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Prospects of GTL-Power Integration on a Modular GTL Plant

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Abstract

Because of the capital intensiveness of gas-to-liquids (GTL) projects, much research has been focused on optimization to reduce the capital and operational cost, increase the efficiency, reduce the size and lower the emission levels associated with GTL technology processes. In this work, an effort to optimize the GTL plant has been proposed through the use of waste heat from produced steam in a typical modular GTL plant. The waste heat from the steam generated was used to simulate electricity production alongside the production of GTL diesel. The GTL plant was retrofitted with a steam turbine unit to handle the concurrent production of GTL fuels and electricity. The integrated GTL system was simulated in Unisim using the Peng-Robinson property package. A total of 220 MMscfd of medium pressure steam were produced from the synthesis gas and Fischer-Tropsch units. The integrated GTL plant produced 2534 b/d of GTL diesel and gasoline together with 4 MW of electricity. The economics analyses results show that the GTL liquids product alone yielded an NPV of US$231.8 million, with a payout time and internal rate of return (IRR) of 4.5 yrs and 22% respectively without the inclusion of an electricity generating unit. The integration of an electricity generating unit to the conventional GTL increased the profitability of the GTL project, an NPV of US$240.5 million was realized which translates to a percentage increase of 4%. The payout time and IRR for the GTL-Power coproduction were 3.3yrs and 30.2% respectively. Thus, there was a reduction in payout time of 0.67% and an increase in IRR of 0.91%. The enhanced GTL-Power co-production configuration has the potential to increase the profit realizable from the GTL project and should be considered an investment option.

Keywords: *Gas-to-liquids; Eelectricity; Co-production; Fischer-Tropsch; Waste heat.*

1. Introduction

Gas-to-liquids technology has gained more popularity as global initiatives towards 'clean energy' rise. Nations seek to limit their carbon emissions by resorting to energy sources with less carbon emission. Natural gas although a fossil fuel, has been viewed to be the bridge fuel between fossil fuels and alternative energy sources. Because of its low carbon emission characteristics, it has been projected to remain in the mainstream in the current energy transition [1-2].

Gas-to-liquids (GTL) offers the technology to effectively utilize natural gas resources that were viewed as uneconomical, stranded, or remote owing to their volume, distance, or pressure limitations. High-quality sulfur-free products are produced from small, medium, or even large gas fields. GTL technologies have offered an opportunity for associated and non-associated natural gas resources to be transformed into premium marketable liquid fuels and chemicals for transportation and use in petrochemical industries. GTL technology provides a platform and mechanism to achieve net-zero flaring by converting the otherwise flared resource into environmentally-friendly fuels [3].

The GTL plant process consists of three primary stages: 1) synthesis gas generation, 2) syncrude reaction using the Fischer-Tropsch reactor, and 3) product upgrading to refine the liquid for various uses. The primary purpose of the GTL process is to produce clean transport fuels and utilize gases that would otherwise be flared. Additionally, GTL plant processes offer the opportunity to generate electricity from by-product steam, off-gases, and even wastewaters [4].

In the generation of electricity from GTL processes, steam produced during the GTL process is employed in steam turbines. Traditionally, electricity generated from GTL plants has been used to power on-site equipment and utilities by utilizing steam from two main sources: 1) high-pressure steam from synthesis gas production and 2) medium-pressure steam from the Fischer-Tropsch reaction. The choice of steam systems to use depends on the GTL operators' goals, demand, and overall economic considerations [5-6].

GTL-Power plants represent a hybrid GTL process that combines two key aspects: 1) the production of GTL liquids, which includes self-sufficient electricity generation for on-site plant and crew needs, and 2) the production of commercial electricity using the heat content of steam and, in some cases, flue gases [7]. This approach, often referred to as GTL-Power co-production, enhances the overall efficiency and profitability of existing GTL plant processes and offers ways to economically optimize heat loss through by-product streams, namely steam and flue gas streams [8]. Utilizing these by-product streams helps reduce thermal inefficiencies within the GTL plant process, with around 17% and 23% thermal inefficiency associated with the GTL steam stream and tail gas stream, respectively, resulting in a total thermal inefficiency of 40% from combined by-product streams [9].

