# Simulation of Flare Gas Recovery System of a Refinery Plant in Nigeria

**Ifeanyichukwu Edeh\* and Yusuf Muizz Olawale**

*Department of Chemical Engineering, University of Port Harcourt, Nigeria*

**\*Corresponding author:** Ifeanyichukwu Edeh, Department of Chemical Engineering, University of Port Harcourt, Nigeria

## ARTICLE INFO

## ABSTRACT

Flare gas recovery system (FGRS) is a new normal in oil and gas industries and it is designed mainly to capture and reuse gases that are routinely manifolded into flare system for combustion. The recovered gases do not only reduce monumental pollution to the environment but also widen the profit margin of the processes that produce them thus incentivising it for industry-wide adoption especially for refineries and petrochemicals which hardly break-even due to high production cost and competitively emerging energy alternatives. This research work attempted to produce 430,600 kg/hr FGRS for a refinery in south-south Nigeria by simulating the plant which recovers certain flare gases from the flare system header and re-routes them as recycles for use in the refinery, Petrochemical plants and other industries. The simulation tool deployed for the purpose is Unisim Design 471 with flare data obtained from Fluid catalytic cracking Unit of the refinery's fuels plant and was run in steady state using Peng-Robbinson fluid package to retrieve methane, ethane, propane, butane, isobutane and debutanized products from the flare stream. The simulated plant shows an average percentage product recovery of 94%. Installation of the FGRS has prospect of reducing carbon dioxide emission to the environment by about ten million tonnes per year. The simulation predicted very high products tonnage for the recovery plant which if implemented would return the said refinery to the path of profitability and compliance to global zero flaring mandate.

**Keywords:** Simulation; Flare Gas; Refinery Plant; Hydrocarbon

**Abbreviations:** FGRS: Flare Gas Recovery System; VOCs: Volatile Organic Compounds; HAPs: Hazardous Air Pollutants; GHG: Greenhouse Gases; FCCU: Fluid Catalytic Cracking Unit; HPU: Hydrogen Purification Unit

## Introduction

A key component of refining business profit determinant is the processing fuel cost. Reduction in refinery products demand affects the energy economics of the process and impacts negatively on the cost of production. One way to achieve the most cost-effective production is to reduce and recover hydrocarbon gases discharged to the flare. A variety of strategies exists for minimizing flaring. These include the use of plant practices and existing equipment to control the processes that produce waste gases. Equipment must be properly maintained to minimize leaks into the waste gas header. Another strategy encompasses an improved understanding of how waste gases are produced under a given set of conditions, so that those conditions can be avoided.

Methods employed to achieve these two strategies are recycling waste gases back into the process or using alternative technologies that produce less waste. A step in these directions is Flare gas recovery system (FGRS) which captures waste gases that would have been flared, either for use in the plant or for sale. The definition of flare gas recovery unit covers only the recovery of normal continuous flaring streams, including flash and stripping gas [1]. Intermittent flaring includes gases flared during unexpected shutdowns or in abnormal unit operating conditions. Intermittent flaring cases are emergency depressurizing in the high pressure or medium pressure flare and should be considered during the design of seal drums and connection facilities. Emissions from flares worsen air quality and produce waste gas. A flare gas recovery system (FGRS) is designed to facilitate CO2

reduction and recovers hydrocarbon for reuse as fuel and feedstock to other refining and petrochemical sections.

Gases sent to the flare originates from process venting. Venting is the release of potentially combustible gases into the atmosphere without any form of treatment. There are two types of venting requirements- venting from normal processes and venting released during emergency [2]. Normal process venting in the refineries includes off-gases associated with process chemistry, inert gas purging or other gas flows that are not consumed in the process or are introduced on purpose. Emergency venting is done to relieve excessive pressure or vacuum caused by an abnormal condition that cannot be controlled by the basic process controls or safety instrumented systems like in case of fire or runaway reactions, human error, equipment and instrumentation failures etc. Venting is a safety practice done to protect process, process equipment and personnel from danger of process pressure, temperature or other conditions beyond and above the safe limit set by process instrumentation. In flaring, venting gases are not released into the atmosphere rather they are captured in a blowdown pipe or vent header from where it is channelled to the flare system for combustion and dispersion.

