Production of Natural Gas and Liquefied Petroleum Gas from Flare Gas using Methanol Based Process

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ABSTRACT: Flare gas utilization has been a topic of discussion among stakeholders of the Nigerian Petroleum Industry and one of the simplest technical and commercial strategies is to send these gases to an existing gas pipeline with spare capacity. Peculiarities of flare gas can pose different challenges but the feasibility of the project depends on exogenous factors such as proximity to gas pipeline and availability of markets. In this work, an energy integrated methanol-based gas processing method for treatment and recovery of Liquefied Petroleum Gas (LPG) is presented using a high flaring intensity Nigerian Marginal oilfield close to an existing gas pipeline. A capacity of 60 MMscfd was determined using the flaring profile of the oilfield and a propane refrigeration system was selected as the cold process. ASPEN HYSYS V9 Cubic Plus Association (CPA) equation of state was used to optimally predict methanol (used as a hydrate inhibitor) partitioning in the methanol-hydrocarbon system. This process produced 57.15 MMscfd of natural gas, 163.7 tonne/day of LPG, and 33.19 tonne/day of stabilized condensate in line with Nigerian gas transport code specifications. The equipment count in comparison to other gas processing schemes, operational flexibility, and ease of scalability indicates that it is an economic technology that will be well suited for solving the gas flare scenario in the Niger Delta region by converting these wasted gas into more useful products.

KEYWORDS: IFPEX-1 process, Cubic Plus Association, Propane refrigeration system, Gas pipeline, ASPEN HYSYS.

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I. INTRODUCTION

Natural gas though a fossil fuel has been identified as a transitional fuel in the bid to utilize cleaner and net zero-carbon energy sources which are expected to bridge the gap between zero-carbon technologies fuels and fossil fuels such as oil and coal (Gürsan & de Gooyert, 2021). Nigeria has the largest gas reserve in the African continent (Statistia, 2020) with an estimated 203.16 trillion standard cubic feet (DPR, 2020) but the resource is yet to be fully harnessed. With about 60% of the produced gases coming from oilfields as associated gas, Nigeria is the 7th highest gas flaring country in the world with an estimated 7.2 million m^3 of gas flared in the year 2020 (GGFR, 2021) accounting for roughly 11% of the total annual gas production (DPR, 2019). Gas flaring occurs as a result of an under-utilization of this transition fuel which is a menace to the environment. With the increasing effects of global warming, there is an urgent need to reduce or mitigate emissions of Greenhouse Gases (GHGs).

Routine Associated Gas (AG) flaring and venting from oilfields have been identified as a significant contributor to accelerated climate change via the release of CO_2 and methane into the atmosphere thus, there is an urgent need to utilize these flared gases. Statistical reports show that about 142 million m^3 of gas was flared globally in 2020 mostly from the upstream petroleum sector (GGFR, 2020). The reasons why oil operators flare were highlighted by (Omontuemhen, et al., 2019; DiSavino, 2019; Ebrahim & Friedrichs, 2013) but lack of gas infrastructure (primarily gas pipeline) and market development (end-users) were observed as the main reasons. Gas pipelines are one of the crucial infrastructures needed to tackle routine gas flaring and are considered as the simplest gas monetization option both technically and commercially (Capterio, 2020) because the gas already has an access to the market.

Distance to an existing pipeline, available gas volume and spare capacity of the pipeline are major factors in determining the viability of this method of flare gas recovery. Studies have shown that 50% of the gases flared in Egypt are within 5 km of an existing pipeline (ECA, 2017) and 90% of the gases flared in Mexico are within 1 km of a gas pipeline (Capterio, 2020). This infers that a significant flare reduction can be achieved if flared gases are sent to a gas pipeline and for this to be achieved; the gas flare would have to be compressed and processed to meet local gas pipeline specifications.

Nigeria has one of the lowest LPG consumption per capita in Africa (Douglas, 2020) at 1.8 kg compared to Ghana, South Africa and Morocco at 3 kg, 5.5 kg and 44 kg per capita respectively (Kiakia Gas, 2019). However, Nigeria's LPG market has seen a steady rise in consumption with predicted forecast to surpass the 1 MMTA mark in 2020 as predicted by energy analysts (Gooder & Hayes, 2020). Availability of the product remains a major challenge as 60% of LPG is imported mostly from the United States and local production from the

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Nigerian Liquefied Natural Gas (NLNG) and other sources accounting for the deficit. Thus, it is of economic and environmental benefit to recover LPG from flared gas to complement the local production capacity in order to reduce import and increase availability.