The medium and high-pressure steams are used to drive steam turbines that operate on the Rankine cycle to produce electricity. In this thermodynamic cycle, the high-pressure steam expands and its thermal energy is converted into mechanical energy that is utilized to drive the electrical generator. Ready-made superheated steam offered by the GTL plant obviates the need for boilers in a conventional steam-turbine cycle thus reducing the capital and operating cost of steam turbine electricity generation through optimal facility integration [10].

Nigeria's peak power generation was 5075MW of electricity recorded in 2016 making it an average utilization of 26.7MW per 1 million head of population, a figure too small when compared to the rule of thumb for industrialized nations [11]. GTL-Power co-production can lift the burden of electricity from the national grid lines by making electrical power available for the host communities where GTL plants are situated, and when more portable GTL plants are encouraged; electrical power would contact more communities.

2. Gas-to-liquids technology

Gas-to-liquids technologies enables the monetization of stranded gas, yielding additional revenue for the operator while addressing the problem of gas flaring. GTL involves the catalytic chemical conversion of natural gas into liquid hydrocarbons and represents a valuable option for utilizing associated stranded or flare gases. GTL processes yield various products, including naphtha, diesel, gasoline, jet fuels, white oils, waxes, methanol, DME, and more. Notably, GTL production results in clean premium liquid hydrocarbon fuels with lower carbon emissions when burned compared to fuels derived from crude oil refining. GTL technologies can be implemented on a large scale or a small scale, known as mini-GTL [12].

Large-scale GTL projects require substantial capital investments, and their economic viability has been challenged by the recent drop in oil prices caused by the COVID-19 pandemic. New opportunities in GTL involve downsizing operations to accommodate small volumes of stranded gases for monetization. The concept revolves around using modular GTL units capable of converting limited quantities of dispersed gases found in various fields in the Niger Delta into transport fuels, which are in high demand in Nigeria. Despite the existence of the Escravos GTL facility in Nigeria, there remains potential for modular GTL units to capitalize on these small volumes of stranded gas that would otherwise be flared [12].

Numerous researchers have focused on monetizing stranded gas using micro-scale or modular technologies. For instance, Kanshio and Agogo [13] conducted a techno-economic assessment of mini-GTL technologies for monetizing flare gas in Nigeria. They identified several promising technologies capable of converting small volumes of flare gas, typically below 1 MMscfd, into premium marketable gas-to-liquids products. They simulated the production of various products such as methanol, anhydrous ammonia, diesel, among others, using technologies like Greyrock, GasTechno, and Proton Ventures. Their assessment involved making economic and technical comparisons among these products and technologies, considering a base case of 500 MMscfd of natural gas. Ultimately, they concluded that methanol was the most economically attractive option among the products studied.

Abanum *et al.* [1] considered in their paper the application of portable gas-to-liquids in the Niger Delta fields. Their work was a review study of the most recent technical innovations in small-scale GTL technologies. They showed data from the available literature that small-scale GTL technologies are economically viable and attractive. They also provided relevant knowledge on the economics of GTL operations in Nigeria. However, their study was not exhaustive as it failed to highlight the operational difficulties inherent in modular GTL operations in the Nigeria locality.

Uzor and Bretz [14] considered the profitability of gas-to-liquids processing technologies. They compared the economics of large and small-scale gas-to-liquids technology. They used a per capita cost estimate to analyze the profitability of 50,000BLPD of the GTL plant and 1000 BLPD. The capital and economic cost of the larger 50,000BLPD plant was supplied by a reputable company in Colorado, and exponential scaling was used in the estimation of the capital and operational cost of the smaller 1000 BLPD plant. They performed a sensitivity analysis on the impact of several parameters on the profitability of the GTL technologies. They discovered that the profitability of the GTL technology is mostly affected by changes in the price of the GTL products. They also discovered that the capital cost of the GTL plant on a given unit capacity gave the next most visible changes in the profitability of the GTL technology.