Gas flaring is a preferred alternative to direct venting because in the former they are burned and oxidized to carbon dioxide which has global warming potential 21 times lower than direct methane [3] release to the atmosphere. Gas flaring versus direct venting reduces the emission of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) by ratio four to one [3]. A new wave of attempts at ensuring a safer environment led various countries of the world to demand that flaring in oil and gas industries be reduced and targets put in place to completely stop the practice through global conventions and pacts extracting commitments from the participating countries. One of such global efforts is Kyoto protocol. The Kyoto protocol was adopted on 11 December 1997 and due to complex ratification process, it's enforcement began on 16th February, 2005.

It enlists commitment of industrialized countries and economies to transit to limiting and reducing greenhouse gases (GHG) emissions in accordance with agreed individual targets. The convention itself only asks countries to adopt policies and measures aimed at mitigating emissions and to report periodically. Based on this, the Federal Government of Nigeria set up regulatory framework for industrial emission control. At the inception of such control, the industries were required to construct flare system to safely burn and discharge vent gases thereby prohibiting industries from direct vent discharges to the atmosphere. It was later discovered that although flaring has lower environmental pollution index than direct venting yet the environment was still massively and negatively impacted by flaring.

In the light of the above mandate, Flare gas recovery system became a necessity not only for refineries but the oil and gas industries in general. Environmental and economic considerations are the key incentives that motivate industries to install recovery systems. Various refineries and other key players in the oil and gas industries began to map out strategies geared towards implementation, integration and domestication of flare gas recovery in their existing process plants. Flare gas recovery system is designed to recover component(s) that would have flared in the flare stack of the flare system. The components include hydrogen, methane, ethane, propane, butane (and isomers), gasoline and slop oil. The component chosen for recovery largely depend on composition of flare gas, economy of the chosen process technology and desired product component.

In view of the literature, Tabriz Petroleum refinery in Iran with expanded capacity of 115,000 barrels per day burned 630 kg/h gas in flare stack and 800 kg/h at peak period at average temperature of 80°C and average pressure of 1bar with mean molecular weight of the gas being 19.9. Khangiran gas refinery, on the other hand, has 32 million cubic metre/day of natural gas production rate and 100,000m³/h of flare gas at temperature of 75°C and pressure of 10 psig at peak period. Gas emission reduction of about 85 % resulted from Flare gas recovery system (FGRS) installed in Tabriz Petroleum refinery and 70% emission decrease recorded in Khangiran petroleum refinery [4].

Most flare Gas recovery system recover Methane as fuel gas for use in powering the process heaters and is the main reason the FGRS plants have associated Amine treatment unit to reduce hydrogen sulphide content of the recovered gas and by extension the sulphur dioxide emission so as to comply with prevailing regulations on refineries' emission. Others key components that are not flared affect Methane recovery (purity) in fuel gas especially those components are substantial in the feed composition hydrogen, hydrogen sulphide, carbon dioxide etc. The profitability index of refining operations can be raised if concerted efforts are made at extending products recovered from FGRS to include other fractions contained in the flare gas. Therefore, the current work investigated the recovery and purity of some valuable constituents of flare gas such as methane, hydrogen, propane, ethane and debutanized products through the simulation of the flare gas system using the Unisim Design 471 software.

## Materials and Methods

### Materials

The source of data for the system simulation included the Flare gas data obtained from the FCC unit of the refinery under study (Tables 1 & 2). The design codes and standards (API 12J) provided the process conditions (temperature, pressure, diameter and height of the standard separators of different orientation and shapes) for the

two three-phase vertical separators in the system. The Gas Processors and Suppliers Association [5]. Engineering data book provided the design and operating parameters for the Demethanizer, Deethanizer, Depropanizer and Debutanizer of the recovery system.