The loss of natural gas resources has led to further research studies on ways to reduce flaring. A process simulation study using ASPEN HYSYS V9 was used to evaluate three methods of gas flare utilization in the Asalloyeh Refinery plant which includes Gas To Liquid (GTL), Gas Turbine Generation (GTG) and Gas To Ethylene (GTE). The study observed that Gas Turbine Generation was the most economical (Zolfaghari, et al., 2017). Many researchers agree that Gas to Power Generation is the most economical means of flare gas recovery but concluded that the remoteness of the flare locations constituted another challenge to effectively send the power generated to the grid on absolute demand. Hence the flare gas recovery presents a more attractive scenario since the recovered natural gas sent to the pipeline could either be used for power generation by independent power plants with a tie-in to the national gas grid or processed at NLNG which are on the verge of bringing on-stream another LNG train to increase overall output. Moreover, Nigeria is not yet able to meet the gas demand from its African neighbours via the West-Africa pipeline. Figure 1 highlights the economic attractiveness of various flare gas utilization technologies and options available as illustrated by (Haugland , et al., 2013; Romsom & McPhail, 2021).

It was based on site-specific factors and variables such as i) gas volumes and qualities ii) distance to markets and transportation infrastructure iii) netback values of gas, LPG, condensate, diesel and electricity.

A process technology that can fit the selected method for gas flare utilization in Figure 1 is the IFPEX-1 process. It is a patented process technology by IFP Energies Nouvelles (Rojey, et al., 1999). IFPEX-1 performs gas dehydration and simultaneous NGL recovery by using a cold process. The addition of methanol in appropriate quantities can prevent hydrate formation in the cold process down to temperatures below -100ºC (Minkkinen & Fischer, 2000) which is then recovered and re-circulated back in the process (Genin & Esquier, 2015). A flow diagram of the process is shown in Figure 2.

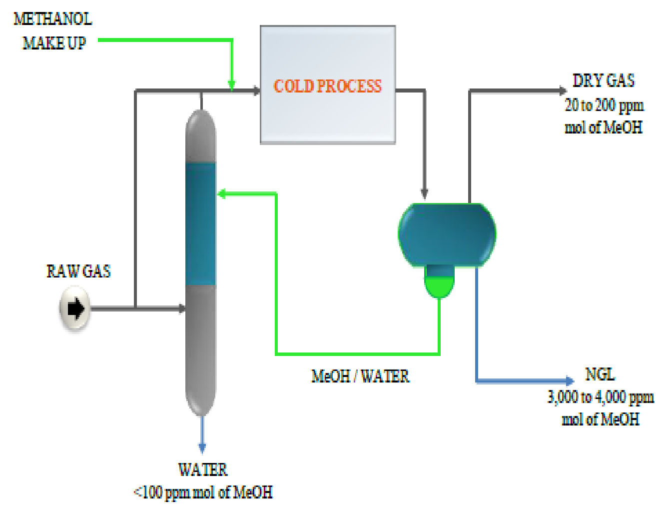


Figure 2: IFPEX-1 Flow Scheme.

