

Assessing the Economic Cost Benefit Analysis of Fractionating Raw Condensate into Specific Products by the Atuabo Gas Processing Plant, Ghana

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Abstract
In Ghana, the condensate market is nascent, but however has the potential of accelerated growth, as the nation continues to discover more gas reserves in addition to the existing reserves.

The objective of the study was to analyze the condensate production by Ghana Gas and assess the economic viability of expanding the existing Atuabo Gas Processing Plant to facilitate the fractionation of raw condensate (which is currently being sold for limited industrial use) into specific products. The study is also geared towards identification of a means of optimizing the country's gains from this product as well as recommending such optimizations for the benefit of the country.

A quantitative survey based on the Net Present Value (NPV) economic model (of a Condensate Fractionation Unit configuration that yields Pentane foamer, Rubber Industrial Solvent Oil, Natural Benzene, Vegetable oil extraction solvent) was used in analyzing the feasibility of condensate production optimization in Ghana. The economic analysis of the raw condensate sale, yielded a net present value (NPV) of US $ 143,080,318.03 whiles that of the fractionated products yielded a positive NPV of US $ 167,471,583.84. Comparing the two models indicated clearly that the fractionated products were more viable and lucrative. This value of approximately US $ 24,391,265.81 was more than the NPV of the economic model for the sale of raw condensate.

Furthermore, the sensitivity analysis which elaborates effects of changes in raw material, prices of product and rate of return due to errors of estimation of investment cost proved, there is a ninety percent (90%) probability that the economic model for the project will yield a maximum NPV at the end of the project. Implying that fractionating condensate would be lucrative for Ghana National Gas Company.

Therefore, the results from the Net Present Value (NPV) economic analysis revealed that Ghana Gas, Atuabo stands to gain immense benefits from fractionating condensate into Pentane foamer, Rubber Industrial Solvent Oil, Natural Benzene, Solvent for vegetable oil extraction. After performing the economic analysis with the net cash flow (NPV) model of both scenarios, it was also ascertained that should the proposed expansion project be carried out, measures should be taken to ensure constant or increased supply of natural gas (plant condensate) and also to reduce capital expenditure in order to enhance the project's success since the afore mentioned are the most influential element.
Keywords: Economic Cost Benefit Analysis, Fractionating, Raw Condensate, Atuabo Gas Plant

1.1 Introduction

Being the first of its kind in Ghana, the Atuabo Gas Processing Plant (GPP) owned by the Ghana National Gas Company (GNGC) is an onshore facility equipped with structures that process raw natural gas from the Jubilee oil field which is located along the Gulf of Guinea in the Atlantic Ocean. The entire system comprises a network of offshore pipelines between the Deepwater Tano and West Cape Three Points block in Ghana. The network consists of a 60 km offshore pipeline from the FPSO (Floating Production Storage and Offloading) Kwame Nkrumah to the Gas Processing Plant and a 111km onshore pipeline from the plant to the Aboadze Thermal Enclave.

The main products of the Atuabo Gas Processing Plant are lean gas for power generation, LP Gas and Natural Gas Condensate for local commercial and municipal consumption. (Anon, 2014a).

Liquefied Petroleum Gas from the processing plant is intended to meet national demand and to generate income for the nation whiles it eliminates periodic shortages of LPG in the country.

Currently there are few existing markets for condensate production here in Ghana, the condensate produced by the GPP is transported by trucks to Tema Oil Refinery (TOR), where it is processed to yield petroleum products like gasoline. Other industries depend on this condensate to fuel their boilers. A typical company in Ghana which uses condensate is Unilever Ghana limited for power generation. Unfortunately, the

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condensate production in Ghana, has limited market therefore its uses are not fully recognized to obtain maximum economic benefits to the nation. The research focus is on the quantitative analysis of the economic potential of further refining the natural gas condensate produced at the Atuabo Gas Processing plant as compared to the current practice of selling raw condensate.

1.2 Background

The Atuabo Gas Plant is a 150 MMSCFD capacity processing plant located at Atuabo in the Western Region of Ghana. The gas plant comprises of an Inlet separation, gas chilling/low temperature separation and de-ethanization, liquids fractionation, ethylene glycol injection and regeneration, instrument air and nitrogen systems, a heat medium system, flare and closed drain systems, plant wide electrical and control systems, and piping.

Natural gas produced offshore is transported through a 60km offshore gas pipeline to the processing plant which processes it to extract lean gas of methane (C1) and ethane (C2). The aforementioned products are transported through the 111km pipeline to Aboadze for power generation. The remaining feed is further processed to extract Liquefied Petroleum Gas (mainly Propane and Butane) and stabilized condensate. As stated earlier, the LPG is transferred to a loading gantry from where it is loaded into bulk road vehicles (BRVs) for distribution across the nation whereas, the raw condensate produced by the plant is currently sent to the local market for mixing with petroleum products. The raw gas condensate product is described as a liquid with API gravity ranging between 45 and 75 degrees. It is a light straw-colored liquid that resembles gasoline or kerosene, Gas condensates are liquids, generally straight chain alkanes in the C2 to C6+ range, which can condense from gas when the temperature and pressure drop sufficiently low. (Anon.,2016a).

Condensates have several trade and industry uses. They can be blended with crude oil to enhance the blend quality for further processing in refineries as it is being done currently at the Tema Oil Refinery (TOR). It can also be used for the dilution of bitumen. It can further be stripped into Naphtha, Pentane foamer, Iso-pentane, Natural benzene and Solvent for vegetable oil extraction for more revenue generation, thus the significance of this research. (Anon., 2010).

1.2.1 General Overview of Ghana Gas Processing Plant (General Processing Outline)

This section gives a detailed description of the Atuabo Gas Processing Plant here in Ghana. Raw gas from the Jubilee Field FPSO, via a transportation pipeline arrives at the Atuabo reception facilities at operation pressure of 130barg and operation temperature of 20 to 30°C. It passes the emergency shutdown valve which isolates the plant from incoming streams into inlet separators. A pig receiver package is provided for scraping the 12-inch raw gas transportation pipeline and for intelligent pig inspection. The composition of the feed gas stream into the processing plant as shown in Table 1.1.

Table 1.1 Composition of the feed gas into the Atuabo Gas Plant (Source: Field Data, GPP, 2014b)

Composition	**(mol%)**
C1	73.5651
C2	9.3245
C3	9.272
iC4	1.4629
nC4	2.9409
iC5	0.6944
nC5	0.589
C6	0.0871
C7	0
$N2_2$	0.7704
CO_2	1.1512
H_2O	0.00422
Benzene	0.0473
Toluene	0.0061
E-Benzene	0.0001
P-Xylene	0.0005
2-Mhexane	0.0072
Mcyclopentane	0.0585
Cyclohexane	0
Molecular Weight	23.09
Specific gravity	0.797
Viscosity, cP	0.096

The inlet gas is metered and transferred with a pressure drop to 109 barg and 15°C through a choke valve installed at the inlet of the separators. The gas stream is led into the three-phase inlet separators connected in parallel and then through the coalescer filters in order to remove liquids (hydrocarbons and water) and solids. The start-up fuel gas is taken off downstream of the filters. The remaining gas at 109 barg and 15°C splits in two streams and then is precooled by exchange with the low temperature gas and liquid hydrocarbons, as a result of the low temperature separation.

Lean glycol from the regeneration unit is injected upstream of the pre-coolers to avoid hydrate formation during the gas precooling and expansion through the Joule-Thompson (J-T) Valve. Prior to entering in J-T Valve, the streams from pre-coolers are combined into a single entity and is isenthalpic expanded under pressure control through J-T valve, from 109barg and 15°C to approximate 51barg pressure and -33,4°C temperature.

After expansion the gas-liquid mixture flows to the Low Temperature Separator where the liquids (hydrocarbons and rich glycol) are separated from the gas. The separated gas, after preheating is directed to the sales gas header. The condensate hydrocarbons are preheated against the feed gas and sent to the deethanizer, while the rich glycol is piped to the glycol regeneration unit.

Before the condensate hydrocarbons stream feeds the deethanizer column, it drops to a pressure of 33.5barg and is combined with the hydrocarbons coming from the inlet separators.

The deethanizer column operates at 33.5barg pressure and separates the condensate hydrocarbons into light ends (methane and ethane) in the tower overhead stream, and a propane plus liquid in the tower bottom stream. The deethanizer column overhead gas is partially taken off for internal fuel usage while the rest of the gas is compressed to 50.64barg and sent to the sales gas header.

The propane plus, from the bottom of deethanizer is directed to the fractionation system where, the liquids are fractionated in: Liquefied petroleum gas (LPG) in the tower overhead stream, condensate product and pentane fuel gas product for the plant's consumption.

Specifications for the products: sales gas, LPG and condensate are presented in the table 1.2:

Table 1.2Product Specification (Source: Field Data, GPP, Anon, 2014a)

Sales Gas	
Water Content	7 lbs/MMscf max
Hydrocarbon dew point	10°C max@50barg
Battery Limit Temperature: Operating/Minimum/Maximum	50°C /0°C /70°C
Battery Limit Pressure: Operating	
• Delivery Pressure at Atuabo Gas Plant	50 barg
• Arrival Pressure at pipeline tie-in at Takoradi Power Plant	40 barg
Wobbe Index	47÷52 MJ/m3
Higher Heating Value	1000 to 1150 BTU/scf
LPG	
RVP@37,8°C	Less than 9,5 kg/cm2
C1/C2 content	Less than 2% vol
C5+ content	Less than 2% vol
95% volume evaporated point	-2°C min, +2°C max
Condensate	
RPV @37°C	Less than 0,65 kgf/cm2
Density	Max 770 kg/m³
Initial boiling point	70°C max
Final boiling Point	110°C min, 190°C max

The sales gas is metered and exported using the 111 km (20-inch diameter) gas export pipeline from Atuabo to Aboadze Thermal Power Plant. Permanent pig launchers and receivers are installed at the start and respective termination points along the sales gas pipeline.

LPG from the fractionation system is directed to LPG Storage Tanks and is exported by pumps via a 2,5km pipeline to LPG truck-loading gantry, located at Anochie. Condensate from stripper is transferred to the Condensate Storage Tanks using pumps.

1.2.2 Process Overview

The Atuabo gas plant has its systems classified under main plant and utilities systems.The main plant systems include:

- System 01: Reception Facilities.
- System 10: Inlet Separation and Fuel Gas Conditioning.
- System 20: Gas chilling/Hydrocarbon Dew Point Control and De ethanization.
- System 30: NGLs Fractionation
- System 40: Glycol Injection and regeneration.

The utilities systems of processing plant are:

- System 42: LPG and Condensate Storage Tanks
- System 50: Instrument air and Nitrogen.
- System 60: Heat Medium system.
- System 70: Flare and Closed Drain.
- System 71: Waste Water Treatment.
- System 72: Service and Potable Water.
- System 73: Fire Fighting System.
- System 74: Drainage System.
- System 75: Cooling System for LPG.
- System 76: Water Intake.
- System 81: Electrical System.
- System 82: Power Generator.
- System 83: Switchgear, Transformers and UPS.
- System 84: Telecommunication System.
- System 85.1: Process Control and Safeguarding (part 1).
- System 85.2: Process Control and Safeguarding (part 2).
- System 85.3: Field Instruments.
- System 91: Testing Apparatus and Analyzers Laboratory.
- System 92: Interconnection.
- System 93: HVAC

1.2.3 Reception Facilities

The purpose of the reception system is to allow depressurization of the raw gas transportation pipeline from Jubilee Field FPSO in case of emergency shutdown. Other functions are also to receive the operation or intelligent pigs and to measure and monitor the amount of raw gas flowing into the processing plant.

System Description

The reception facilities at Atuabo, are designed to receive 150mmscf/d feed gas through 12” transportation line from Kwame Nkrumah FPSO which process Oil and Associated Gas from Jubilee Fields and comprises of three parts: safety system of the raw gas transportation pipeline, pig receiver skid used periodically for scraping or inspection of the transportation pipeline and raw gas measurement and monitoring system.

Raw gas from 12” transportation pipeline arrives at the reception facilities in dense phase at operation pressure of 130 to 207barg (design pressure is 238 barg) and operation temperature of 20℃ to 30℃ (design temperature is 0℃ to 70℃).

In case of overpressure, leakage or fire the emergency shutdown valve installed upstream of the barred tee isolates the 12” gas transportation pipeline towards the gas processing facilities. For offshore pipeline depressurization, a 6” line with manual relief valves are installed at the point of upstream of the ESDV and the relief gas will be sent to high pressure flare header.

To equalize the pressure around the ESDV prior to opening, a 2” bypass line with one automatic shutoff valve and one manual choke valve, is installed. The bypass line starts upstream of the ESDV.

Pig receiver package is provided for pigging operation of the 12” offshore/onshore gas transportation line. The receiver vessel is connected in parallel to the gas pipeline. The pig uses the pipeline’s normal operating pressure and without interrupting the flow or stopping production.

The reception facilities are connected to the HP flare system, vent and drain system with hard piping. Venting gas goes to HP Flare header, and waste water goes to HP Closed Drain header.

Before the gas stream goes to the downstream inlet separator for gas/liquid separation, the flow is metered and monitored.