**Table 1:** The composition of the flare gas.

| S/N | Components | Mole (%) | Weight (%) |
|---|---|---|---|
| 1 | $H_2$ | 4.548 | 0.2081 |
| 2 | $N_2$ | 3.354 | 2.1324 |
| 3 | CO | 0.6498 | 0.4131 |
| 4 | $CO_2$ | 0.523 | 0.5224 |
| 5 | $CH_4$ | 13.8415 | 5.0399 |
| 6 | $C_2$ | 9.9185 | 6.7692 |
| 7 | $H_2S$ | 0.6692 | 0.5176 |
| 8 | $C_3$ | 21.8755 | 21.8939 |
| 9 | $i\text{-}C_4$ | 12.7064 | 16.7624 |
| 10 | $C_4$ | 13.518 | 17.833 |
| 11 | $i\text{-}C_5$ | 5.1201 | 11.0462 |
| 12 | $C_5$ | 6.7455 | 8.3845 |
| 13 | $C_6$ | 1.6011 | 3.1317 |
| 14 | $C_7$ | 1.4272 | 3.2459 |
| 15 | $C_8$ | 0.1955 | 0.5071 |
| 16 | $C_9$ | 0.08616 | 0.2508 |
| 17 | $C_{10}$ | 0.005955 | 0.0192 |
| 18 | $C_{11}$ | 0.00253 | 0.0000898 |
| 19 | $C_{12}$ | 0.0001115 | 0.00000431 |
| 20 | $C_{13}$ | 0 | 0 |
| 21 | $H_2O$ | 3.2113 | 1.313 |
|  | Total | 100 | 100 |

**Table 2:** Flare gas process conditions.

| Property | Value |
|---|---|
| Vapour/phase fraction | 0.9994 |
| Temperature (°C) | 36.6667 |
| Pressure (kPa) | 193.0532 |
| Molar flow (kgmol/h) | 9773.04137 |
| Mass flow (kg/hr) | 430600.0000 |
| STD ideal liquid vol. flow (m³/h) | 817.3501 |
| Molar enthalpy (kJ/kgmol) | -109573.2987 |
| Molar entropy (kJ/kgmol oC) | 175.8756 |
| Heat flow (kJ/h) | -1070864382.5126 |
| Liqure volume flow @ STD. Condition (m³/h) | 854.7363 |

The variables provided included the number of trays, the operating pressure range, the typical efficiencies of the columns as well as their reflux ratios. The Unisim Design R471 (Honey well International Corporation) was used to simulate the flare gas recovery system and generate the data for material and energy balance calculations for the system. The process flow diagram and equipment specification/performance for the system were also generated from the design suite. The Microsoft Excel was used for the calculations of material and energy balances using the data supplied by the Unisim Design R471. The equipment sizing and costing as well as overall process cost estimation and economic analysis were carried out using Ms Excel spreadsheet.

**Methods**

The Unisim Design 471 software simulation environment was put in a steady state mode, and the flare gas data was first defined in the Basis Environment. The flare data composition was inputted through Component Tab using Add button after which the Fluid package was selected as Peng-Robisson by means of Fluid Package tab and Add button. Migration to Simulation environment was carried out by clicking 'Return to Simulation environment' button. The Object Palette was opened by double-clicking on the symbol. Material steam (blue arrow) was selected to represent the Flare gas stream and key process conditions like Temperature, Pressure, Composition, flow etc were keyed into the material stream table and named accordingly.

The unit operations were selected and connected one after the other following the sequence in the process description. Each unit operation turned green when the minimum needed data were supplied. For distillation column operations, Legacy inside-out Solver was used with two liquid check option. The overall material and heat balances were used for accountability of inflow and outflow of all material and energy streams. The data for the balances were obtained from the Design software and calculations effected with Microsoft Excel spreadsheet. The equipment specifications provided the sizing parameters used for cost estimation and profitability analysis which was then applied to determine the prospect and feasibility of the recovery system installation and operation. The pressure, composition, flow etc were keyed into the material stream table and named accordingly.