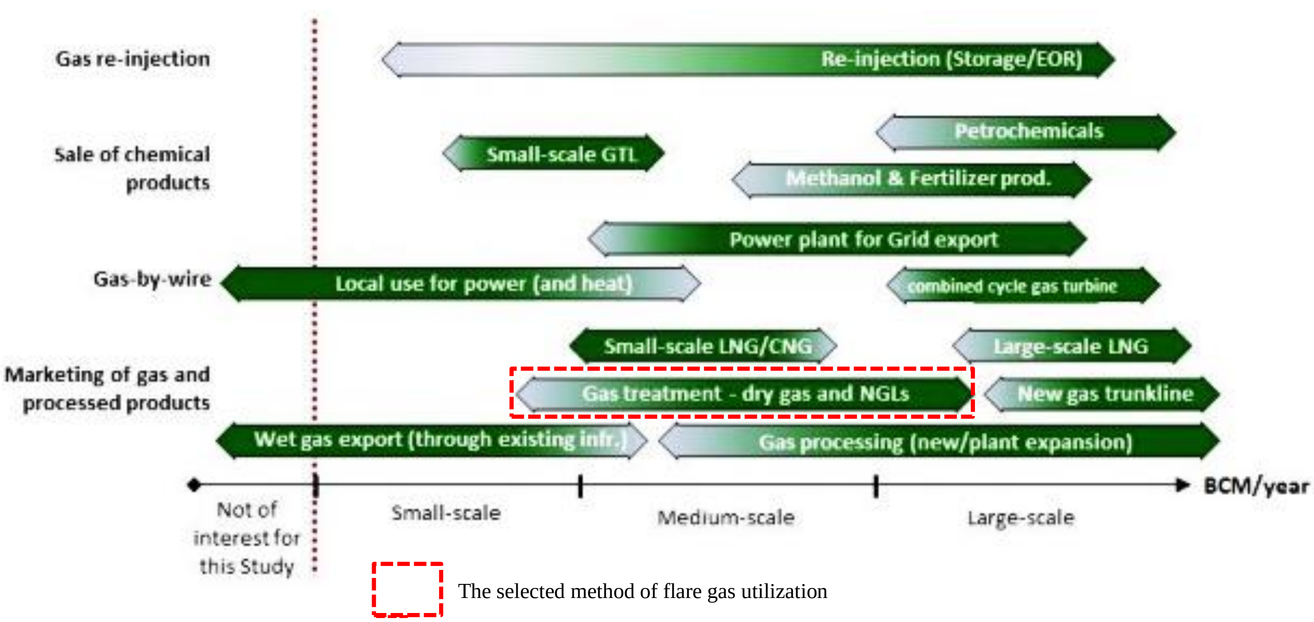


Figure 1: Flare gas utilization strategies vis-à-vis available gas volumes. (Haugland , et al., 2013).

One of the issues in recovering flare gases is the non-constant flow rate of these gases (Barekat-Rezaei, et al., 2018). Small and medium-size production sites cannot offer stable and large quantity of gas hence studying and forecasting the gas flare volume profile is recommended as stated by the Nigeria Gas Flare Commercialization Program (NGFCP) (DPR, 2020). This profile is divided into tranches based on uncertainty over the life span of the field by making a flare gas forecast similar to an oil production profile as shown in Figure 3. These tranches will assist investors on the sustainability of the feedstock supply mechanism and possible projects they might embark on.

sales gas as shown in Figure 4. Associated Gas from Nigerian oilfields have very low acid gas (H_2S and CO_2) content and are termed "Sweet" (< 4 ppmv) hence reducing the processes involved in gas treatment needed to meet gas pipeline specification to only Gas Dehydration and NGL recovery.

From the Nigeria Gas Flare Tracker, the monthly Gas Flare volumes of Marginal Oilfield A were estimated based on the National Oceanic and Atmospheric Administration (NOAA) Visible Infrared Imaging Radiometer Suite (VIIRS) satellite. To determine the daily rate, the monthly gas flare volumes were divided by 30 days.

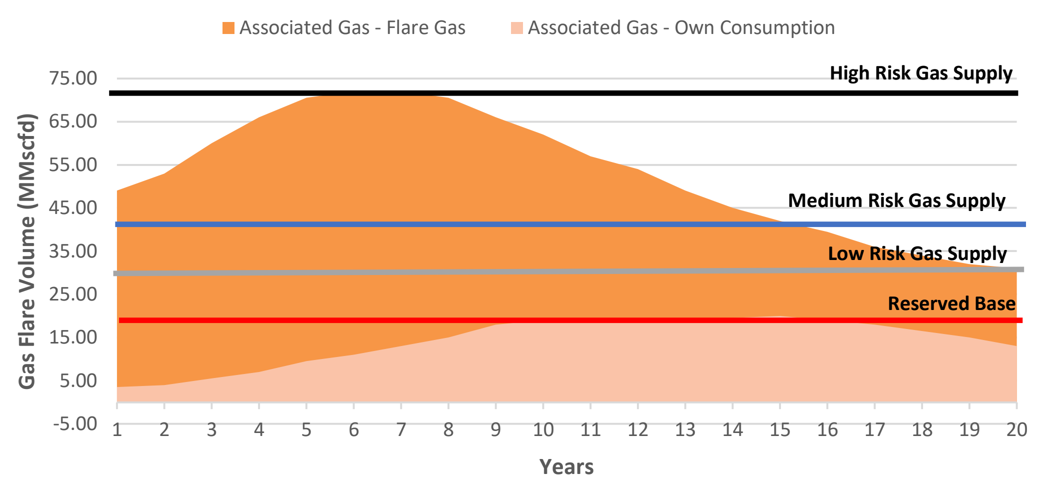


Figure 3: Flare gas forecast in tranches for commercialization (DPR, 2020).

As indicated in Figure 1, gas treatment for the production of dry gas and NGLs is considered in this study as the Nigeria Marginal Oilfield field selected for the study meets the required criteria. Various methods of gas treatment were considered but the IFPEX-1 process was selected.

In this study, the technical feasibility analysis of a relatively low-cost methanol-based gas process (IFPEX-1) was performed for the production of pipeline sales natural gas and LPG production from a flare gas as a solution to mitigate routine gas flaring in Niger Delta oilfields. The selection of the marginal fields and gas volumes was enhanced using aerial satellite flare imagery. Oil field selection was based on nearness to gas pipeline and satellite-based gas flare volume forecast trend as basis for determining the throughput of the gas plant.