1.2.4 Inlet Separation and Fuel Gas Conditioning

Inlet separation facilities are installed to separate liquids and remove solid contaminants from the inlet gas stream before being sent for further gas chilling and fractionation.

System Description

The inlet gas leaves the reception facilities at operating pressure of 128barg and temperature of 20℃ to 30℃. The gas stream splits and takes a pressure drop to 110barg through choke valves prior to entering in two 75% three-phase separators connected in parallel.

To avoid the hydrate formation, during the gas expansion through the choke valves, methanol is injected upstream of the valves. The methanol can be directed to any point of hydrate formation.

Separated liquid hydrocarbon flows from the inlet separator, under level control and then is directed to Deethanizer Tower. Any free water present in the inlet fluids is collected in the separator boot and is sent out under interface level control and then directed to the produced water treatment system.

The pressure in the separators is controlled by a pressure controller and pressure control valve.

The gas outlets from the separators are mixed together in a common line and then flows to two 100% capacity coalescing filters, to remove solid and liquid contaminants particles larger than

≥ 1 micron from the inlet gas stream, before being sent for further gas chilling and fractionation.

The gas passes through a tube sheet and the filter elements in the vessel where finer particulates are removed. Liquids in the both sections of the filters are discharged to the Deethanizer section via on/off level controllers.

Conditioned gas is led out of the top of the filters, the streams are mixed and then the flow is partially taken-off for the start-up fuel purposes and the remaining gas, at the operating pressure of 109barg and temperature 15°C is directed to the Gas Chilling System.

1.2.5 Gas chilling/Hydrocarbon Dew Point Control and Deethanization

The purpose of this system is to remove water and hydrocarbons (C3+) from the gas stream coming from inlet separation facilities, at a level to meet the sales gas specifications: water content of maximum 7 lbs/MMscf and hydrocarbon dew point of 10°C max at 50bar.

System Description

The gas from the inlet separation and filtration section of the plant splits and then passes through a Gas/Gas Exchanger and a Gas/Liquid Exchanger. After coming out from the exchangers, the gas recombines at a temperature of -10 ºC and then flows through a JT valve, undergoing isenthalpic expansion to 51barg and approximately -33,5 ºC. Hydrate formation is prevented by the injection of an 80% / 20% (w/w) ethylene glycol solution onto the tubesheet faces

The gas, condensed hydrocarbons and rich glycol solution enter a three-phase Low Temperature Separator where the separated liquid hydrocarbons flow under level control to the shell side of the Gas/Liquids Exchanger and then to the Deethanizer Column for further separation.

The aqueous phase (rich ethylene glycol) is collected in the boot of the separator and is sent out, under interface level controllers to the glycol regeneration system. The pressure in the Low Temperature Separator and shell faces of the Gas/Gas Exchanger is controlled by J-T valve. The gas stream from the low temperature separator is returned into the shell of the gas/gas exchanger, heated to 13 ºC before passing to the Export gas metering station, and then with a pressure of 50barg flows to the export pipeline.

The Deethanizer Column is fed on the top and removes hydrocarbons lighter than propane. The Deethanizer Column is heated with a reboiler using heat medium from the plant hot oil. The Deethanizer bottoms product purity is controlled by reboiler outlet temperature and the deethanizer is held at a constant pressure using a pressure control valve on the outlet gas stream. The C3+ bottoms product at 110ºC exits the column under level control and feeds the Debutanizer Column, T-300 for further separation. The overhead gas from the deethanizer flows to a Deethanizer Overheads Compressor Suction Scrubber and then to a Deethanizer Overheads Compressor, where it is compressed to meet the sales gas pipeline pressure of 50 barg. The compressed overheads gas is led through Sales Gas Metering Package to the Gas Export Pipeline along with gas separated in the LTS and warmed.

1.2.6 NGLs Fractionation

The purpose of the NGL Fractionation System (30) is to split the NGL from Deethanizer bottoms into the LPG (propane+butane) and Condensate (C6+) to meet the specifications of RVP@37,8°C less than 9,5 kg/cm2 and respectively RPV @37°C less than 0,65 kgf/cm2. Pentane vapours result as secondary product and are used as fuel gas for internal needs of the plant.

System Description

The bottoms stream from Deethanizer Tower is routed under level control to the Debutanizer Tower, which fractionates to produce overheads LPG product to meet specifications.

The debutanizer bottoms product contains too much pentane to meet the RVP specification for condensate, so the stream flows to pentane Pentane Stripper where the pentane is stripped, such that Pentane Stripper bottoms product will meet the condensate RVP specification. The pentane vapours resulted from Pentane Stripper overhead, are sent to the fuel gas system.

The Debutanizer Tower operates at approximately 18barg at a bottoms temperature of 160 ºC. The debutanizer is reboiled with the debutanizer reboiler using heat medium from the plant hot oil, at the temperature of 270 ºC.

The reflux system enhances overhead product purity and is provided by the debutanizer reflux condenser, debutanizer reflux drum and debutanizer reflux pumps. The remainder of the condensed liquid is additionally cooled to 49ºC in LPG cooler and flows to the LPG storage.

The bottoms stream flows under level control to the pentanes stripper column. The pentane stripper overheads vapour stream is partially condensed at 85ºC by pentane cooler and flows to the debutanizer reflux drum. Approximately 10 m3/h of condensed liquid is refluxed to the top and the net vapour flows to the fuel gas system under pressure control.

The pentane stripper operates at approximately 4barg at a bottoms temperature of 116 ºC and strips sufficient pentanes from the condensate to reduce its RVP to less than 0.65 bar (abs). The pentane stripper is reboiled by the pentane stripper reboiler.

The overheads vapour stream from the stripper is partially condensed through the pentane product cooler and collected in the pentane stripper reflux drum. The liquid is refluxed under level control to the stripper, using stripper reflux pumps while the pentane vapours from the reflux drum, are heated to a temperature of 84 ºC using a pentane fuel gas heater (electrical heater). It is then directed as a gas fuel to the heat oil medium system.

The bottoms stream from the pentane stripper is cooled to a temperature of 50 ºC in the condensate product cooler and flows under level control to the condensate storage capacities.

Glycol Injection and regeneration

This system provides Ethylene Glycol (EG) injection to absorb water and control hydrate formation in the gas cooling system associated with regeneration of the Rich EG recovered from the LTS system.

System Description

The Lean Glycol solution, 80% / 20% (w/w) is continuously injected at a pressure of 110barg onto the Gas/Gas Exchanger and Gas/Liquid Exchanger tubesheet faces to prevent hydrate formation along the cooling system and J-T valve. The EG is contacted with the gas using spray nozzles.

The injected glycol physically absorbs any water present in the gas and becomes rich in water, with an EG concentration of approximately 70 % (weight).

The mixture of rich glycol, hydrocarbon gas and liquids then passes through a J-T expansion valve and flashes to a temperature of -33. 5°C into the Low Temperature Separator to separate the gas, condensate, and glycol−water phases.

Overhead gas from the Low Temperature Separator, passes through the Gas/Gas Exchanger before being combined with the Deethanizer overhead and sent into the sales gas header. The LTS is controlled to maintain the proper dew point of the blended outlet gas. The C3+ condensate from the stabilizer is warmed through the Gas/Liquid Exchanger and then goes to the Deethanizer for further separation.

The aqueous phase (Rich EG) is collected in the boot of the Low Temperature Separator and is sent out under interface level controls to the glycol regenerator skid where the glycol is preheated by flowing through the glycol distillation column, the reflux coil and the surge tank coil. It is then flashed into the glycol flash drum at 3.8 barg pressure.

The flashed gas is directed under pressure control, to the flare system. The rich glycol from the flash drum, is evacuated under level control and filtered in the glycol particulate filter and glycol charcoal filter. It is then sent to the glycol regenerator for water separation using distillation principles.

The reflux in the glycol distillation column is generated by condensing of the vapours that rises to the top of the column, through the heat exchange with cold rich glycol coming from LTS, in the reflux coil. Reboiling heat in the distillation column is provided by the glycol regenerator tube bundle, which uses hot oil medium flowing through a two-pass tube. The reboiler temperature is controlled and at set at 121°C.

Lean glycol exits the regenerator and is further cooled with finned pipes. The lean glycol is then pumped to a pressure of 110barg with the glycol pumps and then sent to the lean glycol header for injection.

1.3 Condensate Processing at Atuabo Gas Plant

The processes, systems and equipment deployed at the Atuabo gas plant for condensate production are outlined in the sections below; it involves the separation of condensate from the raw natural Gas feed.

1.3.1 Separation of Condensate from Raw natural feed

The raw natural gas feed initially goes through a water knockout vessel to remove water. The remaining mixture is mixed with glycol, precooled and passed through a J-T expansion valve before it finally moves into to a Low Temperature Separator (LTS), where the gas is chilled to condense the heavier hydrocarbons at -33°C. At this point, acid gases and other impurities are removed. The purpose of glycol introduction into the system is to dehydrate the gas to prevent freezing.

The heavier hydrocarbons which make up the condensate is sent to the condensate stabilizer for removal of the remaining light ends. The condensate from the stabilizer then goes into product storage tanks for use. The remaining gas stream with the lighter ends passes through a series of de-ethanizer, de-propanizer and de-butanizer sections to strip off and recover ethane, propane and butane respectively for further usage.

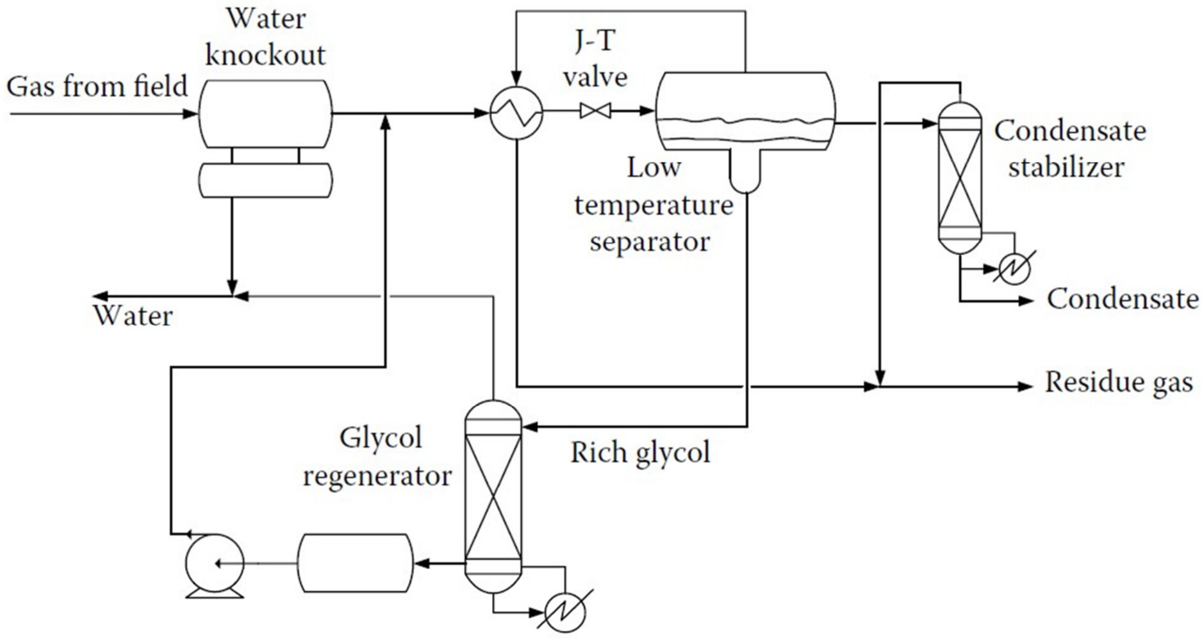

Figure 1.1 Condensate Recovery Process (Source: GPP, 2014)

1.3.2 Condensate Storage Tank

The stabilized condensate leaving the fractionating area of the gas plant is stored in floating roof tanks for onward transport by tanker trucks to consumers. The purpose for the condensate storage tanks is to store the stabilized condensate. The condensate is then loaded into trucks and transported to consumers periodically.

General Description

The processed condensate from the condensate product cooler flows into two storage tanks. The design filling rate for each tank is the flow rate of the condensate from the cooler. Since the Reid vapour pressure at 37.8oC of the stabilized condensate is 65.5kPa, no flashing occurs when the storage tanks are being filled. The filling is not done parallel but sequentially. Once a tank is filled to the maximum operating level, the operators switch to another tank by operating the manual inlet valve. The valve interlock system automatically set the valves when the second tank is selected for filling after the first is full. The interlock system prevents all the valves form being closed at the same time.