## Results and Discussion

### Process Description

The flare gas streams from different sections of the refinery represented by Fluid Catalytic Cracking Unit (FCCU) flare gas from a header was routed either to Flare system or Flare gas recovery system. Flare gas produced during normal process conditions were directed to the Flare recovery system (FGRS) (Figure 1). The FCCU had the largest number of relief valves and 60 percent of the refinery section flare emanated from this unit. Flare gases produced during normal process conditions were directed to the FGRS while those released during

emergencies were channelled to the Flare system for combustion and dispersion. The flare gas at 193.1 kPa and 36.67°C heading to FGRS was passed through a Let-down valve where the pressure of the gas was reduced to almost vacuum of about 6.895 kPa. It then entered the Liquid ring Compressor at vacuum suction pressure and underwent compression to a discharge pressure of about 1620 kPa.
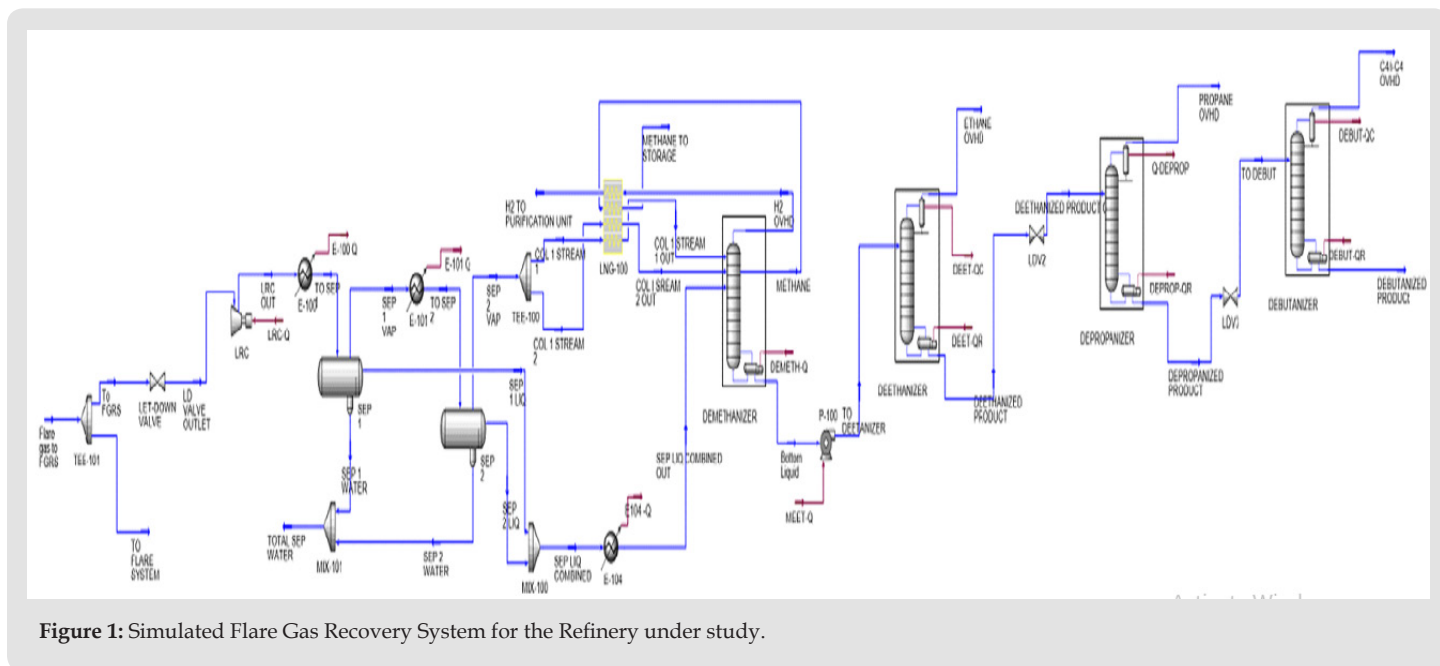