II. MATERIALS AND METHODS

A. *Flare Site Identification and Flare Gas Volume Estimation*

With the aid of Satellite imagery from the Nigeria Gas Flare Tracker and Google Earth, a Marginal Oilfield was identified in the Niger Delta region for gas commercialization as indicated in Figure 4. Marginal oilfield "A" was selected because of its high flaring intensity (76.5 m^3/bbl) and low gas utilization flaring as much as 70% of the produced gas (DPR, 2019). It is also approximately 5 km away from the 2 Bscfd capacity East-West (OB3) Gas Pipeline for evacuation of

This is illustrated on a time-series plot as shown in Figure 5. Based on the plot, there has been a gradual increase in gas flaring and with the Excel Forecast tool, various forecasts were determined but for this work, a 60 MMscfd plant was considered as the volume to be utilized. The compositional analysis and process condition of the flare gas is shown in Table 1.

Table 1: Saturated flare gas feed composition and process condition.

Flare Gas Composition (Mole Fraction Basis)			Flare Gas Condition	
1	N_2	0.10	Pressure (kPa)	2746
2	CO_2	0.46	Temperature (ºC)	26.7
3	C_1	82.72	Gas Flowrate (MMSCFD)	60
4	C_2	6.73	Gas Richness (C_3+, GPM)	2.98 (Rich)
5	C_3	5.68		
6	i-C_4	1.56		
7	n-C_4	1.60		
8	i-C_5	0.40		
9	n-C_5	0.26		
10	C_6	0.16		
11	C_7+	0.20		
12	H_2O	0.14		

Note: The condition of the Flare Gas is reported based on the HP Separator condition.
Source: Marginal Oilfield A gas composition.

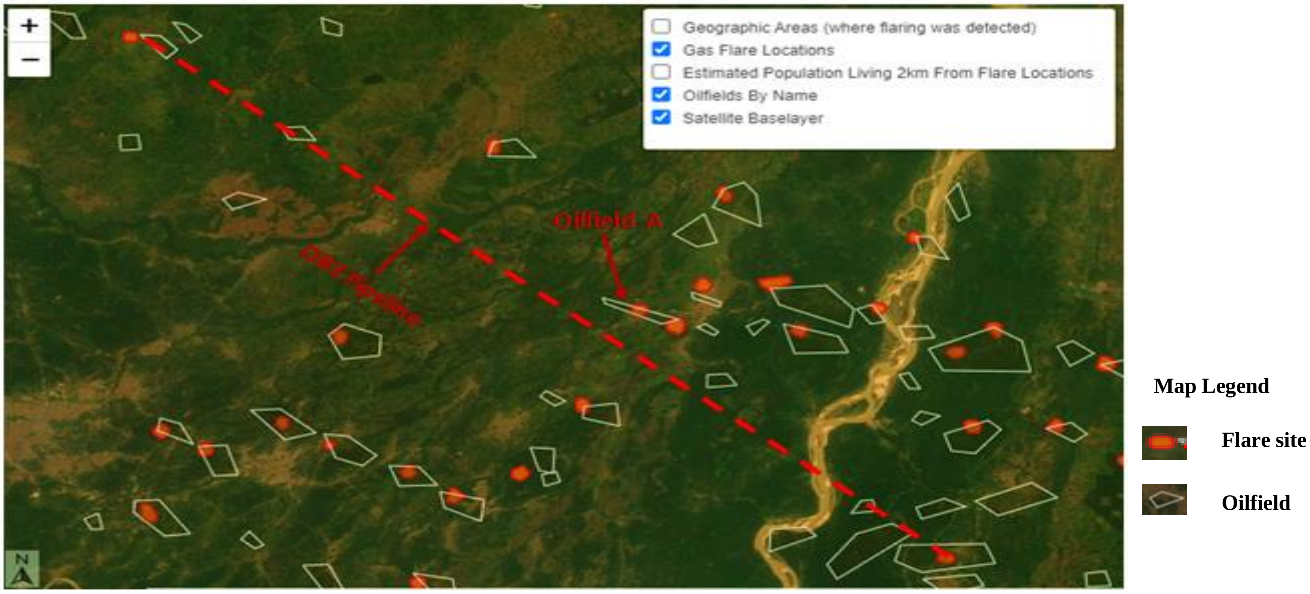


Figure 4: Map of Marginal Field A and OB3 Gas Pipeline (NOSDRA, 2014).