Fulford *et al.* [15] conducted a study on a new approach to gas monetization in Nigeria. They proposed GTL as the solution for small volumes of associated gas. They insisted that operators usually flare gas with volume ranges of 1 MMscfd for individual flares and 10-20 MMScfd for a group of flares. They attributed the huge gas flaring in Nigeria to be due to excuses of gathering costs, gas processing and treating facilities, especially for small volumes of gas in small fields, and lack of infrastructure and funding to deliver gas to the markets.

He [4] presented a study on flare gas monetization with modular GTL units. They considered the conversion of 4MMscfd of wellhead-associated gas into premium GTL gasoline. They utilized the synthesis gas to methanol (STM) process using fixed bed catalytic reactors.

Anyasse and Anyasse [16] presented methods to mitigate gas flaring using small-scale gas-to-liquids technology. They began by presenting challenges faced by conventional GTL synthesis gas reforming methods. They highlighted the benefits and importance of the transition to newer and better GTL synthesis gas technologies such as catalytic partial oxidation reformers. They highlighted how the innovative new synthesis gas alternative designs when combined with efficient Fischer-Trospch technologies would yield profitable GTL products and hence mitigate the environmentally harmful act of gas flaring.

2.1. Process in GTL technology conversion

The processes in GTL technology comprise steps involved in the recovery of the stranded gas to the production of premium GTL products. These take place in various stages of the GTL process and are classified as follows

1. Recovery and treatment of the stranded/flare gas
2. Production of synthesis gas
3. Production of synthesis crude
4. Product upgrading

The first step which some researchers do not attribute as a core step in the GTL conversion chain is the recovery and treatment of the stranded/flare gas. Usually, most conventional production facilities whether onshore or offshore have associated gas flare points where the excess associated gas is flared. When there are no gas utilization options, this gas is flared as means of pressure relief in the system and also for the reason of space constraints especially on offshore platforms [4]. When eventually, this gas is structured for conversion and via gas-to-liquids, gas recovery means must be deployed to channel the gas to the GTL plant. It should be known that the gas coming from the well contains impurities to the GTL plant. Some of these impurities are acid gases, nitrogen, water vapour. The gas must be pre-treated to remove or reduce the concentration of these impurities in the gas stream before entry into the main GTL process facility. This would ensure a more efficient GTL operation, better yield, comparatively lower pollution, and less operational costs in the GTL production chain. Acid gases must be reduced as they cause catalyst poisoning and corrosion of the metallic components of the GTL plants which translates to huge financial implications when replacement is to be made [6].

Pre-treated natural gas is sent to the synthesis gas unit. The synthesis gas unit is a relevant conversion step not only for GTL conversion but for other petrochemicals. In the synthesis gas step, the natural gas is converted to synthesis gas which is a mixture of hydrogen gas and carbon monoxide gas. The synthesis is gas unit represents the area of immense investment cost and is usually the target area for optimization by many researchers working in GTL plant optimization [15]. Usually, the synthesis gas unit begins with a pre-reformer reactor that converts the higher molecular mass hydrocarbons like ethane, propane, and butane plus into methane and synthesis gas.

The pre-reformer is useful in cracking the heavier molecular mass hydrocarbon molecules (ethane plus) present in the natural gas stream. This would prevent the formation of olefins, production of soot, and much carbon dioxide production in the synthesis gas unit. The pre-reformer equation is given

$$C_nH_m + H_2O \rightarrow \left(n + \frac{m}{2}\right) H_2 + nCO for\ n \geq 2 \quad (1)$$

$$CO + 3H_2 \leftrightarrow CH_4 + H_2O \quad (2)$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \quad (3)$$

Pre-reformer operates adiabatically and the exit temperature depends on the inlet compositions and temperature. Usually, the exit temperature of the pre-reformer should be between 212^{o}F and 572^{0}F lower than the inlet temperature of the reformer.