**Figure 1:** Simulated Flare Gas Recovery System for the Refinery under study.

The liquid ring compressor uses liquid ring formed from service liquid and its centrifugal action to compress the gas to extremely high temperature thereby making post-compression cooling a necessity. The compressor was modelled by using a centrifugal hybrid with adiabatic efficiency of 50 % typical of the most Liquid ring compressors. Hot and compressed flared gas then enters the trim cooler E-100 where its temperature drops to 57.22°C at 1620 kPa. At this point, it is routed to the three-phase separator, SEP 1 where the partially condensed gas stream is flashed into vapour, liquid and water. The vapour fraction is cooled further to a cryogenic condition of -42.78°C and 1615 kPa in another cooler E-101 before heading for another phase of flashing in a second three-phase separator SEP 2 where the remaining water and liquid in the condensed gas stream are knocked off. The liquid and water from both separators are manifolded into MIX-100 and MIX-101, respectively for further cooling where necessary.

The combined liquid stream serves as feed and enters the lower feed tray (15th stage) to the Demethanizer. The cooled gas stream at -42.78°C and 1615 kPa is split into two fractions at ratio 4:1 in a splitter TEE-100. The bulk gas fraction, COL1 STREAM 1 goes for further cryogenic cooling in multi-exchanger LNG-100 in the same way as smaller gas fraction COL 1 STREAM 2 does to a much lesser extent. COL 1 STREAM 1 leaves LNG-100 at -153°C and 1600 kPa to serve as reflux to the 30-tray Demethanizer which is a reboiled

absorber and it enters through the top stage (tray). COL 1 STREAM 2 on the other hand at -95oC and 1600 kPa enters the column at the 2nd stage to function as the top feed. The reboiled absorber operates at 1600 kPa and 1650 kPa at the top and bottom stage, respectively at corresponding temperature of -153°C and 25°C. Hydrogen, being the lightest component in the feed stream, is withdrawn as vapour from the top of the column in order to increase the purity of methane, the main product of interest, is removed as side product in vapour form from the 4th stage. Both methane and hydrogen overheads are routed through the multi-exchanger LNG-100 for cold heat recovery to the both reflux and top feed stream. Purity of the methane and hydrogen produced are 91 % and 48.6 %, respectively.

The purity of hydrogen is low because of hydrogen disulphide and other impurities in the hydrogen overhead. Overhead hydrogen withdrawal is another way of reducing hydrogen disulphide content in methane for which purpose amine treatment is deployed in most technologies. The Demethanized liquid is withdrawn from the bottom of the column at 56.32°C and 1650 kPa. The liquid serves as the feed to the Deethanizer entering through 13th stage after being pressurised by the pump, P-100 to 2600kPa and heated to 54.72°C. The Deethanizer is a 30-tray distillation column which operates at 2590 kPa, 1.21°C at the top and 2700 kPa, 114.5°C at the bottom. Ethane is withdrawn at 88.8 % purity as a vapour from the top of the column while Deethanized product removed from the bottom of

the tower is the feed stream to the Depropanizer after pressure step-down to 1750 kPa in a let-down valve LDV2.