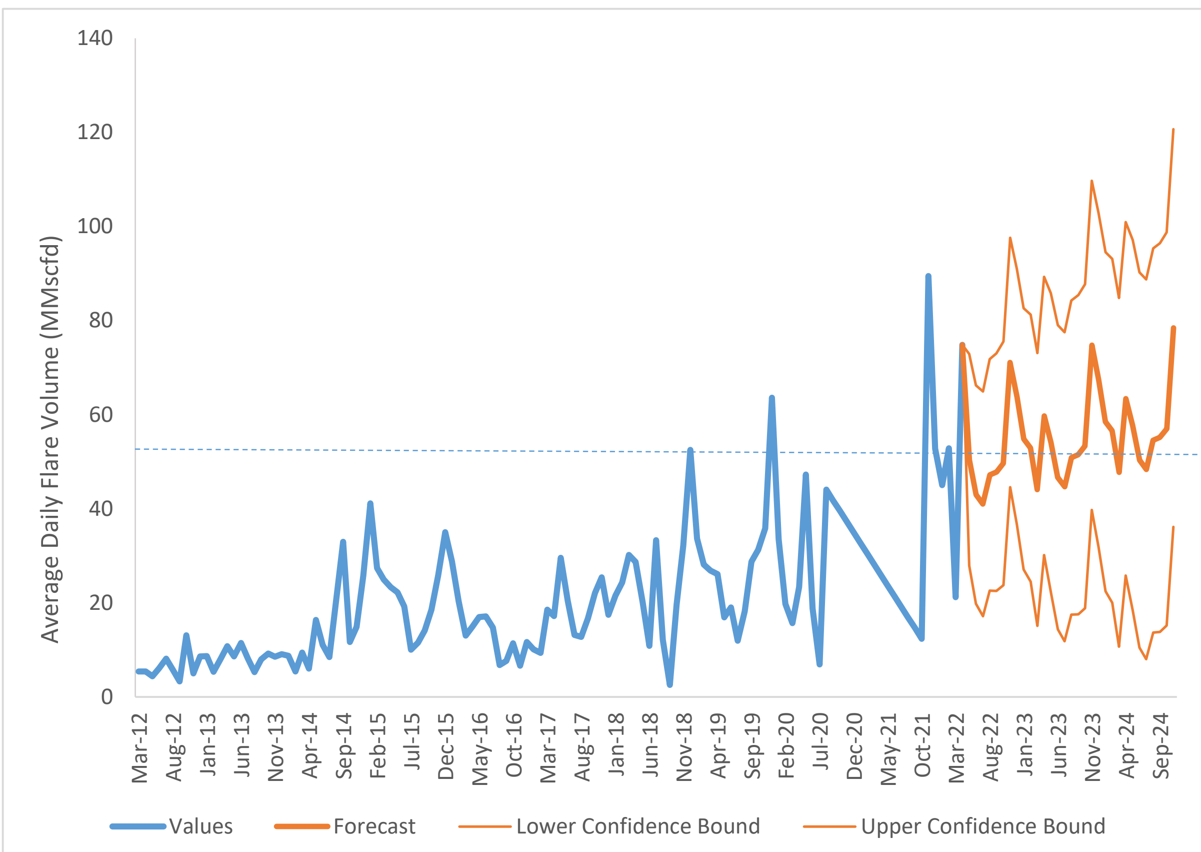


Figure 5: Gas flare profile of "Marginal Oilfield A".

B. Cubic Plus Association (CPA) Equation of State (EoS)

The CPA EoS property package in ASPEN HYSYS V9 was used as it provides a more accurate prediction of methanol partitioning or distribution in a Vapour-Liquid-Liquid Equilibrium (VLLE) when compared with other Equations of States like Peng Robinson and Soave-Redlich-Kwong (SRK) (Aspentech, 2017). This is based on the experimental results of the Gas Processors Association (GPA) Research Report RR-117 (Chen, et al., 1988). CPA is a combination of SRK

EoS with an associated term derived from the Wertheim theory for better handling of mixtures with hydrocarbon bonding compounds like methanol. The Ng and Robinson model for hydrate formation was used to determine the adequate amount of methanol to be used.

C. Process Modelling of IFPEX-1, Propane Refrigeration and NGL Fractionation Processes

The feed gas was saturated using a saturator process unit which was then split into two streams in an 80/20 ratio. The larger gas stream goes into a knock-out (KO) separator to recover NGLs and remove excess water before proceeding into a mixer unit where methanol is injected. The smaller gas stream serves as stripping gas in the MeOH/H_2O stripper which recovers methanol from the aqueous stream of the three phase Low Temperature Separator (LTS). The methanol make-up stream is added to the overhead stream of the MeOH/H_2O stripper which is rich in methanol to make up for methanol losses in the product streams before going to the cold process.