Detailed Description

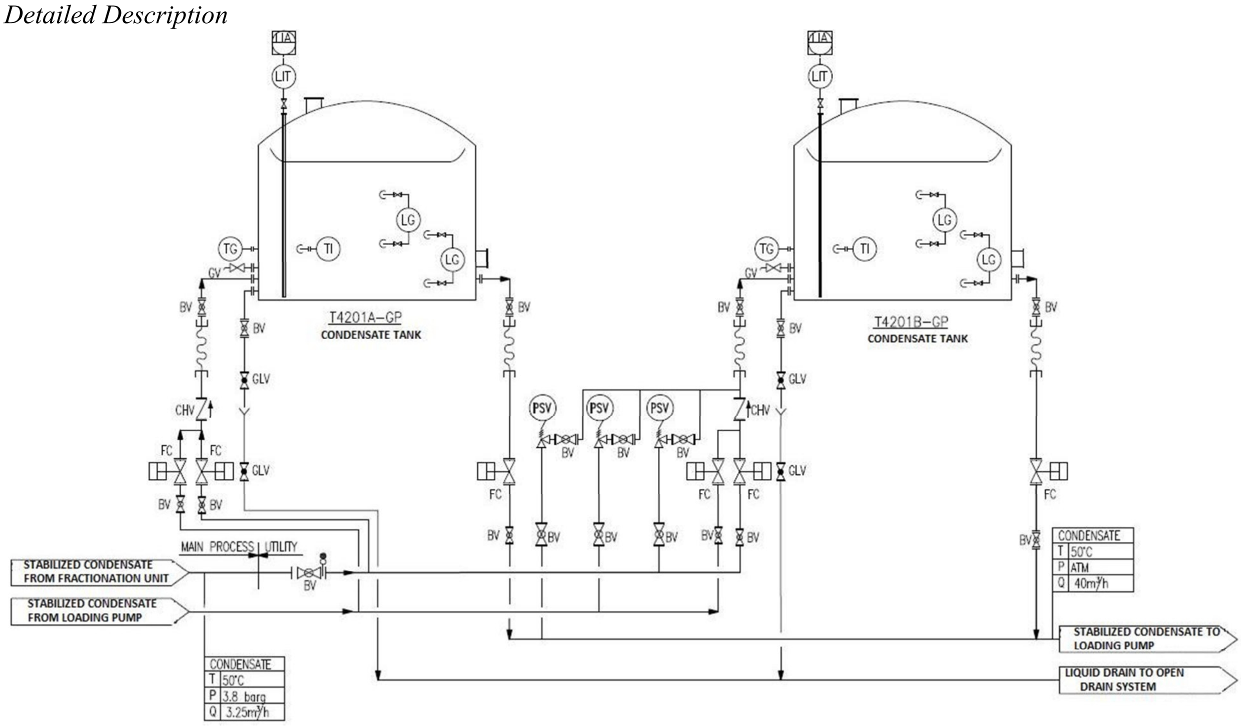

Figure 1.2 Condensate Tanks System

Condensates are stored in two internal floating roof storage tanks, each with a nominal capacity of 500 m^3. There are fire dikes outside of the two tanks.

Each tank has the following characteristics:

- Tank type: Internal floating roof
- Tank capacity: 500 m3
- Height: 10400mm
- Internal Diameter: 8200mm
- Maximum design pressure: ATM
- Minimum design pressure: ATM
- Normal operating pressure during filling: ATM
- Normal operating pressure during loading: ATM
- Design Temperature: 48.89oC
- Operating Temperature: 48.89oC
- Liquid Levels

The tanks are operated at a constant atmospheric pressure since they are floating roof. This design does not require overpressure and vacuum protection. Each tank is provided with a series of bottom water drains to avoid the accumulation of water at the tanks bottoms. No vapour is produced in the tank since condensates are stabilized. However, each tank is provided with vent to avoid the formation of vapour. To prevent sending water to offloading tankers, the operators should check whether there is water at the bottom of the tanks, using the valves at the bottom of the tanks. Each tank is provided with a sample connection point that allows operators to take samples for analysis in the laboratory. Liquid pressure safety valves with set point of 16 barg are installed to protect the pipe from overpressure due to thermal expansion when the pipe is blocked between two isolation valves. There are also level gauges and temperature indicators fitted on the tanks.

1.3.3 Condensate Loading Pumps

Two (one spare) condensate loading pumps, each having a capacity of 40 m3/h are installed east of the tanks. The pump elevation is lower than the tanks. This is required to give sufficient NPSH to ensure proper pump operation. When the pumps are stopped, they are isolated from the tanks by means of valves at the pump inlets.

If an operation requires that condensate be transferred from one tank to another, loading pumps are used for this service as well. They therefore serve as loading pumps and inter-tank transfer pumps, control system as well as valves interlock will allow this. Each pump is provided with a minimum flow recirculation line to protect the pump in case of too low operating flow. This minimum recirculation line is particularly useful during transient operation such as pump start up, pump alignment during loading rate ramp up and ramp down, pump shut down. Water should be removed from the inlet of the pumps, using the water drain valve. The operators shall check that no water is accumulated at the inlet of the pumps. At the discharge line of the pump is installed a check valve to prevent backflow of fluid into the pump. There are also connections to recycle the fluid into the tanks since the pumps also serve as inter tank transfer pumps. Condensate flow from the condensate pumps to the loading arm.

Pump parameters: Capacity: 40m3/h Head: 46m
Shaft Power: 7.03kW
Motor Power: 11.6 kW

Condensate Metering and loading

Condensate being transferred into trucks is metered using a loading meter. During loading, the arm is positioned on the tanker topside and the loading pumps are activated to push the condensate into the tanker truck. The transport tankers have holding capacities ranging from 20,000 to 27,000 kg.

1.3.4 Facilities Deficient at the Atuabo Gas Plant

For condensates to be stripped or fractionated to obtain products such as, among others, it needs to be done using a Condensate Fractionation Unit (CFU) which is currently not available at the Ghana Gas Facility, in Atuabo.

Currently, the Gas Processing plant receives an average of 109.389 metric tonnes of raw natural gas condensate from the Jubilee field daily. This tonnage translates to 39927.01 metric tonnes annually, they also sell the raw condensate for an average of 2.00 Ghana cedis (Ghc) per kilogram (equivalent to US $ 500.00 per metric ton) and this generates an average revenue of US $15039613.15.

1.4 Problem Statement

Currently in Ghana, the raw gas condensates produced by the GPP is mainly sold to some industries to fuel their boilers and to generate electrical power which is sold at US $ 500 per metric ton. Comparing it to the global market prices of condensate fractionation products that is, Iso- Pentane used as industrial solvent and cosmetic constituent which is sold at an average price of US $ 1000 per ton, Natural benzene for manufacturing synthetic fibers, pesticides, plastics etc. which is sold for US $733-$ 751 /metric ton, GNGC's revenue from the resource is comparatively minimal.

It is obvious that the economic potential of condensate has not been fully exploited in the country. With the commencement of production from the new Tweneboa-Enyenra-Ntomme (TEN) oil field, there are plans to develop and tie-in more wells to the Atuabo GPP by Tullow Oil Plc and Ghana National Gas Company (Anon., 2016b). This will yield more natural gas which in turn translate into increased production of natural gas liquids like LPGs and Condensates, hence an imminent abundance of the resource in the country. In this regard, there is a need to optimize revenue generation from the soon to be abundant resource. Hence, the research topic which seeks to address or investigate the expansion of the Atuabo Gas Plant to facilitate condensate fractionation as a means of maximizing GNGC'S economic benefits from the natural gas condensate resource.

1.5 Research Objective

The main objective of this work was to analyze or investigate the current condensate production by Atuabo Gas Processing Plant and assess the economic viability of expanding the existing Atuabo Gas Processing Plant to facilitate the fractionation of raw condensate (which is currently being sold for limited industrial use) into specific products.

1.5.1 Specific Objectives

- To examine the range of condensate by-products and their industrial applications
- To propose a suitable fractionation design schematic for the fractionation of condensate at Atuabo.
- To undertake an economic cost benefit analysis of the proposed expansion of the Atuabo plant using the NPV method.
- To conduct an analysis of the project model to determine its sensitivity to operating parameters.

LITERATURE REVIEW

2.1 Introduction

As stated in the previous chapter, condensate is a Natural Gas Liquid (NGL) which has several trade and industrial uses. It can be used to make plastics. The International Energy Agency (IEA) carried out a survey for natural gas liquids (NGLs) especially on condensates, between 2008 and 2015 and stated that gas condensates are normally blended into other crude oil to enhance the quality of the blend for refiners, this form of condensate is known as spiked condensate. It can also be fractionated into naphtha, gasoline and other petroleum products in a process known as condensate splitting (Al-Mutairi and Elkawad H., 2013). Petrochemical and other industrial facilities use the condensate for fueling their boilers. Condensate is also used for the dilution of bitumen, a technology that facilitates the pipeline transportation of highly viscous oils. Also, products such as Naphtha, Pentane foamer, Iso-pentane, Natural benzene and Solvent for vegetable oils extraction can be produced from condensate. All these would be described extensively in this chapter.

Condensate is derived solely from natural gas production but can also be obtained from natural gas fractionation; the process where the raw gas is stripped into various hydrocarbon components such as CH4, C3H8, C4H10 and the heavier components (C6+). Generally, at least 50% of a condensate stream can be distilled into naphtha, with the balanced combination of kerosene and distillate. Condensates have been proven to possess useful commercial properties. Studies of condensate applications have been identified.

Condensate is being produced in Ghana by the Atuabo Gas Processing Plant, with an average production of 130m3/d, provided the plant obtains a feed of 110mmSCF/d of raw natural gas from the Jubilee oil field. The condensate is then transported by Trucks and used by industries for heating boilers or for further processing into other petroleum products by the Tema Oil Refinery (TOR).

2.2 Concepts and Theory

Condensate is a light straw-coloured liquid that resembles gasoline or kerosene. It has an American Petroleum Institute (API) gravity of 50° or higher and a specific gravity ranging from 0.5 to 0.8. It is primarily composed of heavier hydrocarbons such as pentane (C5H12), hexane (C6H14), heptane (C7H16), octane (C8H18), etc. Hydrocarbons are organic compounds containing only carbon and hydrogen (Anon., 2016a). It can condense when temperatures and pressures drop sufficiently low and is normally stabilized by the removal of unnecessary impurities such as hydrogen sulfide, mercaptan, and carbon dioxide. Condensate has a mass density of 690kg/m3 and a viscosity of 0.45. Its Reid vapour pressure at 37.8°C is 65.5 Kpa (Pyzuir, 2015).

Condensates can be either recovered from gas processing plants, after being processed from raw natural gas or from oil and gas field wells. Condensate recovered at field level is known as field or lease condensate whereas that recovered from gas processing plants is commonly referred to as plant condensate. Regardless of the source of condensate (Lease or Plant), the uses and applications are the same (Pyziur, 2015). The table 2.1

below shows the composition of the condensate.

Table 2.1 Composition/Information on Condensate (Source; EP Energy, 2014)

Components	Weight%(1)	CAS No.
Propane	20-60	74-98-6
Ethane	1-60	74-84-0
n-Pentane	5-25	109-66-0
n-Hexane	2-13	110-54-3
Heptane	1-10	142-82-5
Octane	1-10	111-65-9
n-Butane	2-5	106-97-8
Cyclohexane	1-5	110-82-7
Toluene	0.1-5	108-88-3
Ethyl benzene	0.1-5	100-41-4
Xylenes	0.1-5	1330-20-7
Benzene	0-2	71-43-2
Hydrogen Sulfide	Varies	7783-06-4

Note: It is out of these components combination that the by- products are generated with the help of additives and under very high pressures and temperatures.

2.3 Related Literature Review

In a paper presented by Quarm M. et al. (2012), at GNPC, it was mentioned that as early as 1896, wells were drilled in and around Half-Assini as a result of oil seeps found onshore Tano basin. Today one can still see some of these seeps at Bokakere. Between 1978 and 1985 oil was produced from the Saltpond field. A number of oil, oil/gas and gas fields have been found in the Tano basin. In all eighty-nine (89) wells have been drilled in the country. Six (6) discoveries have been made and also 75% of 50 exploratory wells have been drilled successfully with varying degrees of hydrocarbons. This report from GNPC confirms the fact that Ghana has indeed the changes of gaining much income from its oil and gas exploration.

In a report submitted by Pyziur (2015), he stated that, condensates have several economic potentials, emphasising that, they can be blended with crude oil to enhance the blend quality for further processing in refineries. It can also be fractionated into naphtha in a process known as condensate splitting. Condensate can be used for the dilution of bitumen and heavy crudes, and also as a petrochemical feedstock for steam crackers and boilers. According to the same report by Pyziur (2015), the United States (US) was considering an alternative to build condensate splitters to produce more light products such as gasoline. This move was to ease up the stress on the existing refining towers as condensate production had increased. As of now, the US has one dedicated 75MB/d condensate splitter located in Port Arthur, Texas to handle the current load.

In another report submitted by Begum D.A et al, 2010, a simulation was conducted on condensates, aimed at underscoring the value of three products; naphtha, kerosene and diesel after processing it in a fractionation column, using natural gas condensate as the column feed. In the report, various design specifications were incorporated to access the quality of the three products.

This indicated that condensates thus; have extensive uses and if properly and efficiently harnessed in Ghana, could do the nation a whole lot as it prepares to tie in further wells for mass gas production. Hence, the proposal of this work is aimed at the evaluation of the potential of condensate production in the country.