Further from the pre-reformer are the main reforming operations using several available reforming technologies. The synthesis gas reforming technologies commonly used are steam-methane reforming, partial oxidation reforming, autothermal reforming, CO_2 reforming and Bi-reforming of methane. The choice of reforming method to use lies in the type of product to be produced. This is governed by the H_2/CO ratio. GTL plants that utilize Fisher-Tropsch reactors downstream for synthesis crude conversion require an optimum H_2/CO ratio of 2. Autothermal reforming and Bi-reforming of methane are technologies with an H_2/CO ratio close to the required value of 2. Steam methane reforming has a high H_2/CO ratio and is mostly utilized in the industrial production of hydrogen gas from natural gas [2].

The equations of reaction for a typical autothermal reforming reaction in the GTL plant are given as

$$CH_4 + 1.5O_2 \leftrightarrow CO + 2H_2O \quad (4)$$

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \quad (5)$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \quad (6)$$

Equation 4 is an oxidation reaction wherein methane is oxidized to carbon monoxide and water. Equation 5 is the reforming of the methane with steam to produce hydrogen and Carbon monoxide known commonly as synthesis gas. A water gas shift reaction (equation 3.6) usually forms in the process.

The Fisher-Tropsch unit is an exothermic reactor that converts the synthesis gas into synthesis crude. The reactions proceeds by addition of the (-CH_2-) groups according to the equation of reaction below

$$nCO + 2nH_2O \ \rightarrow (-CH_2-)n + nH_2O \quad (7)$$

Usually, methane is also produced in the unit as given in the stoichiometric equation below

$$CO + 3H_2O \ \rightarrow CH_4 + H_2O \quad (8)$$

The product produced in the F-T unit is not in the final state and is still crude (similar to crude oil from reservoirs). It has to be refined in the product upgrading unit. This unit is tailored to bring out the specific desired product output by adjusting its operational parameters. This unit includes the cracking, isomerization, and hydrogenation units [17].

2.2. Economic considerations in GTL technology

Economic considerations in GTL processes are very crucial steps of project investment decisions before the embarkation of GTL projects. Many factors affect the profitability and economic attractiveness of GTL ventures. Amongst these factors are: the capital cost of GTL technologies, the Operating cost of GTL technologies, the crude oil price, and the feedstock price (i.e., natural gas) [12].

Amongst these, the price of crude oil is the most influential on the economics of GTL. High crude oil prices entail high GTL product prices because GTL products are sold relative to the cost of conventional crude oil products substitutes. Most commercial GTL plants have been abandoned due to low crude oil prices. Following the price of crude oil, the next factor that influences the profitability and economic sensitivity of GTL investment is capital cost. Most commercial plants are very costly and as a result, investors have shied away from them. Options are now available in small-scale modular plants with significantly reduced capital costs [18]. The higher the capital cost the higher the risk which presents unique challenges, especially in this era of volatile oil prices. Operational costs also affect GTL investments. The rising cost of catalysts is the single most influential parameter contributing to the high operational cost of GTL processes when feedstock costs are treated as separate costs [12,19].

2.3. Electricity generation from GTL process steam

GTL facility upgrade enables the integration of liquid production schemes and electricity generation systems on an existing GTL plant. The system functions in a closed-loop wherein each system compliments the other. The GTL liquids production process furnishes heat in form of steam to the electricity generation network [20]. Electricity is produced by converting the thermal energy in the steam to mechanical and then electrical energy. The electricity produced is utilized as energy in the liquids production and also as a utility in the overall process. A typical steam turbine operates according to the figure given below.

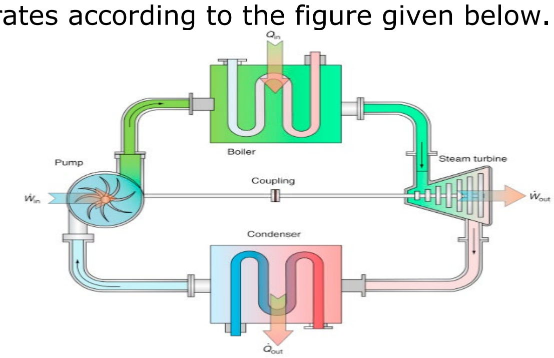

Figure 1. Schematic diagram of Steam turbine system based on Rankine cycle [20].