The cold process can either be a propane (C_3) refrigeration, turbo-expander or Joule Thompson expansion valve. For this work, C_3 refrigeration (modelled in a sub-flowsheet) was used because it met the dew point requirement of the gas, recovered high volumes of NGLs and minimized methanol losses from the sales gas. The cold process cooled the gas stream to -35ºC before entering the LTS. At this point, the Hydrate formation Analysis Stream tool in ASPEN HYSYS V9 was used to determine the required methanol make-up volume to be added to prevent hydrate formation in the material stream.

The overhead stream from the LTS then passes through two heat exchangers to pre-cool the feed streams upstream of the process, thus reducing the cooling duty of cold process before being fed into the pipeline. The LTS aqueous stream primarily composed of water and methanol is sent to the MeOH/H_2O stripper for methanol recovery. The hydrocarbon liquid stream of the LTS and KO separator is pumped into the deethanizer at an elevated pressure of 3727 kPa to recover ethane and methane with some propane at the top of the column. The heavier hydrocarbons are recovered at the deethanizer bottom as liquid and are fed into the debutanizer at a lower pressure. LPG is recovered at the top of the column while stabilized condensate is recovered at the bottom. The recycle unit was optimally placed to reduce the convergence time while the Modified HYSIM Inside-Out solver was used for the various columns.

III. RESULTS AND DISCUSSION

A. Gas Hydrate Inhibition

Methanol is a crucial solvent in the IFPEX-1 process hence it was recovered after injection in the LTS to reduce its consumption. It was also recovered from the de-ethanizer overhead stream by recycling it into the feed stream of the process as shown in Figure 6. Methanol is more volatile than water and was simply regenerated from the cold decanted aqueous stream of the LTS by stripping it with a portion of the saturated feed gas resulting in a recovery of 97.8% of methanol. Higher recoveries of 99.9% can also be attained at higher pressures. The condition of the feed gas guaranteed the vapourization of methanol from the aqueous stream because of its very low partial pressure in the gas phase and the inhibition of water vapourization by the stripping gas is guaranteed by the saturated water content of the feed gas used for stripping (Genin and Esquier, 2015). The make-up Methanol flow rate (90 molwt%) was calculated to be 5 kg/h as it was adequate to suppress hydrate formation at -35ºC at the cold process and other processes downstream using the Ng and Robinson Hydrate formation model analysis tool. Despite the very high recovery of methanol, small losses occurred in the Pipeline Sales Gas stream (14.16 kg/h) which is sold with the product stream.

A. NGL Recovery and Product Fractionation

To condense NGLs from the gas stream to meet the requirements as stipulated in the Nigerian National Gas Transportation Network Code specification, a temperature of -35ºC needed to be achieved in the LTS while limiting ethane recovery in the liquid stream of the LTS. The propane refrigeration loop with a circulation of 28,940 kg/h was utilized with an evaporating temperature of -40ºC (typical for a propane refrigeration cycle) as shown in Figure 7. The De-ethanizer was designed for propane recovery into the NGL stream and ethane rejection into the pipeline gas since the Nigerian market to support ethane recovery is not robust, this increasing the available pipeline gas quantity while meeting specs. The Debutanizer LPG stream was designed to meet the domestic cooking gas specification of the Nigerian market based on the NIS 555: 2020 standard with emphasis on the vapor pressure which should not exceed 7 bar (Ekundayo, 2020). The condensate was stabilized and can be sold as feedstock for Condensate Distillation Units or exported. The three major products and their process conditions are shown in Table 2.

B. Utility Consumption and Energy Integration

From the simulation, heat integration was employed using heat exchangers to recover or lose heat. The Feed/Sales Gas Exchanger and the Gas/Gas Exchanger utilized the cold vapour stream of the LTS to precool the incoming feed gas thereby reducing the duty of the propane chiller by about 36.2% while the Feed/Debutanizer Exchanger and Feed/Deethanizer Exchanger utilized the Debutanizer Bottoms and Deethanizer Bottoms to preheat the Deethanizer feed reducing the duty of the NGL fractionation by approximately 8.1%.