2.3.1 Methods of condensate fractionation

According to Pyziur (2015), he mentioned that in refining scenarios condensate can be transformed not only by full-fledged refineries, but also by a type of facility known as acondensate splitter. While akin to an oil refinery in its premise, the technologies in a condensate splitter are simpler involving only atmospheric distillation. And therefore they can be constructed more quickly and at considerably less cost than conventional refineries when compared on a barrels-per-day processing metric. He further stated that, the fully- fledged refineries are for fractionation condensate to Nathpta, Gasoline, Kerosene and Diesel, this is synonymous, to the current practice in Ghana, which is blending with crude oil to enhance the blend quality for further processing in refineries as it being done currently at the Tema Oil Refinery (TOR). Expanding a refinery to improve its capacity and economic gains is not an outlandish project in Ghana. The Residual Fluid Catalytic Cracking (RFCC) Unit of the Tema Oil Refinery (TOR) was constructed as an expansion to enable the refinery further process crude oil atmospheric distillation residue which was then being sold to industries to be used as boiler feed and other menial purposes. The facility fractionates the residue into LPG, naphtha, gasoline etc. hence significantly improving the profit margin and becoming the highest earning facility in TOR. Thus the proposal of this research study is to expand the current Atuabo plant with a fractionation unit to extract the by-products stated previously.

2.3.2 Existing Condensate fractionation units around the globe

The global market for natural gas condensates has grown significantly over the years, especially with increasing production from the resource from the condensate rich tight reserves of America, Iran's reserves and that of many other countries. This has forced countries like Iran, Qatar, Bangladesh, America etc. to move into condensate refining to improve their economic benefits as well as its relevance in the manufacturing industry.

According to Pyziur (2015), he compared the domestic utilization of condensate in the US and its exportation abroad. He also pointed out its economic and political importance as well as its market dynamics in terms of condensate production in the US. From his report, condensate traded at an average premium of $2.50/bbl above the price of WTI Crude when the prompt month Mont Belvieu Natural Gasoline contract as a proxy for condensate prices was taken into consideration. In 2012 however, a discount of $3.70 was averaged to WTI's condensate which only increased it value as compared to the initial value. Then in 2014, the discount went to a

$9.60 value, and an $8.60 averaged discount in January 2015. This means that refining condensate into its premium by-product can increase its economic value with time in the world market. He also stated that ten percent (10%) of Gas refineries in the United States of America could be repositioned to further process condensate without reconfiguring the entire refinery by building condensate splitters to cut down capital expenditure as done at the Kinder Morgan Facility.

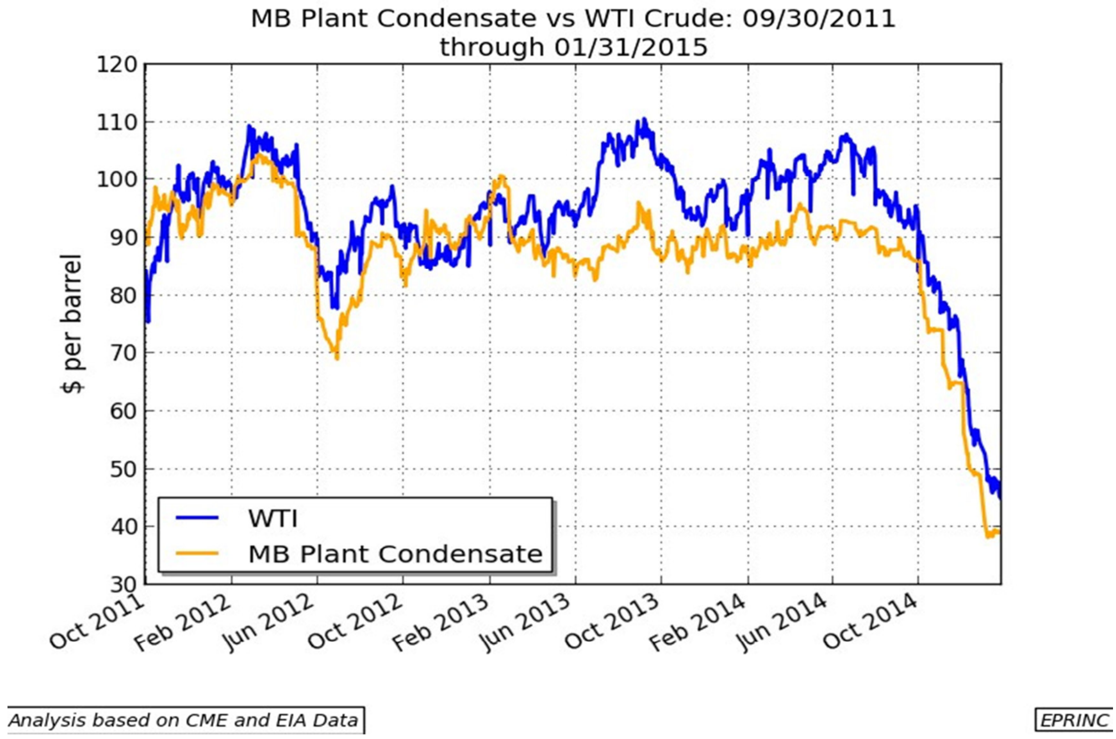

Figure 2.1 Comparison of plant condensate and crude prices (Source; Pyziur (2015)

Kinder Morgan (KM) has constructed a petroleum condensate processing facility located around its Galena Park terminal on the Houston Ship Channel. The approximately $360 million project, which is supported by a long-term fee-based agreement with BP North America consists of two units which split condensate into its various components, such as light and heavy naphtha, kerosene, diesel and gas oil. It has access to feedstock from the Kinder Morgan Crude and Condensate (KMCC) pipeline through a terminal called Pasadena. The facility can be further expanded to meet large markets. The facility includes 1.9MBbls of new tankage on 60 acres within KM's Galena Park Terminal with a total capacity of 100,000 barrels per day (bpd) its design provides possibility for a third unit to increase total capacity to 150MBbl/d.

According to Begum D.A et al, (2010) the total gas condensate production rate in Bangladesh is 6725.5 BBLD, the publication highlighted a variety of useful products that can be produced by refining condensate thus the establishment of new refineries. With the given specification of raw material, a proper process is required to get the desired products but in many cases the required information for designing a process is not readily available. To obtain prior data before implantation of the plant, simulation is a standard and reliable tool. Distillation column is used for the separation of different fraction of condensate. The heavy part of the condensate is used as diesel whereas the lighter parts are divided into different fractions for different uses, hence this configuration is tailored to produce diesel, kerosene and liquefied petroleum gas.

In China, Sinopec International Petroleum Service also with an annual feed of about 40000 metric tonnes of condensate operates a refinery for the fractionation of raw condensate. Sinopec has a plant that was designed specifically for an annual processing capacity of 25,000 tonnes per annum of condensate. The fractionation unit is designed to separate condensate into petrochemical products like pentane foamer, isopentane, solvent oil and natural benzene, which is a major objective of this research study. The process, configuration and schematic diagram of Sinopec International Petroleum Service is well explained below.

2.4 Condensate Fractionation Unit

Presently this type of Condensate Fractionation Unit is being used in China by the Sinopec Company to maximize their economic income. This unit is simpler to construct because it involves only atmospheric distillation towers and considerably less cost is involved in the setup. The condensate Fractionation unit is made up of sets of distillation towers, which have bottom pumps, reboilers, reflux pumps, reflux drums and air coolers. Here, the bottom reboiler utilizes heat transfer fluid to provide the process heat duty required for the fractionation process. The heat transfer fluid flows through the reboiler shell side to provide process reboiling duty for the tower. The bottom product is sent to the next tower for further fractionation and distillation. Figure 2.1 below is a typical example of a Condensate Fractionation Unit.

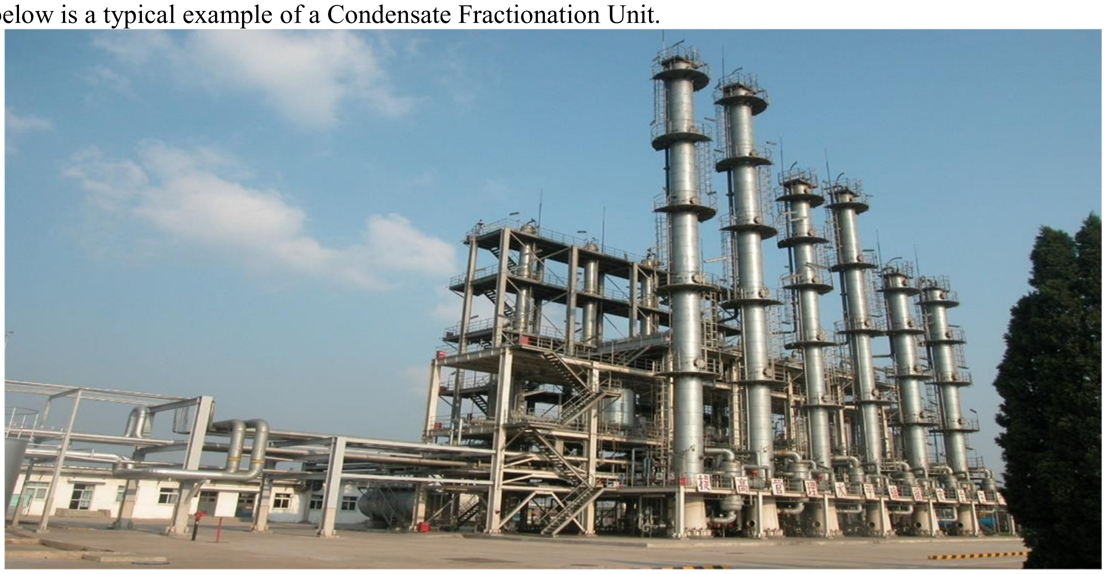

Figure 2.2 Condensate Fractionation Unit (CFU), (Source: Sinopec-China, 2014)

2.5 Condensate Fractionation Process Description

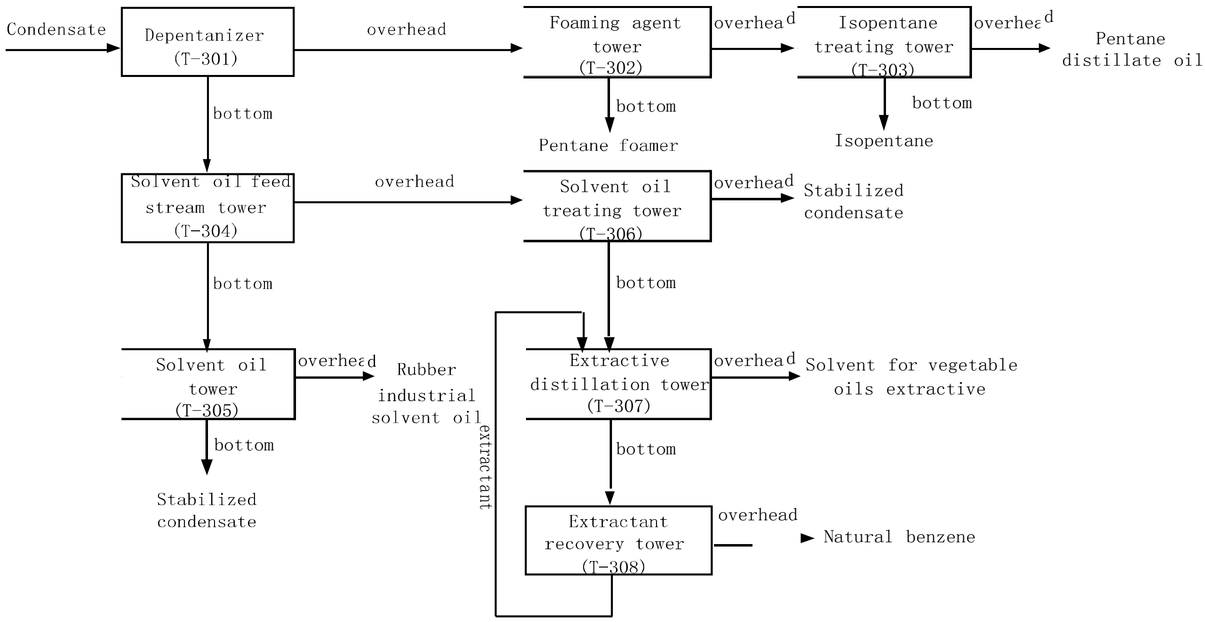

Figure 2.3 Flow chart for CFU process (Sinopec, China)

The condensate stream is passed through a depentanizer column (T-301) where pentane, C5 is stripped off and the remaining carbons, C6 and C6+which are distilled at the bottom are directed to a solvent feed stream tower (T-304). The C5 then goes into a foaming agent tower (T-302), where pentane foamer, one of the main by-products, is distilled at the bottom. The overhead product from T-302 then goes to an isopentane treating tower (T-303) where isopentane, another important by-product, is distilled at the bottom. The overhead from T-303 yields pentane distillate oil.

At T-304, the overhead distillate product which is C6 is treated in a solvent oil treating tower (T-306). Stabilized condensate is recovered at the overhead of T-306. The bottom distillate product is however sent to an extractive distillation tower (T-307), where a by-product, solvent for vegetable oils extraction is distilled at the overhead. The bottom distillate product from T- 307 is sent to an extractant recovery tower (T-308) where another by-product, natural benzene is distilled at the overhead.

