 3.6 graphical presentation of the effect of feed position on Propane Recovery (18 tray Depropanizer)

Table 3.6 Summary of Depropanizer sensitivity study using different number of trays

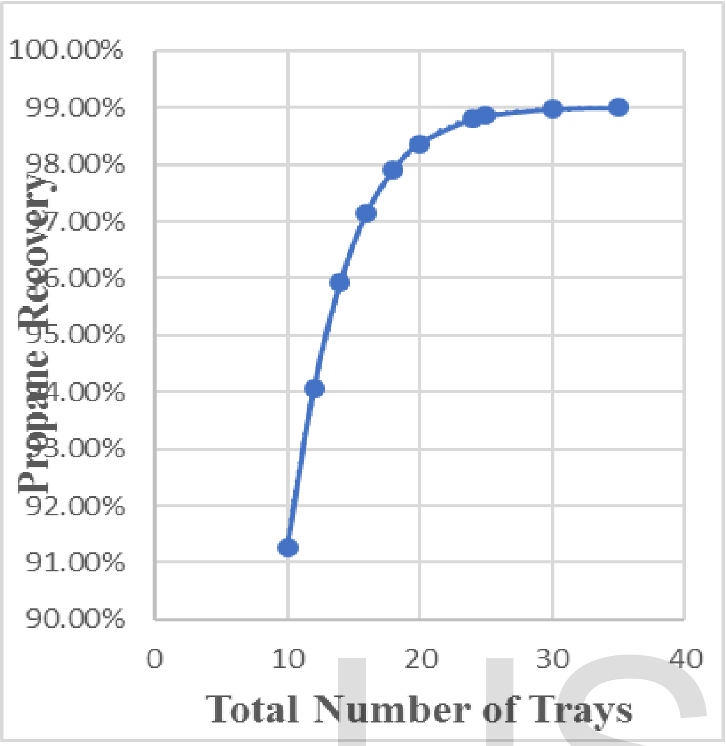

Figure 4.4 graphical presentation of the relationship between number of trays and propane recovery in the Depropanizer

TOTAL TRAYS NUMBER	OPTIMUN FEED LOCATION
10	3
12	4
14	5
16	7
18	8
20	10
24	14
25	15
30	20
35	25

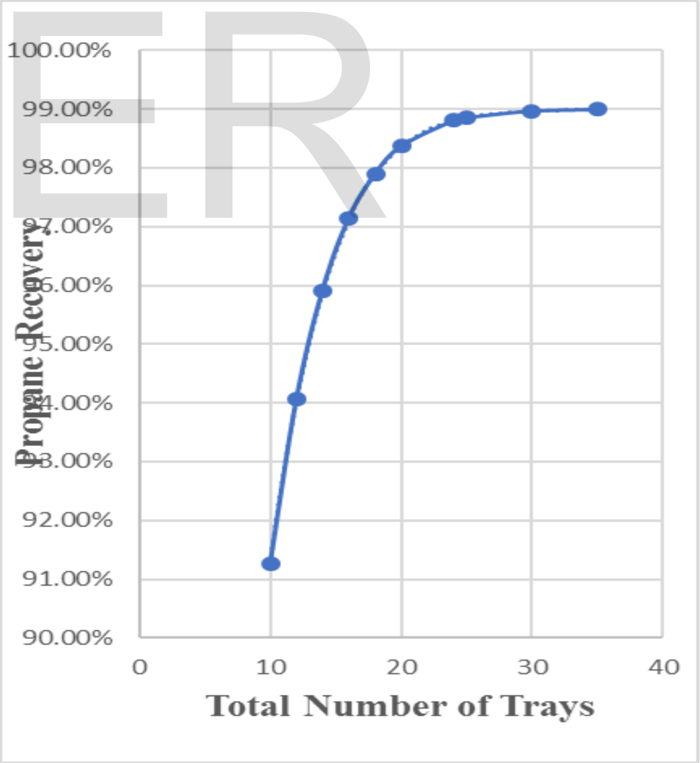

Figure 4.4 graphical presentation of the relationship between number of trays and propane recovery in the Depropanizer