C. Benefits of Methanol based Gas Processing for a Gas Flare Recovery Project

Research works illustrate the benefits of the methanol-based gas process over other processes for gas treating and processing. Some of these benefits include:

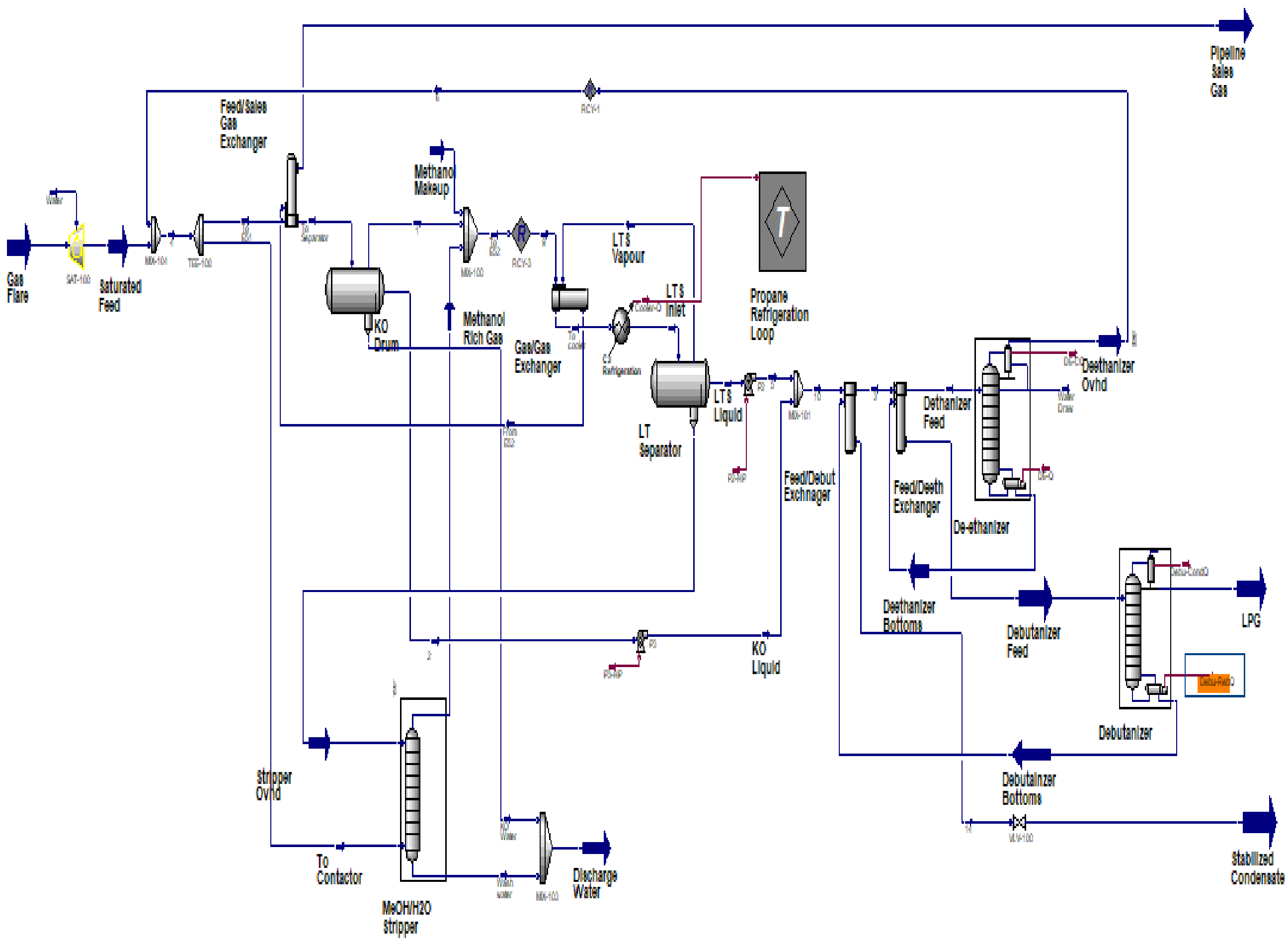
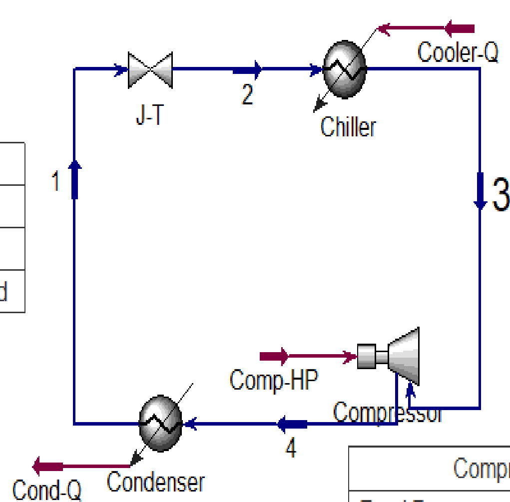


Figure 6: Process Flow Diagram of the IFPEX-1 process and NGL fractionation columns in ASPEN HYSYS V9.