At T-304 again, the bottom distillate product, C6+ is sent to a solvent oil tower (T-305) where the final important by-product, rubber industrial solvent oil is recovered as the overhead distillate product. The bottoms product however is stabilized condensate. Figure 2.2 below a process flow diagram for the CFU respectively.

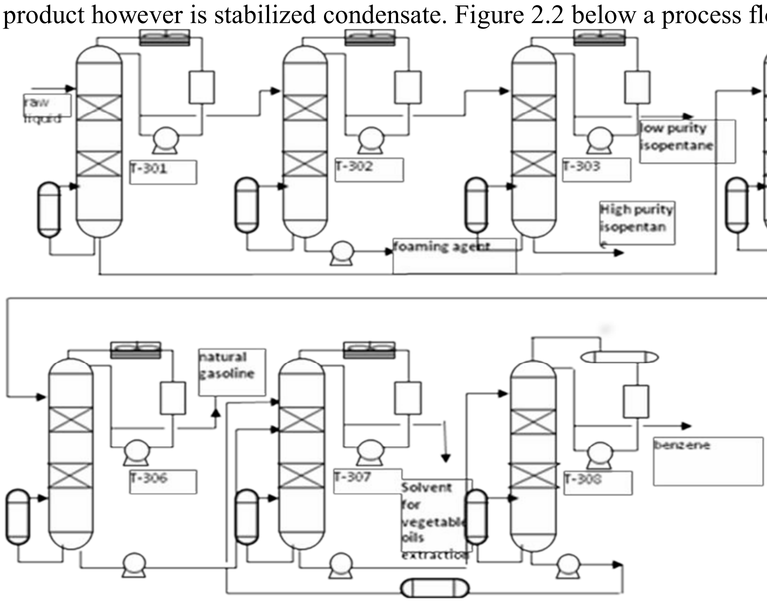

Figure 2.4 Process Schematic Flow Diagram (Source: Sinopec China, 2014).

2.6 Potential Applications and By- Products of condensate

As stated in the previous sections condensate can be fractionated into other by-products such as gasoline, pentane foamer, iso-pentane, naphtha, natural benzene and solvent for vegetable oils extraction. According to an article written for the International Council on Clean Transportation (ICCT), in 2014, it emphasized that the main economic objective in fractionating or refining any raw product is to maximize the value added in converting it into other finished products. The table below shows the current global market price obtained for the sale of raw condensates as compared to the sale of the refined product.

Table 2.2 Market value of raw condensate and its products, (Source: EIA, 2016)

Product	Condensate	Iso- Pentane	Solvent for vegetable oils extraction	Rubber industrial solvent oil	Natural Benzene
Price($/Ton)	750.97	1081.39	1201.54	1246.60	1126.45

Production data from Sinopec International Petroleum Service (contractors for the construction of the Atuabo GPP) shows that the percentage of individual condensate products indicated in the chart below can be obtained from raw condensate fractionation.

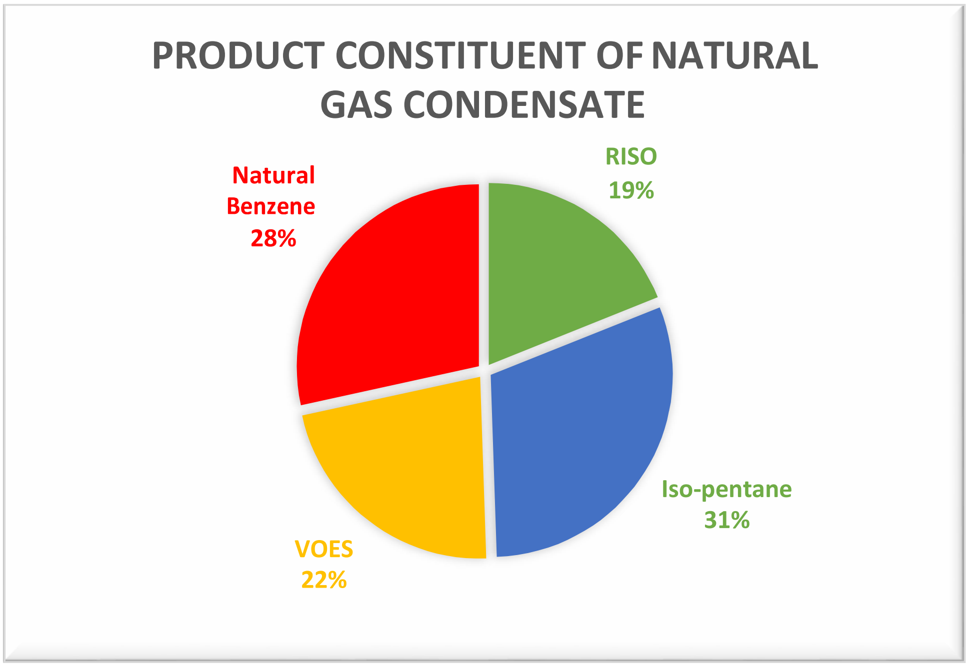

Figure 2.5 Product percentage constituent of natural gas

A brief description of the uses and specifications of the various by-products are elaborated below.

2.6.1 Natural Benzene

According to a report by Southwell, S.E. 2010, he stated that in 2013, China was the country which consumed benzene the most, followed by the United States of America, due to its wide range of uses. Benzene is a sweet-smelling, clear liquid with hydrocarbon formula of C6H6 structured in a ring form'. It is a natural component of petroleum, and is used as an additive in gasoline for its anti-knock properties. It is found in crude oil as well. The molecules of benzene which comprises of six carbon atoms, is part of the hydrocarbon family or compounds and is mostly called aromatic because of the pleasant odour.

Uses

- Natural Benzene is also widely used in industry, as one of the top 20 chemicals produced.
- It is used to manufacture or make synthetic fibers, pesticides, lubricants, drugs, plastics, detergents, resins, rubber and dyes.

Aside condensates, benzene can found in products like vinyl thinner, inks and ink markers, lacquer thinner hydraulic fluids, kerosene, gasoline, glues adhesives, asphalts, calibrating fluid and solvents. Figures 2.4 and 2.5 show pictures of some uses of benzene.

Figure 2.6 Cleaning agent produced from Benzene

Figure 2.7 Gamma Benzene Hexa-chloride

2.6.2 Iso-Pentane

Iso-pentane as a by-product of condensate is commonly used together with liquid nitrogen to get a liquid bath temperature of 160°C. It is just one percent or less a natural gas. It has five carbon atoms with a branched chain alkene and called 2- methyl -butane with a chemical formula of C5H12. Iso-pentane is a liquid that is extremely volatile and flammable at room pressure and temperature. It is also colourless and odorless in nature. This product would readily boil and vaporize on a hot and warm day because of its boiling point which is slightly above the room temperature.

It can be absorbed into the body by inhalation and ingestion and may explode on heating. The vapour is heavier than air and may travel along the ground, making the probability of distant ignition possible. As a result of flow and agitation, electrostatic charges can be generated. The figure 2.5 below is an end product of Iso Pentane.

Uses

- Iso- pentane is typically used as a blowing agent in some industries and also as industrial solvent.
- It can also be used as an ingredient for some cosmetics such as body wash products, shaving gel and some specific type of toothpaste.

Figure 3 Blowing agent obtained from iso-pentane (Source: Shivamadhesive.com)

2.6.3 Solvent for vegetable Extraction

Many solvents have been tried over the years for extraction of oil from vegetables. Mostly the vegetables such as sunflower are fragile in the sense that, they cannot with stand the heat from steam distillation hence the solvents are used for the extraction. Petroleum products such as methanol, ether ethanol or hexane are mostly the solvent used. Hexane has about the best characteristics of them all. It has a great and aggressive capability to mix and dissolve with vegetable oils so that it can wash the desired oils out of a fibrous or solid material. (Gorelova and Komarova, 2016). Hexane is a liquid and has a boiling point of 69°C (156°F), it also has the ability to relatively and easily remove oil from solids.

The azeotrope is convenient for efficient removal of the solvent from solids (or "meal") using direct steam contact. Hexane has a long record of use without as much irritation of human skin or the immediate or severe toxicity of many competitive solvents. It is selective and leaves the proteins, sugars and some undesired gums largely undisturbed in the meal. It does not mix with water, allowing fairly simple processes to keep it in the system while water passes through the extraction process as moisture in the seed, meal, oil or air. Lastly, hexane has a relatively 'tolerable' odor and a low tendency to cause discomfort when one is subjected to a brief exposure.

Figure 4 Solvent for vegetable oil extraction

2.6.4 Naphtha

Naphtha is a petroleum liquid which is difficult to explain or define because of the various components constitution which include olefins, aromatic paraffin and naphthenes. According to Hori, 2000 and Speight, 1999, naphtha is a liquid that has a high boiling point from 30 degrees Celsius to approximately 200 degrees Celsius. It has carbon number and boiling range similar to gasoline.

Uses

Naphtha is mostly used in the industries for formulations and processes as a solvent; that mostly depends on the purity and stability. It can also be used as solvent for diluting paint as shown in the pictorial diagram below.

Figure 5.10 Shop Klean- Strip Quart Naphtha. (Source; Lower.com)

2.6.5 Gasoline

According to a publication by Delaware health and Social Services, US, gasoline is a hydrocarbon liquid that is highly flammable and volatile. It is produced by refining hydrocarbons such as condensate or petroleum. Gasoline is either pale brown, pale pink or colourless depending on the additives used for doping. It has a strong solvent smell and also has a wide range of complex mixtures of chemicals which include xylenes, toluene, benzene, ethyl benzene and oxygenates.

Uses

Gasoline is commonly used as fuel for internal combustion for engines of motorbikes, trucks, cars boats as well as other machines and vehicles for transport.

2.7 Project Economic Analysis

Economic cost benefit analysis is an appraisal technique used to verify whether a project will reach certain set objectives. In other words, it is used to predict whether a project will be profitable or not. Economic analysis focuses on opportunity cost and not solely on market prices. Opportunity cost in this sense is a measure of the cost of using scarce resources of

society for example land or petroleum resources and capital. The benefits inculcated in economic analysis refers to the value of the goods and services derived from the project or resources.

2.7.1 Methods of evaluating investments or projects

There are a number of methods or criteria used in investment evaluation. Different methods are used to analyze different investment projects. However, the most popular amongst these methods are;

- Net present value
- Internal rate of return
- Payback period

Generally, the net present value method and internal rate of return are often used by large organizations to valuate investments. The NPV method has over the years become the most commonly used of the three methods above as an indicator of corporate economic evaluation and is well accepted for a vast range of analytical processes (Helfert, 2001). This is because when organizations evaluate the economic viability of a project, the time value of money is essential that is money earned today is worth more than the same amount earned in the future.

2.7.2 The Net Present Value (NPV) criteria

The NPV model is simply the present value of future cash flow less initial cost of investment made (Ross et al., 2005). This method brings all project future cash inflows and outflows to a present value discounted at a desired rate. Cash inflows are positive whereas cash outflows are negated. If the NPV of all cash flows is positive at the assumed minimum rate of return, it implies the actual rate of return from the project exceeds the minimum desired rate of return. On the other hand, a negative NPV, implies the actual rate of return from the project is less than the minimum desired rate of return (Budnick, 1988). Net present value is a measure of how much profit is made on an investment and lays emphasis on the time value of money.

In calculating the NPV of a project;

- Firstly, the expected future cash flows need to be established.
- Secondly the required return for project needs to be estimated.
- The third step is to find the present value of the cash flows and subtract the initial investment.

The equation for NPV calculation is as follows;

$$NPVn = PV1 + PV2 + \ldots + PVn$$

$$PV = \frac{}{FV\ (1 + r)}$$

Where;

- PV is present value
- FV is future value
- r is interest (discounted rate)
- n is number of years from the present

The NPV of a project is calculated over a specific time period of interest as indicated in the formula above. If the project NPV is greater than zero, the project is considered to be profitable over that time period. If the project NPV is less than zero, the project is considered to be non- profitable over that time period. An NPV of zero means the project will break even.

2.7.3 Advantages of the NPV method

The NPV method for economically analyzing projects has the following merits;

- It recognizes the time value of money hence a more scientific approach compared to other methods.
- It depicts actual monetary quantity a project is likely to yield.

- It makes use of all cash flow spread over the project period.

2.7.4 Disadvantages of the NPV method

The NPV method does not always answer all the questions hence the demerits below;

- It is affected by the size of the investment (Warren, 1982).
- The method is comparatively complex and cannot be understood by a layman.
- The method may not be satisfactory when the project under scrutiny involves different amounts of investments

METHODOLOGY

3.1 Introduction

This chapter focuses on the various methods and techniques that was used to achieve the research work. Based on the objectives stipulated in the previous chapter together with the nature of the research which is a form of exploratory research, both qualitative and quantitative research analysis were employed. The details of the various methodology deployed are described below, these consist of primary and secondary collection of data, net cash flow analysis (net present value) and sensitivity analysis model.