The Deethanized product is separated into propane and Depropanized product in a distillation tower, Depropanizer which is also a thirty-tray column operating at 1700 kPa, 50.22°C and 1750 kPa, 118.6°C at the top and bottom end respectively. Propane of 98% purity is obtained at the top of the tower in form of vapour while Depropanized product obtained as liquid is the feed to the Debutanizer after pressure reduction to 550kPa in a let-down valve, LDV3. It enters the fractionator at the 14th stage. Depropanized liquid at 68.55°C enters the 25-stage Debutanizer through the 12th stage where it fractionated into butane/isobutane vapour at the top end and Debutanized liquid at the bottom end. The column operates at 500 kPa, 45.55°C at the top and 600 kPa, 104.7°C at the bottom end. The Debutanized liquid is the gasoline fraction in crude stream. In all of the above, the flare stream is fractionated into mainly methane, ethane, propane, butane/isobutane and Debutanised liquid (Gasoline) which can be all reused in many ways in the refining operations to boost profitability and reduce environmental pollution. The products can also be sold out directly to the consumers.

**The Composition of the Simulated Flare Gas Recovery System**

The composition of flare gas in mole fraction before entering the simulated FGRS as well as those leaving the FGRS at the different stages is shown in (Table 3). From the table, each component is recovered from the respective units demethanizer, deethanizer, depropanizer, and debutanizer, although at different proportions. The recovery system shows a high performance of average percentage recovery of about 94% for all products and by-products (Table 4). With reference to the desired products, the Depropanizer unit returns the highest recovery of 99.9 % for propane while the Demethanizer unit has least recovery profile of 88.44 % for methane because a fraction leaves with Hydrogen. This is a compromise for hydrogen withdrawal from Demethanizer as overhead in the adopted design technique to reduce the need to subject the produced methane to Amine treatment plant which further reduces the cost of the FGRS.

**Table 3:** Flare gas mole compositional analysis.

| | Composition before FGRS | | Composition after leaving FGRS | | | | | |
|---|---|---|---|---|---|---|---|---|
| S/N | Components | Feed's initial composition | $CH_4$ from demethanizer | $H_2$ from demethanizer | $C_2$ from deethanizer | $C_3$ from depropanizer | $C_4$/i-$C_4$ from debutanizer | debutanizer product from debutanizer |
| 1 | $H_2$ | 0.04548 | 1.13E-02 | 0.48599 | 5.01E-19 | 9.99E-31 | 9.99E-31 | 9.99E-31 |
| 2 | $N_2$ | 3.35E-02 | 5.54E-02 | 0.28835 | 3.76E-13 | 1.03E-26 | 1.00E-30 | 9.93E-31 |
| 3 | CO | 6.50E-03 | 1.50E-02 | 4.95E-02 | 1.06E-12 | 6.04E-26 | 1.00E-30 | 9.93E-31 |
| 4 | $CO_2$ | 5.23E-03 | 2.35E-03 | 1.22E-04 | 4.45E-02 | 2.52E-08 | 6.11E-21 | 9.98E-31 |
| 5 | $CH_4$ | 0.13842 | 0.91 | 0.17582 | 8.68E-04 | 1.00E-12 | 4.83E-28 | 9.98E-31 |
| 6 | $C_2$ | 9.92E-02 | 5.27E-03 | 1.93E-04 | 0.88801 | 3.93E-03 | 1.13E-11 | 1.23E-26 |
| 7 | $H_2S$ | 6.69E-03 | 3.99E-04 | 1.56E-05 | 5.92E-02 | 5.61E-04 | 5.82E-12 | 2.79E-26 |
| 8 | $C_3$ | 0.21876 | 1.62E-04 | 1.71E-06 | 7.56E-04 | 0.98001 | 4.73E-04 | 1.97E-13 |
| 9 | i-$C_4$ | 0.12706 | 3.72E-06 | 1.66E-08 | 3.77E-08 | 1.51E-02 | 0.47327 | 2.94E-06 |
| 10 | $C_4$ | 0.13518 | 1.08E-06 | 3.25E-09 | 1.43E-09 | 4.48E-04 | 0.51673 | 9.71E-05 |
| 11 | i-$C_5$ | 5.12E-02 | 4.19E-09 | 3.65E-12 | 4.21E-15 | 1.36E-09 | 2.63E-04 | 0.34232 |
| 12 | $C_5$ | 6.75E-02 | 1.91E-08 | 2.52E-11 | 8.40E-14 | 2.05E-08 | 9.26E-03 | 0.43539 |
| 13 | $C_6$ | 1.60E-02 | 1.42E-11 | 4.16E-15 | 1.67E-20 | 7.97E-15 | 3.02E-10 | 0.10719 |
| 14 | $C_7$ | 1.43E-02 | 1.50E-13 | 1.74E-17 | 3.05E-25 | 2.27E-19 | 2.78E-15 | 0.09555 |
| 15 | $C_8$ | 1.96E-03 | 2.25E-16 | 6.80E-21 | 1.00E-30 | 1.21E-24 | 5.04E-21 | 0.01309 |
| 16 | $C_9$ | 8.62E-04 | 1.38E-18 | 1.31E-23 | 1.00E-30 | 3.09E-29 | 4.73E-26 | 5.77E-03 |
| 17 | $C_{10}$ | 5.96E-05 | 1.53E-21 | 5.86E-27 | 9.96E-31 | 1.00E-30 | 1.00E-30 | 3.99E-04 |
| 18 | $C_{11}$ | 2.53E-05 | 8.25E-24 | 9.02E-30 | 9.95E-31 | 1.00E-30 | 1.00E-30 | 1.69E-04 |
| 19 | $C_{12}$ | 1.12E-06 | 1.01E-26 | 4.55E-33 | 9.93E-31 | 1.00E-30 | 1.00E-30 | 7.47E-06 |
| 20 | $C_{13}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | $H_2O$ | 3.21E-02 | 3.38E-06 | 7.13E-08 | 6.64E-03 | 2.84E-08 | 5.56E-20 | 1.00E-30 |