Chiller		
DUTY	5.286e+006	kJ/h
Feed Temperature	-39.24	C
Product Temperature	-40.00	C



1		
Temperature	50.00	C
Pressure	1900	kPa
Mass Flow	694.6	tonne/d

3		
Temperature	-40.00	C
Pressure	116.5	kPa
Mass Flow	694.6	tonne/d

Compressor		
Feed Pressure	116.5	kPa
Product Pressure	1935	kPa
Power	1447	kW

Figure 7: Propane refrigeration loop sub-flowsheet.

Table 2: Summary of product material streams.

S/N	Process Stream Condition	Pipeline Sales Gas	LPG	Stabilized Condensate
1	Pressure (kPa)	1569	784.5	101.3
2	Temperature (ºC)	23.84	47.51	21.78
3	Gas Flowrate (MMSCFD)	57.15		
4	Mass Flow (kg/h) / (tonnes/day)		6822 / 163.7	1383 / 33.19
	Component	**Mole Percentage Basis (%)**		
1	N_2	0.0010	0.0000	0.0000
2	CO_2	0.0048	0.0000	0.0000
3	C_1	0.8684	0.0000	0.0000
4	C_2	0.0707	0.0004	0.0000
5	C_3	0.0469	0.2972	0.0006
6	i-C_4	0.0044	0.2772	0.0118
7	n-C_4	0.0033	0.3117	0.0290
8	i-C_5	0.0002	0.0585	0.3756
9	n-C_5	0.0002	0.0550	0.2229
10	C_6	0.0000	0.0000	0.1594
11	C_{7+}	0.0000	0.0000	0.2006
12	H_2O	0.0000	0.0000	0.0000
13	MeOH	0.0002	0.0000	0.0000
		Specification		
1	Hydrocarbon Dew Point (ºC)	-35.59		
2	Water Content (Ibs/MMscf)	0.6197		
3	Higher Heating Value (Btu/scf)	1151		
4	Vapour pressure @ 37.8ºC (bar) – ASTM D1267 (7bar Max)		6.221	

1. Integration of two gas processes (Gas dehydration and NGL recovery) into one process resulting in a smaller footprint (Minkkinen & Jonchere, 1997).
2. It is a relatively low Capital Expenditure (CAPEX) and Operating Expenditure (OPEX) investment when compared with TEG process and molecular sieve process for gas dehydration with a 30 to 40% saving on OPEX and 40 to 50% saving on CAPEX respectively (Genin & Esquier, 2015). This is largely due to lower equipment count and consumables of the IFPEX-1 process.
3. It is environmentally friendly as no greenhouse gas emissions are made to the atmosphere in comparison with TEG and molecular sieve dehydration processes. Also, the water recovered can be reused as 97.8% of the methanol was recovered from the produced water based on the simulation results.

From figure 6 it is observed that no heating is required, when compared to other dehydration processes. Hence reducing hot utility requirement.

Table 3: Summary of energy consumption.

S/N	Equipment	Electrical Consumption (kW)
1	LTS Draw Off Pump	14.22
2	KO Draw Off Pump	1.236
3	Propane Refrigeration Compressor	1447
	Process Unit	**Duty (kJ/h)**
1	Propane Refrigeration Cooler	5.286×10^6
2	Deethanizer Condenser	3.215×10^6
3	Deethanizer Reboiler	6.378×10^6
4	Debutanizer Condenser	8.140×10^6
5	Debutanizer Reboiler	8.400×10^6

IV. CONCLUSION

The importance of gas pipeline infrastructure as an important feature in mitigating Associated Natural Gas flaring in oilfields has been discussed. Proximity to an existing gas pipeline, gas volumes and spare capacity of the pipeline were major factors considered in this flare gas utilization strategy. The IFPEX-1 process was adopted as an economically viable process for the production of pipeline sales gas and domestic LPG for cooking based on local regulatory specification. This ensures optimal use of the flare gas by monetizing the gas and its derivative while completely eliminating gas flaring and also reducing gaseous pollutants into the environment. The IFPEX-1process is a more economical alternative providing significant CAPEX and OPEX savings with further heat integration of the refrigeration and fractionation system which reduced utility consumption by 36.2% and 8.1% respectively based on the simulation results.

Though the OPEX is comparatively low, methanol losses in the Pipeline Sales gas stream are common hence the need for sufficient methanol storage on site for effective operation. This residual methanol in the pipeline gas is inconsequential and does not affect the product specifications. Overall, the process is easily scalable for both marginal and large oil fields presenting a unique solution with several benefits.

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