Figure 1 is a schematic diagram of a steam turbine system based on the actual Rankine cycle. The diagram typically consists of four major devices namely, the boiler, the steam turbine, the condenser, and the pump. The boiler is given heat through the burning of fossil fuels using oil, gas, or coal or through renewable energies such as wind, solar, geothermal, etc. The boiler heats the saturated liquid water pumped to it and a superheated vapour is achieved as the desired temperature is reached by the boiler. The superheated vapour is then fed to the steam turbine unit where the thermal energy is converted to mechanical energy to do work [10]. The steam having lost its energy to the steam turbine flows with reduced pressure to the condenser where cooling and phase change occurs to saturated water at the condenser temperature. The saturated water leaving the condenser flows to the pump where it is pumped again to the boiler and the cycle repeats. In all of these, the steam mass flow rate remains constant.

In a GTL system, the steam turbine system is restructured by removing the boiler unit. This is because high-pressure steam is custom-made from the GTL processes downstream. Thus, the resulting steam is pumped directly to the turbine. However, in this case, the saturated water from the condenser is separated as fresh superheated steam flows into the turbine system from the GTL process units. The saturated water in this case is channeled to be used in the heat exchanger units for cooling [20].

3. Materials and methods

3.1. Materials

The materials utilized in this study is Unisim software used for the process simulation. Unisim software is a process simulation software developed by Honeywell. It has wide usage in modeling and simulation of chemical, petrochemical and oil and gas related projects. Unisim allows the modelling, simulation and optimization of various processes while helping to design, analyse systems. It has built-in functionalities that enables adequate troubleshooting and system aimed at improving process and operational efficiency. Engineers use Unisim software to create steady state and dynamic simulations which includes complex processes such as reactions, operations, heat exchangers etc. In this work, Unisim is used to model the GTL simulation process and the heat integrations for the conversion of process heat to electricity.

3.2. Methods

The methods comprise the modeling and simulation of the GTL process and the electricity generation process using GTL process heat. The case study considered in this paper was a 25 MMscfd of associated gas in Asa, in Ohaji-Egbema located in the Niger Delta region of Nigeria. This volume of gas was targeted for processing and conversion to premium diesel and gasoline using modular GTL technology. The study seeks to simulate the process of the conversion of the gas to GTL products alongside the production of electricity using the produced steam recovered in the process. Simulations of the processes were carried out using Honeywell Unisim R380 software. All the simulations of the process and plant modeling were done with Unisim software. The plant processes for the GTL product simulation consisted of the gas treatment, synthesis gas production, the Fischer-Tropsch reaction, and the product workup while the electricity production was simulated as a heating system using Unisim turbine systems.
The parameters considered in this study for economic evaluation are

i. The capital cost GTL plant without an electricity generation system is MMUS$228
ii. Turbine capital cost of US$8 million
iii. Feedstock cost is $2.5/Mscf
iv. The OPEX of the GTL plant is 5% of the CAPEX
v. The OPEX of the steam turbine is US$0.02/kWh
vi. The sales price of electricity is US$0.086/kWh
vii. The operational period of the plant is 25 years
viii. The operational days per year is 350 days
ix. The prices of the refined GTL products are $100/bbl for diesel and $90/bbl for gasoline
x. 35% income tax rate was used for base case
xi. Owner's equity is 100%

The cost summary for the projects is given in Table 1.

Table 1. Cost summary for the project

Costs	GTL	Electricity	GTL-Electricity
CAPEX, MMUS$	228	8	236
OPEX, MMUS$	11.4	0.672	12.072

3.3. Gas treatment process

The GTL plant is very sensitive and impurities impact greatly on the performance of the plant. Substances such as CO_2, H_2S, water vapour, and mercaptans greatly impair the functionalities of the GTL plant. High CO_2 corrodes the plant metallic plants and increases the acidity of the process. H_2S causes catalyst deactivation and thus limits the operational efficiency of the process, thereby increasing operational cost. Sulphur components such as mercaptans and nitrogen must be removed to the acceptable levels to be fed into the GTL plant. The gas treatment process comprises the gas sweetening process and the gas dehydration process. In GTL plant gas dehydration processes are not so important as the water content of the gas stream is not a major problem.