3.2 Approach for Data Collection and Analysis

The research approach used for this study is an exploratory research design, which involves collection of data by interviewing some respondents. The data compilation procedure used in the work was in the form of primary and secondary data collection. The secondary data were collected from books, articles, papers and internet source to review literature whiles other data was also taken directly from the Gas Plant through; face to face interviews and Call-in sections with the various stakeholders such as the Process Engineers and Managers with various sample questions stipulated in Appendix A.

As stated earlier, most of the data used in the research (calculations) are real data collected from the existing facilities (Atuabo Gas Processing Plant) whereas others were inferred from similar projects. In the mathematical model for the economic analysis, certain assumptions were also made but contrary to mere baseless assumptions. The assumptions were such that they mimic real life situations inferred from other projects and facilities. In making these assumptions, worse case or close to worse case scenarios were used to make bare the performance of the proposed measures under these conditions.

3.2.1 Face-to-face Interview

As mentioned above, face-to-face interviews were used for the collection of most data used in the research. The following key players were contacted because they are directly involved in the research study; thus condensate production and utilization in Ghana, sample question for each respondent is represented in the table 3.1 below.

Ghana Gas Respondent

- The Plant Manager
- Specialist from China (Sinopec, China)
- The Utility Department (Operations Supervisor)
- The Process Department (Process Engineer)
- The Maintenance Department (Maintenance Planner)

Tema oil Refinery Respondent

- the specialist at the Residual Fluid Catalytic Cracking unit (RFCC)

Chiefs and Landlord of the Ellembele district

Sampling Techniques

There are different types of techniques used for sampling data, namely; cluster sampling, stratified sampling, simple random sampling, multistage sampling and purposive sampling also known as judgmental sampling. For the sake of this research study, purposive sampling technique was used for the selection of the stakeholders. According to Palys, T. (2008), purposive sampling, also known as judgmental, subjective or selective sampling, is a type of non-probability sampling technique used for analyzing specific and unique information.

In trying to achieve the aims and objectives of the research, purposive sampling as the name implies, focused on the people (stated above) who were selected based on the research questions and could best address the question which were selected. In this case people who are directly involved in the handling of the current condensate production at the Atuabo Gas Processing Plant, they have the adequate and necessary information, including experience in the study area. Sample question for each stakeholder is attached in the appendix A. The table 3.1 shows data collected from each respondent.

In summary the results and analysis of data taken for the research have been used extensively in the literature review and the next chapter also highlights some of the data obtained.

Table 3.1Primary Data Collection Process

Target People	Sampling Technique and Data Collection Method	Type of Data Required	Number of Respondent
Ghana Gas	Purposive Sampling/ face to face interview	➢ Overview of the processing plant. ➢ Daily production rate values. ➢ How many personnel are currently working at the condensate loading unit. ➢ Which companies come for the condensate that are produced. ➢ The current price of condensate per kilogram. ➢ Current salary of employees at the condensate processing unit (also known as utility unit). ➢ The approximated production values from the TEN production.	8
Tema Oil Refinery	Purposive Sampling/ Call in section	Current use of the condensate.	1
Local Assembly	Purposive Sampling/face to face	➢ How to acquire a land in this district, thus the procedures involved. The price for an acre of land.	4
Correspondent from China (Sinopec)	Purposive Sampling/face to face	➢ Overview of the condensate fractionation plant in China. Daily production rate of condensate in China. By products of condensate obtained from the condensate fractionation plant in China. ➢ Uses of by-product of in China. Economic value of by products in China.	5

3.3 Net Cash Flow Analysis (Net Present Value)

The most common method of evaluating oil and gas projects is by using the after tax net cash flow model that is net present value. In assessing the success rate of a project or investment, the net present value is used or preferred to some future value that will arise. In other words, money at hand is more valuable compared to money to be collected in the future. The value of future money is subject to inflation hence the decision to use net present value in the analysis. Again, net present value provides concrete numbers that can be used in comparing a number of projects. Net present value of a project or investment is the sum of the present value of the difference between cash outflow and cash inflow at the required rate of return.

In this research, the net present value of the cash flow model for the current practice of the Atuabo gas processing plant and that of the proposed method of optimizing gains are calculated and compared to pin point which practice or method has the highest economic potential.

The cash flow model of raw condensate sale's economic analysis will include the following elements;

- Annual condensate production
- Gross revenue from condensate sales
- Operation expenditure deduction
- Labour cost deduction
- Tax deduction
- After tax income

The cash flow model of raw condensate sale is generated using the following equations:

Gross Revenue = ∑ [Annual condensate received × Condensate market price] Opex = Condensate quantity ×Operating expenditure per ton of condensate

N et Revenue = Gross Revenue − Labour − Operating expenditure Corporate Tax = Income tax rate (25%) Net revenue

After Tax Income = Net revenue − corporate tax

The cash flow of the model for the economic analysis of condensate fractionation will on the other hand consist of the elements below;

- Annual production of the various products of fractionation
- Gross revenue from the sale of the products
- Loan repayment deductions
- Labour cost deductions
- Operation expenditure deductions
- Tax deductions and after tax income

The various fields of the cash flow for the condensate fractionation project per year is given by the following equations: Gross Revenue = ∑[Annual production of product × Product market price]
Opex = Condensate quantity ×Operating expenditure per ton of condensate
N et Revenue = Gross Revenue − Loan repayment − Labour − Operating expenditure Corporate Tax = Income tax rate (25%) Net revenue
After Tax Income = Net revenue − corporate tax
After generating the net cash flow model for each scenario, the present value of the after tax income for each year is obtained by discounting its future value at a periodic rate of return (discounted rate). The NPV now becomes the sum of the annual present values calculated. The present value of a cash flow is given by;

$$PV = \frac{FV}{(1+r)^{n}}$$

Where:

- PV is present value
- FV is future value
- r is interest (discounted rate)
- n is number of years from the present The

decision rule for NPV analysis is that;

- A positive NPV means a project is profitable
- A negative NPV means a project is not profitable
- A zero NPV means a project will break even
- In comparing two or more projects the one with the highest NPV is the most profitable

3.4 Sensitivity Analysis

Uncertainties in the cost of equipment, labor, operation and raw materials as well as in future prices received for products can have a major effect on the evaluation of investments. It is important in appraising the risk involved to know how the outcome would be affected by errors in estimation, a sensitivity analysis is made to show the changes in the rate of return due to errors of estimation of investment cost and raw material and product prices. These will be affected by the type of cost analysis performed (Rough estimate or detailed analysis), stability of the raw material, product markets, and the economic life of the project (Jenkins G and A.E. Herberger, 1992).

Also, in an investment project evaluation, the bases (NPV) for the calculations depend on a set of input values such as costs (capital and operational), discount rate and tax. It is potentially possible that these values may change in the future. In order to take into consideration all consequences and extremities, an analysis of the effect of changes in the starting values used for the evaluation need to be made in advance. Sensitivity analysis is the calculation procedure used to highlight the effect of changes in the project value use for an evaluation under uncertainties due inappropriate predictions. The output of the sensitivity analysis will give a clear pictorial view of the effect of variations in input values on the project's success.

In this research, the outcome of the sensitivity analysis is represented by a simple tornado chart which clearly depicts the effect of individual input values on the projects overall NPV.

3.5 The Proposed Fractionation Unit

As stated in the literature review, different condensate refineries across the world have different configurations. While some are tailored to produce white petroleum products (gasoline, gasoil, naphtha and kerosene), others produce petrochemicals (iso-pentane, benzene, rubber industrial solvent etc.) as raw materials for the manufacturing industry.

The proposed design for the Atuabo fractionation unit is similar to that of Sinopec International Petroleum Service in China. The unit will be configured to produce petrochemical products like benzene, iso-pentane, vegetable oil extraction oil and rubber industrial solvent. The reason for this configuration is that there are no local sources for the aforementioned products on the Ghanaian market hence all such products are imported. This presupposes that should GNGC enter into this venture, it will become the sole producer of these products in the Ghanaian market. On the other hand, products from the other type of configuration (naphtha, gasoline etc.) have several producers or sellers like Tema Oil refinery, BOST, Fuel Trade and Sage petroleum. Going in for such a configuration will mean entering a market with a high level of competition which may not auger well for GNGC.

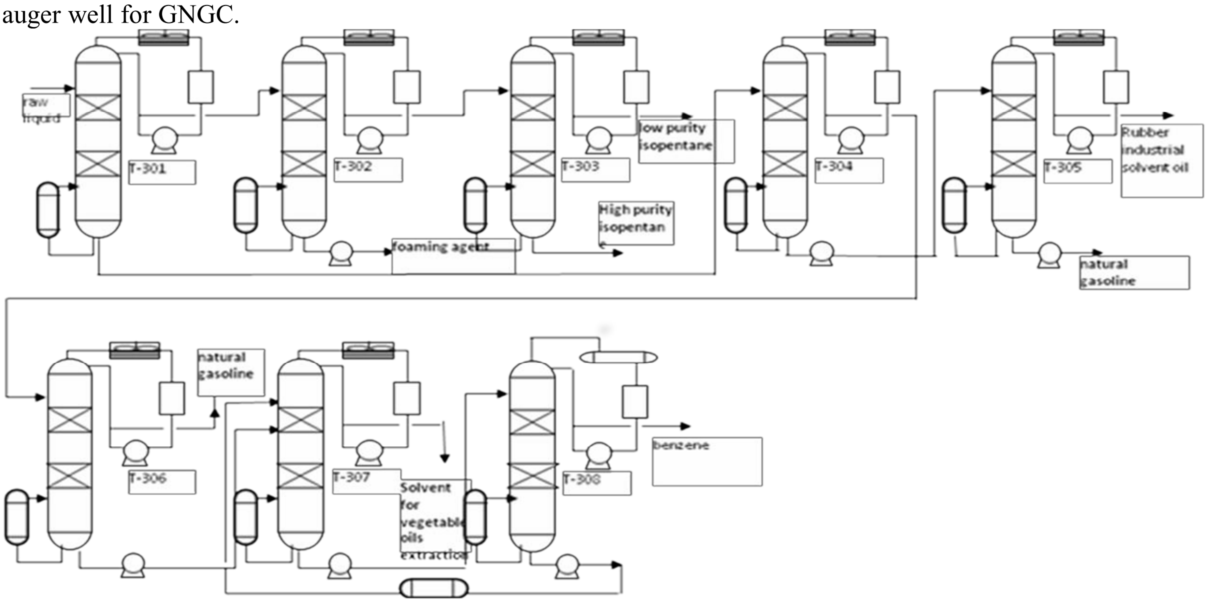

Figure 3.1 Proposed fractionation unit design (Source: Sinopec China, 2014)

The proposed unit will in all ways be equivalent that of Sinopec China. However, it will have a lower capacity of 200 metric tonnes daily production.

3.6 Comparative Analysis

In China, Sinopec International Petroleum Service with an annual feed of about 40000 metric tonnes of condensate operates a refinery for the fractionation of raw condensate. Sinopec has a plant that was designed specifically for an annual processing capacity of 25,000 tonne per annum of condensate. The debutanizer bottom product condensate is used as feed stream. After the distillation process, condensate is separated into pentane foamer, isopentane, solvent oil and natural benzene which generates the higher revenue as shown in table 3.1. Their average daily production is 120 metric tonnes of raw natural gas condensate.

Table 3.2 Income Generated from fractionated products

Sinopec GHANA GAS Sinopec Commissioning Team Training Course

Purpose of fractionated products:

Product	Condensate	Pentane foamer	Solvent for vegetable oils extraction	Rubber industrial solvent oil	Natural benzene
Price/ (RMB/ Ton)	5000	7200	8000	8300	7500

Comparing the above situation with the current values, of raw natural gas condensate received from the Jubilee field daily which relatively 39927.01 metric tonnes annually, it ideal for Ghana to consider fractionating the raw condensate to generate more revenue for the country. Details of the economic analysis of the extra revenue generation are elaborated in the next chapter.

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter focuses on the cost benefit analyses of fractionating condensate into its products in comparison to the gains from raw condensate sale as is being done currently by GNGC. The analysis is based on the most common method of evaluating oil and gas projects; using the after tax net cash flow model that is net present value.

4.3 Economic Evaluation of Raw Condensate Sales

The sale of raw condensate as the current practice of the Atuabo Gas plant appears to be more profiting especially when consideration is given to the huge cost involved in undertaking the expansion project coupled with the colossal amounts to be expensed as operational cost. However, a quantitative analysis is needed to ascertain or quantify the difference. In this regard, an NPV analysis using Microsoft excel was carried out on the current practice at GPP, this is elaborated below.

4.3.1 Production Data

The table 4.1 below details the data collected pertaining to the operations of the Atuabo Gas Processing Plant.

Table 4.1 Raw data collected from the Atuabo Gas Plant (Source; Field Data)

ITEM	VALUE
Daily condensate production	109.389 tonnes
Operating expenditure (Opex)	$5.00 per ton of condensate
Number of employees at condensate storage unit	5
Number of days facility operates in a week	7 days
Production downtime	36.5 days
Price of condensate	$500/ton
Monthly salary range of employees at condensate storage unit	$1011.89 - $1264.86 (Ghc 4000 – Ghc 5000)

The facility operating for seven (7) days in a week implies that it operates everyday throughout the year that is 365 days. From the data collected and analysed, the Ghana National Gas Company (Ghana Gas, Atuabo) receives an average of 109.389 metric tonnes of raw natural gas condensate from the Jubilee field daily. This tonnage translates to 39927.01 metric tonnes annually. Inferences made from the above collected data are summarized in the table below.