**Table 4:** Products and their percentage recovery.

| Products | % recovery |
|---|---|
| Methane | 88.44 |
| Hydrogen | 96.65 |
| Ethane | 98.36 |
| Propane | 99.99 |
| Butane/iso-butane | 98.68 |
| Debutanized product | 81.17 |

**Table 5:** Purity of the recovered products.

| Products | Purity (%) | Standard purity (%) | Ref. |
|---|---|---|---|
| Methane | 91 | ≥75 | [5] |
| Hydrogen | 48.6 | 99.99 | [6] |
| Ethane | 88.8 | ≥90 (by weight) | [5] |
| Propane | 98 | ≥73 | [7] |
| Butane/iso-butane | 99 | ≥86.46 | [7] |
| Debutanized product | 99.99 | NA | NA |

The recovered products can either be recycled for reuse in the refinery having met the refinery grade specifications or can be sold out based on 100 % composition (Table 5). Due to the low purity of hydrogen, it is sent to the hydrogen purification unit (HPU) for further purification (Figure 1). The debutanized product characterization is a clear indication that it is a low-octane number product with RON of about 72 and a lighter product with API gravity density lower than that of Gasoline. It can be inferred, subject to further laboratory test, to be a light naphtha with prospect for Gasoline blending and is costed accordingly using this criterion. As shown from (Table 5), propane and butane are above the minimum required specifications for the refinery, and methane also passes the specifications of Gas Processor Supplier Association [5]. These products can be sold to increase the profit margin of the refinery.

**Table 6:** Characterization of Debutanized product.

| Property | Value |
|---|---|
| True Vapour Pressure at 37.8°C (kPa) | 102.0915 |
| Reid Vapour pressure at 37.8°C (kPa) | 101.6628 |
| Flash point °C | -46.4724 |
| Refractive index | 1.3620 |
| Research octane number | 72.9453 |
| Viscosity at 37.8 °C (cP) | 0.2187 |
| Viscosity at 98.9 °C (cP) | 0.1311 |
| IBP ASTM D86 @ 5% vol. (°C) | 36.1391 |
| EBP ASTM D86 @ 95% vol. (°C) | 103.4713 |
| API specific gravity at 60/60F(kg/m³) | 0.6403 |
| Sulphur total by mass (wt%) | 1.15742e-024 |

## Debutanized Product Characterization and $CO_2$ Emission

The amount of $CO_2$ emission reduction by the recovery system was 9,848,562 tonne/year. This reduction is great and could impact positively on climate change. The debutanized product is the by-product of debutanizer which by composition is $C_5$ and $C_5$+. That is, $C_5$ - $C_{12}$ with traces of butane/isobutanes. (Table 6) shows the properties of debutanized product as obtained from the debutanized stream attachment tab of the software.