The gas sweetening process is done to reduce the levels of acid gases in the natural gas stream. The gas sweetening plant is designed and retrofitted depending on the inlet composition of the gas which affects the percentage of acid gases in the raw natural gas stream. The gas sweetening process used for this work is the diethanolamine (DEA) system. The process flow diagram from Unisim is given in Figure 2.

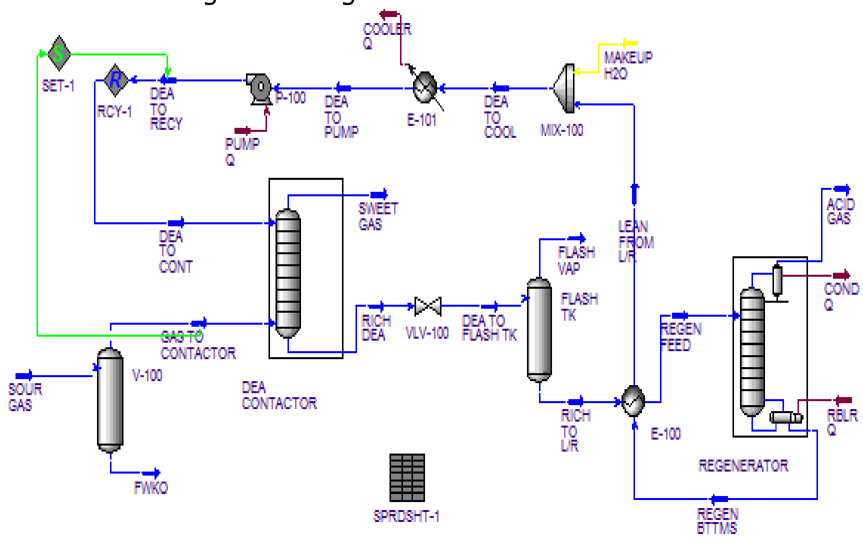

Figure 2. Process flow diagram (PFD) of gas sweetening process using DEA.

The inlet gas of flowrate 25 MMscfd of gas enters the knockout drum at 86°F and 1000 psia. From the knockout drum, 0.236MMscfd of saturated hydrocarbon gas liquids were separated from the gas stream and 24.76MMscfd of gas is sent to the contactor. Sour natural gas of flowrate 24.76MMScfd enters the contactor at 1000 psia and 86°F temperature. Rich DEA enters the contactor at a flowrate of 37.92 MMscfd at 995 psia and 95°F. The DEA strips the sour natural gas of its acid gas and the sweet natural gas comes out of the contactor. The sweet natural gas at the exit of the contactor is at 23.29MMscfd and pressure and temperature of 995 psia and 95.46°F respectively. The DEA that has acquired the acid gas from the sour natural gas becomes rich DEA and flows to the regenerator where it is regenerated and recycled to be used in the process again. The process is a cycle that repeats itself. At the end of the process, 1.985MMscfd of acid gas is separated and 23.29 MMscfd of sweet gas is produced.

3.4. GTL products modeling

The GTL products were modeled step by step according to their various units. The first was the pre-reformer modeling, then the reformer followed by the F-T process, and lastly the upgrading unit.

The sweet natural gas from the treatment plant enters the GTL plant at 104°F and 435 psia. Because the temperature is low for the pre-reformer a heater was used to increase the temperature of the inlet natural gas to 850°F suitable for the pre-reformer activity. Another inlet to the GTL pre-reformer unit is steam which will react with the natural gas. Steam enters at 485°F and 560 psia. A conversion reactor was employed to simulate the pre-reformer reactions, while the water gas shift reaction was modelled using an equilibrium reactor. Operating conditions for the pre-reformer were set at 986°F and 435 psia in terms of temperature and pressure, respectively. The resulting pre-reformed gas was directed to the autothermal reformer (ATR), which serves as the primary reforming unit. The ATR was represented as a conversion reactor, and its water gas shift reaction was simulated separately in an equilibrium reactor. Due to the exothermic nature of the ATR reaction, an upper temperature limit of 1886°F was imposed to prevent soot formation.