Table 4.2 Analyzed data collected from the Atuabo Gas Plant (Source: Field Data)

ITEM	VALUE
Annual condensate production	39927.01 tonnes
Annual Operating expenditure (Opex)	$199635.05
Number of employees at condensate storage unit	5
Number of days facility operates annually	365 days
Annual gross revenue from condensate sale	$19963505
Average salary of employees at condensate storage unit	$1138.38 (Ghc 4500)
Annual labour cost for condensate storage unit employees	$68,302.56

Note: Annual condensate production= Daily production ×days worked (365)
Annual Opex =opex per ton of condensate × annual condensate production
Annual gross revenue =annual condensate production ×condensate market price
Annual labour cost =Average salary ×number of employees ×12(months)

A 10% (36.5 of 365 days) production down time inferred from Atuabo GPP operations was also assumed for the project's economic analysis. The assumed downtime caters for both planned and unplanned maintenance as well as unforeseen events such as FPSO breakdown (that is, interruptions in natural gas supply), reduction in demand which chokes process flow etc.

4.3.2 Cost Elements

Cost elements utilized in analyzing the cash flow of the current practice are operating expenditure and labour cost. Currently about US $ 5 per ton is being expended on the practice of raw condensate sale. Through face to face interviews, it was established that a total number of 5 staff work on the current condensate storage and offloading unit. The salary (including risk allowance) of these employees amounts to US $ 683025.05 annually.

Taxation

The maximum corporate income tax of 25% from Ghana's Corporate Income Tax Law is use for the economic analysis of the project. The tax rate levied on the project represents the highest corporate tax rate in Ghana in accordance with the Income Tax Act 896, 2015.

4.3.3 Other Assumptions

A discounted rate of 10% is used for the economic (NPV) analysis of the practice.

4.3.4 Raw condensate sale economic model

The table 4.1 below details the economic model representing the annual cash flow for the sale of raw condensate. The gross revenue in this case is simply a product of the annual production and the market price of condensate. The net revenue is equivalent to the gross revenue less operating expenditure and labour cost on which tax is levied. Expressed in equations using the first year,

$$\text{Gross revenue} = 39927.01 \times 500$$
$$= \$19963505$$

$Net\ revenue$ = Gross revenue − Opex − Labour cost

= 19963505 − 199635.05 − 68302.56

= $19,695,567.39

Corporate Tax = Tax (25%) × Net revenue

= 0.25×19,695,567.39

= $4923891.849

After tax revenue= 19,695,567.39 − 4923891.849

= $15039613.15

The economic analysis of the raw condensate sale generates an average revenue of US $15039613.15 for the Atuabo Gas Plant annually thus after operating expenditure (Opex), labour and corporate tax have been deducted. When this practice continues for the next twenty years with an assumption that all parameters remain the same, it will yield a net present value (NPV) of **US $ 143,080,318.03** which implies that the practice is profitable. The table 4.1 below shows parameters and calculations carried out using Petroleum Contract and Economic module calculator.

Table 4.3 Economic model of raw condensate sales (Source: Microsoft Excel calculation)

YEAR	CONDENSATE QTY (TONNES)	GROSS REVENUE ($)	Opex ($)	Labour ($)	Net revenue ($)	Corporate Tax ($)	After Tax Income ($)
2016	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2017	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2018	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2019	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2020	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2021	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2022	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2023	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2024	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2025	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2026	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2027	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2028	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2029	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2030	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2031	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2032	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2033	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2034	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2035	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
2036	39927.01	19963505	199635.05	68,302.56	19,695,567.39	4923891.849	15039613.15
NPV							**$ 143,080,318.03**

4.4 Economic Evaluation of Condensate Fractionation

This section focuses on the quantitative analysis of the economic potential of refining natural gas condensate received from Ghana's Jubilee Field into the various products stated in previous chapters as opposed to the sale of raw condensate. This is in a quest to maximize the economic gain from Ghana's oil and gas resources. The cash flow model used in the thesis is similar to that which is used in petroleum exploration and production industry but devoid of specific fiscal terms that is no royalty, government share or entitlement.

4.4.5 Project Assumptions

The following assumptions were made for the purpose of the project's economic modeling:

- Discount rate for NPV calculations is assumed to be 10%
- The project is expected to employ about 20 extra employees in addition to GNGC's current work force. The categories of additional employees will range from engineers and technicians who will work in

the condensate refining section through to administrative officers and janitors.

4.4.1 Project Information

The fractionating project will focus on improving the capacity of the current Ghana National Gas Company refinery in Atuabo to facilitate raw natural gas condensate fractionation.

Land Acquisition and Civil works

Land and required civil works for the project are estimated to cost a lump sum of **US*$ 2,040,475.59*** from a feasibility study that was conducted. A detailed breakdown of the cost is provided in the table 4.2 below. The cost of land used for the analysis is quoted in reference to the current cost of land in the Ellembele district (where the Gas Processing Plant is situated) obtained through interviews with landlords in the area. Though realistic, this data is subject to changes due to economic factors at the time of acquisition.

Table 4.4 Land acquisition and civil works estimate (Source: Field Data)

Required land size	*5 acres*
ITEM	**COST**
Price per acre	$ 8,095.12
Civil works	$ 2,000,000.00
***Total cost of land & civil* works**	***$ 2,040,475.59***

Fixed Installations

Some equipment will be installed and tied in to the existing GNGC infrastructure at a total cost of **US $ 150,000,000.** A detailed breakdown of the equipment and their individual cost is given in the table below. The unit prices of the various components in the table below were obtained from different manufacturers across the globe.

Table 4.5 Breakdown of fixed installation cost

Item	**Unit Price ($)**	**Quantity**	**Cost ($)**
Reboiler	617000	9	5553000
Reflux Drum	596000	8	4768000
Reflux Pump	640000	8	5120000
Bottom Pump	879000	6	5274000
Depentanizer Column	13500000	1	13500000
Feed Stream Tower	13670000	1	13670000
Foaming Agent Tower	11300000	1	11309000
Isopentane Treating Tower	16200000	1	16200000
Solvent Oil Treating Tower	20000000	1	20000000
Extractive Distillation Tower	15600000	1	15600000
Extractant Recovery Tower	14800000	1	14800000
Air Cooler	258000	7	1806000
Piping	4250	5000	21250000
Miscellaneous			1150000
TOTAL			**$ 150,000,000.00**

Labour Cost

From interviews conducted, the salary (including risk allowance) of an employee in Atuabo Gas Processing Plant is averaged US $ 1,318.38 whereas the number of employees that man the existing natural gas fractionating unit is 20.

Table 4.6 Labour cost Details (Source: Field Data)

Number of employees	20
Average employee salary	$ 1,138.38
Annual labour cost	**$ 273,210.22**

Loan Assumptions

The project analysis was carried out with the assumption that GNGC cannot finance the expansion project hence a loan will be acquired. The interest rate on the loan is assumed to be equivalent to the World Bank's interest rate. The amount to be borrowed is equivalent to the capital expenditure which consists of land acquisition, civil works, fixed installations and a three year labour cost. Loan calculations were based on the compound interest formula;

$$P = \frac{r(PV)}{1-(1+r)^{-n}}$$

Where;
P represents amount payable per year
PV represents Present value i.e. amount borrowed
r represents interest rate
n represents number of periods (number of years x compounding frequency) The table below details the terms of the loan.

Table 4.7 ***Details of loan terms***

Amount to be borrowed	**$ 152,860,106.25**
Interest rate	25%
Repayment duration	5 years
Compounding rate/frequency	Quarterly (4 times annually)
Amount payable per year	**$ 38,666,754.61**

4.4.2 Production Information

The operations data below are inferred using production information from GNGC. The costs estimated includes forward escalation for the future projection of the project.

Production Volumes

Production data used for the economic modeling such as the following are inferred from the Sinopec International Petroleum Service's production data discussed in chapter two.

- Production rates or volumes
- Production downtime

Table 4.8 ***Annual production data***

Raw material (condensate)	39927.01	tons
Rubber Industrial Solvent Oil (RISO)	7565.12	tons
Iso-Pentane	12188.25	tons
Vegetable Oil Extraction Solvent (VOES)	8825.97	tons
Natural Benzene	11347.68	tons

Operating Expenditure

Cost of production for the condensate refinery is assumed to be **US $ 20 per unit ton** of raw natural gas condensate. The operation expenditure of US $ 20 per ton of raw material consists of the following costs:

- Catalyst and chemicals
- Maintenance
- Utilities (energy, water etc.)
- Insurance

4.4.3 Market Prices

The current global market prices for natural gas condensate products from its refining are detailed in the following table. However, the price of raw condensate reflects the Ghanaian market price. Although global prices for commodities are not fixed, prices for raw condensate and its refinery products are assumed to be constant for the 20-year period used for the economic evaluation.

Table 4.9 Market Prices of condensate an associated products

ITEM	PRICE ($/ton)
Raw material (condensate)	500
RISO	1,246.94
Pentane foamer	1,081.69
Veg. Oil Ext. Sol.	1,201.87
Natural Benzene	1,126.76

4.4.4 Taxation

The same tax levy used in the economic analysis of raw condensate sale is applied to this analysis since it is still within the same petroleum downstream sector as well as country.

4.4.5 NPV Economic Model of the GNGC Expansion Project

The expansion is estimated to cost One hundred and fifty-two million eighty hundred and sixty thousand one hundred and six U.S dollars (**$ 152,860,106.25)** with the project/construction phase lasting a period of about two (2) years. The following are some of the equipment's' and facilities that should be considered.

The table below details the annual cash flow of the project over a period of 20 years. The computations of the various fields were made using the following equations;

Gross Revenue = ∑[Annual production of prouced ×Product market price]

Opex = Condensate quantity ×Operating expenditure per ton of condensate

N et Revenue = Gross Revenue − Loan repayment − Labour − Operating expenditure Corporate Tax = Income tax rate (25%) Net revenue

After Tax Income = Net revenue − corporate tax

The project's economic analysis using the annual cash flow yielded a positive NPV of **US $ 167,471,583.84** as indicated in the economic model below which clearly means the project is viable and lucrative. This value is approximately twenty-four million three hundred and ninety-
one thousand two hundred and sixty-five U.S dollars (US $ 24,391,265.81) more than the NPVof the economic model for the current practice. In NPV analysis, the project with highest NPV is the most suitable which in this case is the expansion project. This means GNGC and Ghana as a whole stand to gain more from expanding the Atuabo Plant as compared to the gains from selling raw condensate. To further test the viability of the expansion project, a tax rate of 35% (Petroleum Exploration and Production Tax) being the highest rate in the Ghanaian oil and gas industry was applied to the expansion project analysis. The project still yielded a greater NPV compared to that of condensate sale. The cash flow for that model is shown in the appendix B

Table 4.10 Economic model for condensate fractionation (Source: Microsoft Excel calculation)

YEAR	CONDENSATE QTY (TONNES)	PROUCT QUANTITY (TONNES)				GROSS REVENUE ($)	COST			NET REVENUE ($)	CORPORATE TAX ($)	AFTER TAX INCOME ($)
		RISO	PENTANE FOAMER	VOES	NATURAL BENZENE		LOAN REPAYMENT ($)	LABOUR ($)	Opex ($)			
2016	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72		798540.2	1950463.943	487615.9859	1462847.958
2017	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72		798540.2	1950463.943	487615.9859	1462847.958
2018	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72		798540.2	1950463.943	487615.9859	1462847.958
2019	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72	273210.22	798540.2	1677253.723	419313.4308	1257940.292
2020	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72	273210.22	798540.2	1677253.723	419313.4308	1257940.292
2021	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2022	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2023	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2024	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2025	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2026	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2027	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2028	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2029	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2030	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2031	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2032	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2033	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2034	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2035	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33
2036	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	10084502.11	30253506.33

NPV **$ 167,471,583.84**

4.4 Sensitivity of the GNGC Refinery Expansion Project

Data used for the analysis may vary over the years due to uncertainties in the industry. Although some of the uncertainties within the scope of the project can be manipulated, others such as global market prices and tax are beyond the control of the organization (GNGC) undertaking the project. It is therefore imperative to test the project's sensitivity to these uncertainties. In this view, the condensate refinery (GPP expansion) project's overall net present value (NPV) is tested against variations in the following project parameters:

- Feed volumes (raw condensate annual production)
- Capital expenditure (amount borrowed)
- Loan interest rate
- Market prices of products
- Production downtime
- Operational expenditure
- Discounted rate

The tornado chart below shows the project NPV's sensitivity to variations in the above parameters.