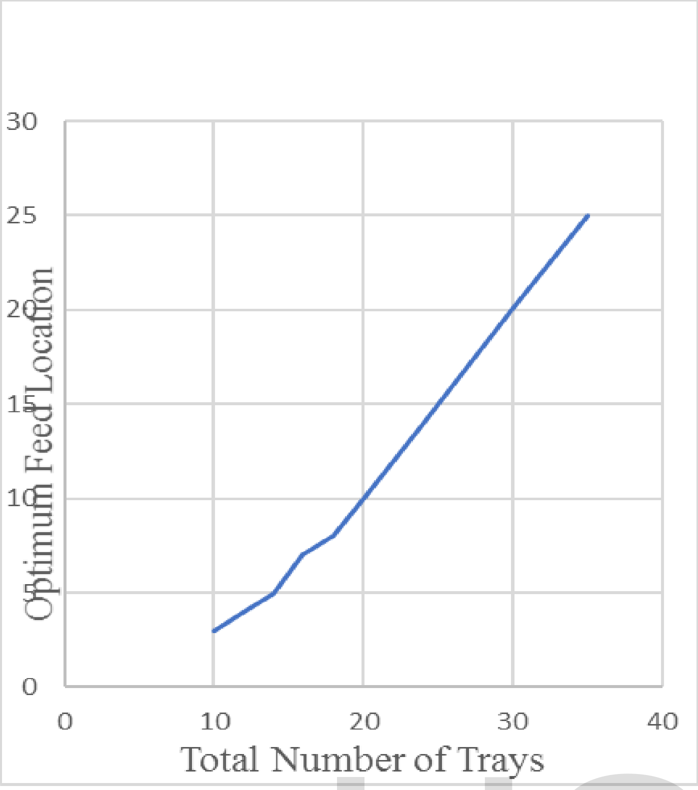

Figure 4.5: the relationship between number of trays and optimum feed location in the Depropanizer

Table 4.5 Summary of Debutanizer sensitivity study using different number of trays

Total Number of Trays	Optimum Feed Location	C4 RECOVERY
10	3	88.85%
12	4	91.53%
14	5	93.43%
16	7	94.66%
18	8	95.49%
20	10	96.01%
23	13	96.43%
25	14	96.57%
30	19	96.73%
35	24	96.76%