Downstream of the ATR, a heat exchanger was connected to reduce the syngas temperature to 100.4°F. This temperature reduction aimed to convert the steam generated in the ATR back into water, which could then be separated before the Fischer-Tropsch (FT) reaction. This reduction in volume flow helps minimize the size of the reactor. However, 100.4°F is too low for the low-temperature Fischer-Tropsch (LTFT) process, which typically operates in the range of 392-464°F. To address this, a heater was included in the model to raise the temperature of the FT reactor (FTR) inlet to 410°F.

The FTR was modelled as a plug flow reactor (PFR) to resemble the flow pattern in a multi-tubular fixed bed (MTFB) reactor. A starting volume of 1000 m3 was chosen for the FTR. The FT reaction set was defined as kinetic and included both the FT reaction and the methanation reaction. Stoichiometric coefficients for the FT reactions were determined based on the Anderson-Schulz-Flory (ASF) distribution, and the kinetics were implemented using the Iglesias rate of reactions.

The products of the MTFB reactor included both gaseous and liquid components. These products were separated within the reactor by gravity, with gases exiting from the top and liquid products trickling down and exiting from the bottom. The gaseous products were cooled by heat exchange with water to 100.4°F (38°C) before entering a three-way separator along with the liquid products. This step was taken to separate the water that had left the reactor as steam, eliminating unnecessary recycling and preventing water from entering the product upgrading process. Figure 3 illustrates the process flow diagram (PFD) for the GTL plant process.