## Material and Energy Balances

From (Table 7), the total input and output of materials are equal. This shows that there is no accumulation of mass within the system. The zero-percentage difference between the total material at the inlet and outlet of the system also corroborates the perfect mass agreement between them. Similarly, (Table 8) shows the energy balance, and the heat accumulation resulting from the balance means that heat is added to the system faster than it is removed from the system. The percentage error in the energy balance is 0.017 %. This might be as a result of cumulative error resulting from each individual unit operations balances but the percentage error is not very significant [6]. The signs in (Table 8) were as assigned by the software. The negative signs were assigned to material stream enthalpy and positive sign to energy stream enthalpy. The overall sign carried by the total heat flow in or heat flow out is an indication of which stream dominates the contribution to the total sum and is disregarded in the analysis that follows.

**Table 7:** Overall material balance for the FGRS.

| Material stream | Input (kg/hr) | Output (kg/hr) |
|---|---|---|
| Flare gas to FGRS | 430600 | |
| Total Sep water | | 5532.094562 |
| Methane to storage | | 22190.87023 |
| H2 to purification unit | | 11735.41046 |
| Ethane | | 33125.90999 |
| Propane OVHD | | 96438.26059 |
| C4/i-C4 OVHD | | 148807.4456 |
| Debutanized product | | 112770.0085 |
| Total | 430600 | 430600 |
| Percentage difference (%) | | 0 |

**Table 8:** Overall energy balance for the FGRS.

| Energy streams | Heat inflow (kJ/h) | Heat outflow (kJ/h) |
|---|---|---|
| Flare gas to FGRS | -1070864383 | |
| Total Sep water | | -875786649.24 |
| Methane to storage | | -83886352.84 |
| $H_2$ to purification unit | | -21238999.53 |

| | | |
|---|---|---|
| Ethane OVHD | | -106445541.9 |
| Propane OVHD | | -227596016 |
| $C_4$/i-$C_4$ OVHD | | -330140970.2 |
| Debutanized products | | -248134764.9 |
| LRC-Q | 352324655.6 | |
| E-100-Q | | 419209558.4 |
| E-101-Q | | 110104181.7 |
| E-104-Q | | 9749669.805 |
| DEMETH-Q | 53416266.03 | |
| DEETH-QR | 112747298.5 | |
| DEET-QC | | 45572219.45 |
| Q-DEPROP | | 206430964.3 |
| DEPROP-QR | 215385563.4 | |
| DEBUT-QC | | 161614705.8 |
| DEBUT-QR | 173649612.7 | |
| MEET-Q | 975242.7338 | |
| Total | -152365743.5 | -152339995.3 |
| Difference | | -25748.27019 |
| %difference | | 0.017 |

## Conclusion

The simulation of a flare gas recovery system (FGRS) that has the capacity to recover an average of about 94 % for all the products and by-products including methane, propane, hydrogen, ethane, butane/iso-butane and debutanized product has been carried out [7]. These products have purity greater than those specified for natural gas (GPSA [5]) and can either be reused or sold directly. The carbon dioxide emission reduction to the environment obtained from the FGRS was 9,848,562 tonnes/year. With this reduction, the pollution index is minimized and this will make the environment cleaner for survival. Based on the result of this work, installing FGRS in the refinery will help to reduce $CO_2$ emission to the environment and by extension climate change. It sales of the products recovered could help to increase the profit margin of the refinery.

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