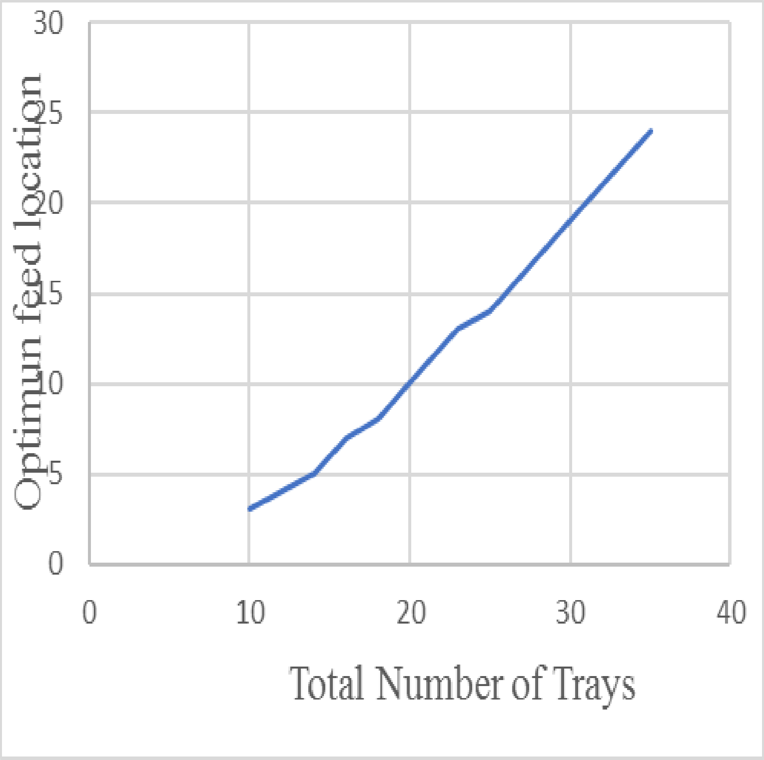

Figure 4.7 graphical presentation of the relationship between number of trays and butane recovery in the debutanizer

3.2 Discussion of Result

From Table3.1-3.5 and Figure 3.2-3.6, it can be observed that the propane recovery keeps increasing as the feed-inlet position changes (from top to bottom) until propane recovery reached its maximum at tray position 3 and after then there was continuous reduction in the propane recovery up to the last tray position. This shows that maximum propane recovery is not directly proportional to increasing inlet feed location (from top to bottom). The optimum feed location tray is the tray position that gave the maximum amount of propane recovery. it can be observed that as the number of trays in the depropanizer increases the propane recovery also increases, this trend continued till depropanizer with 20 trays and after which further Increment in the number of trays will yield very small and insignificant increment in the amount of propane recovery hence optimum number of tray is 20 trays.

From Table 4.4 and Figure 4.6, it can be observed that the amount of butane recovered keeps increasing as the feed location changes (from top to bottom) until butane recovery reached its optimum at tray position 3 and after then there was continuous reduction in butane recovery up as tray position moves towards the base of the column. This shows that maximum butane recovery is not directly proportional to increasing inlet feed location (from top to bottom). The optimum feed location tray is the tray position that gave the maximum amount of butane recovery. It can be seen that as the number of trays in the debutanizer increases, the optimum feed location tends to increase also, this trend continued up till debutanizer with 23 trays and after which further Increment in the number of trays will yield very small and insignificant increment in the amount of butane recovery hence optimum number of tray is 23.

3.3 Model for predicting feed location

Using the data from sensitivity study of depropanizer, a mathematical model was developed for the estimation of the optimum feed location for a depropanizer given number of trays.

$$y = 0.8994x - 7.2474 \qquad (1)$$

$R^2 = 0.9912$, Where X= Total number of trays, Y= Optimum feed location.

Using the data from sensitivity study of debutanizer, a mathematical model was developed for the estimation of the optimum feed location for a debutanizer given number of trays.

$$y = 0.8492x - 6.538 \qquad (2)$$

$R^2 = 0.9923$, Where X= Total number of trays, Y= Optimum feed location.

3.2.2 Model validation

Given a depropanizer of 24 trays, let use equation.1 above to estimate the Optimum feed location

- Optimum feed location as predicted is 14.10 which means 14th tray position.
- Error of 0.71%

Given a debutanizer of 20 trays, let use equation.2 to predict the Optimum feed location

- Optimum feed location as estimated by equation 2 is 10.44 which means 10th tray position
- Error of +4.46%

4.CONCLUSIONS

The results from this work has been able to show that a depropanizer of 24 trays with the feed located at the 14th tray will yield 98.80% recovery of propane, this is a tremendous improvement when compared to the convectional design of the same 24 trays with the feed located at the 11th tray with a lesser recovery of 97.77%. It has also shown that a convectional debutanizer of 23 trays with the feed located at the 13th tray will yield 96.43% recovery of Butane from the pretreated and conditioned stranded natural gas stream.

5. RECOMMENDATIONS

- Existing plants management should consider the possibility of in cooperating the conclusions made in this work into their plant design for optimum recovery of LPG at no significant cost.
- Similar study should be carried out on different stranded natural gas that are currently flared to ensure maximum utilization of this natural resource.

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