The sensitivity runs were made with oracle crystal ball assuming eighty-five percent (85) percent certainty. In the analysis, assumptions were made on the variables with respect to the minimum and maximum values they can take after which a simulation was run on the forecasted element (After tax NPV). A total of one thousand (1000) runs were made. The results of the sensitivity analyses as illustrated by the below tornado chart shows that the quantity of raw material (condensate feed) is the most significant variable of the economic model. It has an eighty-one percent (81%) positive influence on the projects after tax NPV. Capital expenditure on the other hand has a negative thirty-three percent influence on the NPV. The level of influence of variations in the other project parameters are shown in the tornado chart. Positive figures imply that the particular variable or parameter has a positive effect on the success of the project whereas a negative figure signifies a negative effect.

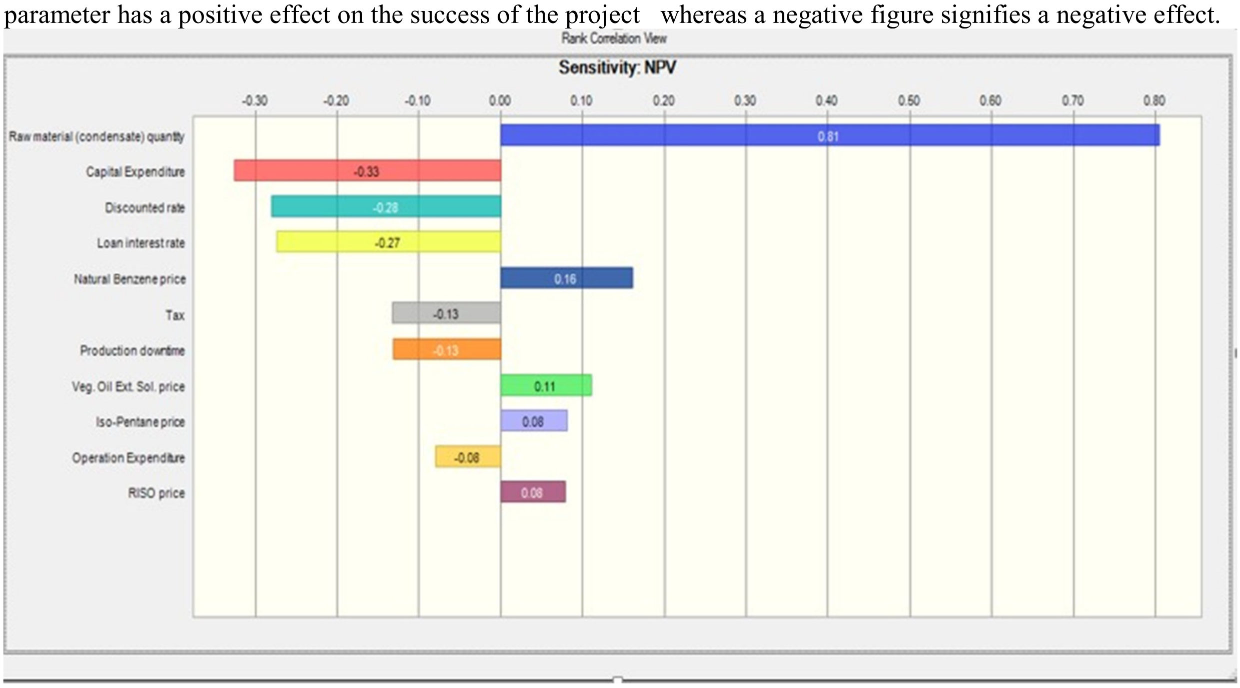

Figure 4.1 Tornado chart for NPV sensitivity analysis

The simulation also revealed that there is a ninety percent (90%) probability the economic model for the project will yield a maximum NPV of one hundred and ninety-five million five hundred and thirty-one thousand two hundred and eleven U.S dollars (U.S

$195,531,211). There is also a ten percent (10%) probability that the project will yield an NPV of ninety million three hundred and seventeen thousand one hundred and seventy U.S dollars (U.S $90,317,173) being the minimum achievable. The probabilities of obtaining other NPV values within 85% certainty are illustrated by the figure below.

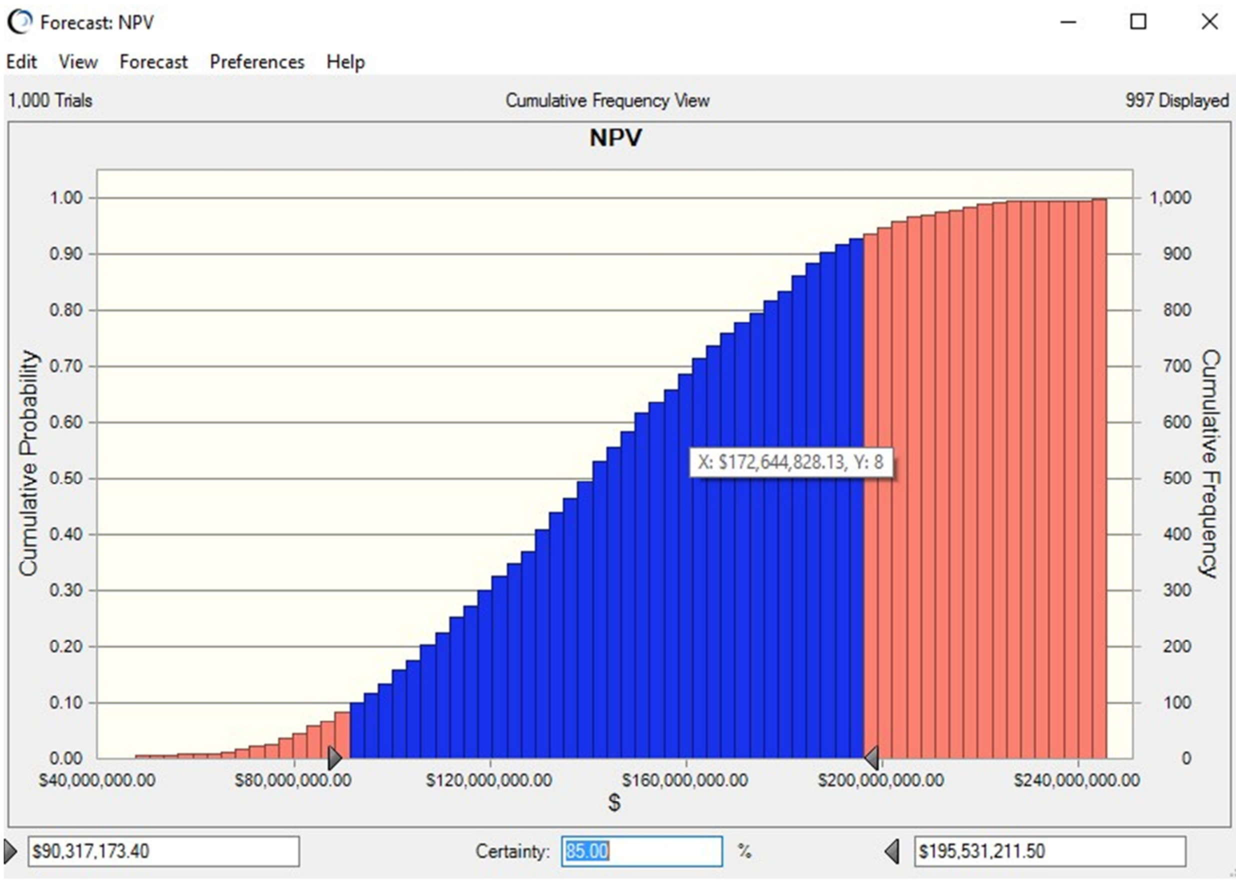

Figure 4.2 Cumulative probability frequency chart for NPV sensitivity analysis

CONCLUSION AND RECOMMENDATION

5.1 Introduction

In this chapter, the results and findings from the NPV model are highlighted. Recommendations and further work are also suggested for further research related to condensate production in Ghana.

5.2 Major Findings

The main purpose of this study was to analyze the condensate production by Ghana Gas and also assess the economic viability of expanding the existing Atuabo Gas Processing Plant to facilitate the fractionation of raw condensate (which is currently being sold for limited industrial use) into specific products. The economic viability of the study for the optimization was achieved using a comparative quantitative analysis based on the NPV economic model.

The economic analysis of the raw condensate sale, yielded a net present value (NPV) of **US $ 143,080,318.03** whiles that of the fractionated products yielded a positive NPV of **US $ 167,471,583.84.** Comparing the two models, it is clear that the fractionated products were more viable and lucrative. This value of approximately twenty-four million three hundred and ninety-one thousand two hundred and sixty-five U.S dollars **(US $ 24,391,265.81)** is more than the NPV of the economic model for the sale of raw condensate

Also from the net cash flow (NPV) economic analysis carried out in the previous chapter, it was realized that the condensate has a high rate of return on investment and therefore the nation stands to gain more economic benefits.

Furthermore, the sensitivity analysis which elaborates effects of changes in raw material, prices of product and rate of return due to errors of estimation of investment cost proved, there is a ninety percent (90%) probability that the economic model for the project will yield a maximum NPV of one hundred and ninety-five million five hundred and thirty-one thousand two hundred and eleven U.S dollars (U.S $195,531,211). There is also however a ten percent (10%) probability that the project will yield an NPV of ninety million three hundred and seventeen thousand one hundred and seventy U.S dollars (U.S $90,317,173) being the minimum achievable. Implying that fractionating condensate would be lucrative for Ghana National Gas Company.

In the study, attention was also given to the further refining of condensate to yield useful products. It was realized that the condensate products could be refined to yield Pentane foamer, Rubber Industrial Solvent Oil, Natural Benzene, Solvent for vegetable oil extraction and the like aside blending and mixing with petroleum products. After performing the economic analysis with the net cash flow (NPV) model of both scenarios, it was also ascertained that there is also more value for money when condensate is further stripped into the above mentioned products.

5.3 Recommendations

Further research should be conducted on the expansion of the existing Atuabo Gas Plant to facilitate condensate fractionation. The research should factor actual field data in place of assumptions made in this research work. It should also consider using other economic analysis criteria such as the Internal Rate of Return (IRR) and Payback Period methods to confirm or authenticate findings of this research. In addition to this, the following recommendations should be considered by the responsible stakeholders:

- In the event that above recommendation is carried out, measures should be taken to ensure constant or increased supply of natural gas (plant condensate) and also to reduce capital expenditure in order to enhance the project's success since the afore mentioned are the most influential elements
- Formulating guidelines and procedures that will inform and sensitize key industry players in the Ghanaian oil and gas industry on the economic potentials of condensate.

5.4 Conclusion

The market price per unit quantity of any of the previously discussed condensate products is about twice the price of equal quantity of the raw resource. A lot of manufacturing companies use some condensate products in their process. With this market analysis, it is therefore imperative that Ghana positions itself to exploit the full potential of the oil and gas boom by joining the league of condensate fractionating countries. The way forward in doing this is to enhance the capacity of the Atuabo Gas Processing Plant so that it can fractionate raw plant condensate into finished products. Atuabo Gas Processing plant already has all the supporting facilities for a condensate fractionating unit hence does not require a huge capital to bring the unit into fruition.

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APPENDICESS

APPENDIX A

SAMPLE FACE TO FACE INTERVIEW QUESTIONS TO GHANA GAS RESPONDENTS

- Overview of the processing plant
- Daily production rate values 130m/d
- How many personnel are currently working at the condensate loading unit (5)
- Which companies come for the condensate that are produced
- How current price of condensate per kilogram
- Current salary of employees at the condensate processing unit (also known as utility unit).
- The approximated production values from the TEN production.

SAMPLE FACE TO FACE INTERVIEW QUESTIONS SINOPEC, A CONTRACTOR WORKING AT GHANA GAS

- A GENERAL OUTLOOK of the condensate fractionation plant in China
- Daily production rate of condensate in China
- By products of condensate obtained from the condensate fractionation plant in China
- Economic value of by products in China.
- Prices of product

SAMPLE FACE TO FACE INTERVIEW QUESTIONS WITH CHIEFS AND STAKEHOLDERS OF THE LAND

- How to acquire a land in this district, thus the procedures involved.
- The price for an acre of land

Interview with Tema Oil Refinery correspondent

- Current use or purpose of the condensate taken for

APENDIX B

ECNOMIC MODEL OF CONDENSATE FRACTIONATIONG USING 35% TAX RATE

YEAR	CONDENSATE QTY (TONNES)	PROUCT QUANTITY (TONNES)				GROSS REVENUE ($)	COST			NET REVENUE ($)	CORPORATE TAX ($)	AFTER TAX INCOME ($)
		RISO	ISO-PENTANE	VOES	NATURAL BENZENE		LOAN REPAYMENT ($)	LABOUR ($)	Opex ($)			
2016	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72		798540.2	1950463.943	682662.3802	1267801.563
2017	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72		798540.2	1950463.943	682662.3802	1267801.563
2018	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72		798540.2	1950463.943	682662.3802	1267801.563
2019	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72	273210.22	798540.2	1677253.723	587038.8032	1090214.92
2020	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86	38660754.72	273210.22	798540.2	1677253.723	587038.8032	1090214.92
2021	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2022	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2023	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2024	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2025	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2026	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2027	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2028	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2029	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2030	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2031	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2032	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2033	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2034	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2035	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49
2036	39927.01	6808.61	10969.42	7943.37	10212.91	41409758.86		273210.22	798540.2	40338008.44	14118302.95	26219705.49

NPV $ 145,142,039.33

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