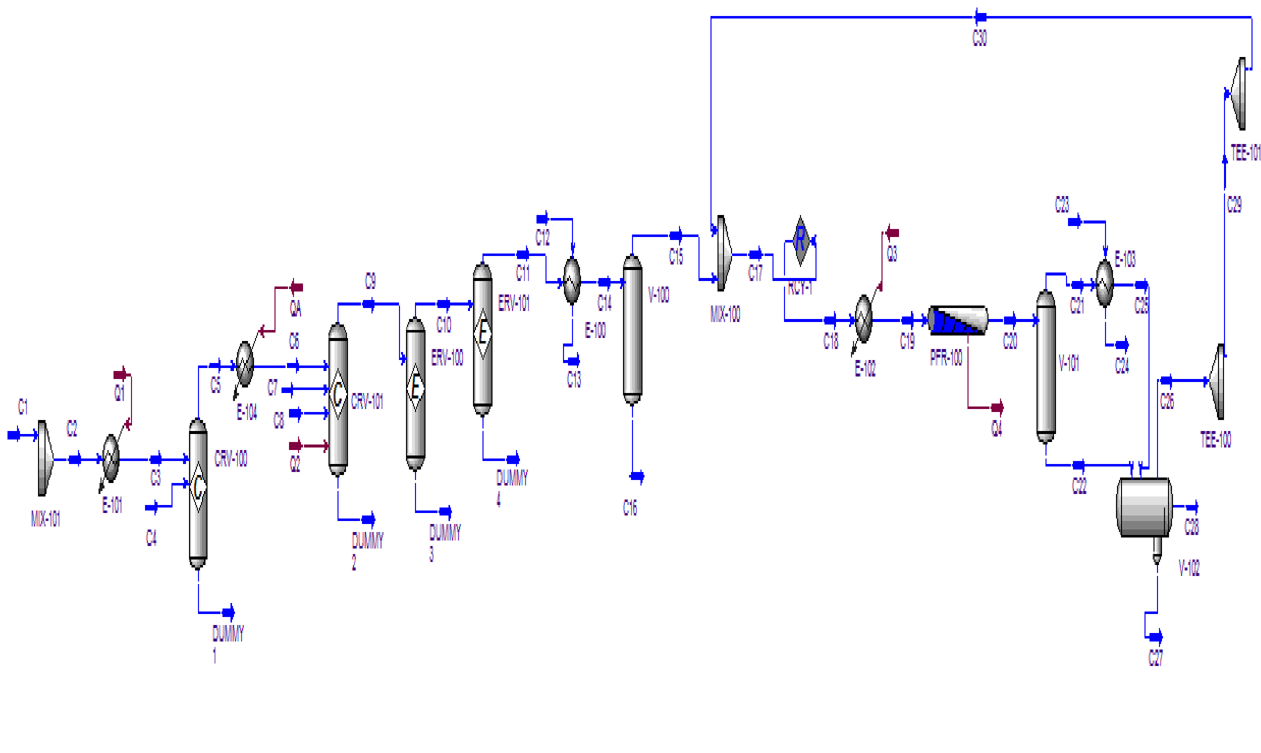

Figure 3. PFD for GTL product modeling in Unisim.

3.5. Electricity production modeling

The electricity production modeling is given in this section. Medium pressure steam is produced in the synthesis gas and F-T units. These streams of steam are routed to the turbine units for electricity generation. The turbine unit was modeled as an expander. The PFD for the electricity generation process is given in Figure 4.

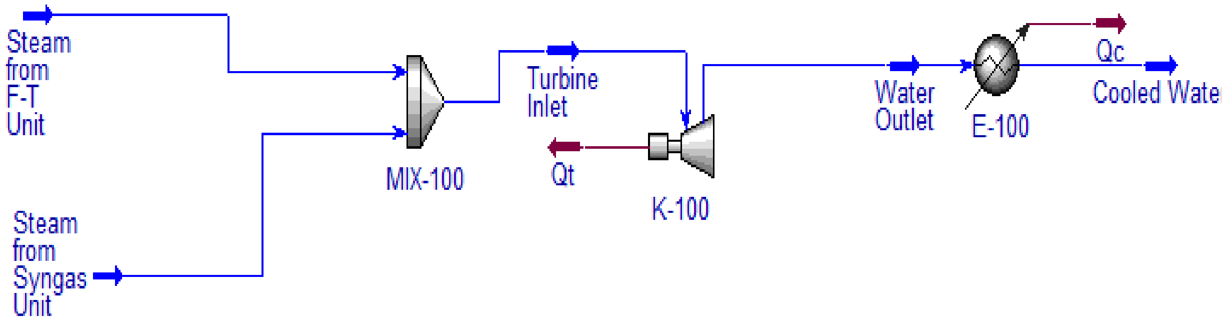

Figure 4. Process flow diagram (PFD)of electricity generation process

Medium pressure steam of 696.2 psia pressure and 502.5°F came from the syngas generation unit. This was routed to the mixer (MIX-100) where it mixed with the steam from the F-T that came at 500°F and 580.2 psia temperature and pressure respectively. The flow rate of the steam from the synthesis gas unit and the F-T units are 5490lbmol/hr (170 MMscfd) and 18670lbmol/hr (50 MMscfd) respectively. The steam stream enters the turbine with a flowrate of 24160 kgmol/hr (220 MMscfd) at a temperature and pressure of 536°F and 580.2 psia respectively. Water is given off from the turbine system which is discharged as wastewater.

4. Results and discussion

The result of the modeling and simulations performed are given in this section. The results shall be given according to how the simulation was performed.

4.1. Results for gas treatment

For the gas treatment system, sour natural gas was entered at the inlet while sweet gas and acid gas came out at the outlet of the plant. The condition of the inlet and outlet are given in Table 2.

Table 2. Natural gas treatment result.

Component	Flowrate (MMscfd)	Temperature (°F)	Pressure (psia)
Sour natural gas inlet	25	86	1000
Sweet natural gas outlet	23.29	95.56	995
Acid gas outlet	1.985	179.7	27.5

From Table 2, it can be observed that the flow rate of the treated sweet gas is 23.29MMscfd while acid gas was recovered with a flowrate of 1.985 MMscfd. The acid gas contains 51% H_2S.

Figure 5 depicts the molar flow of liquids and vapour in the DEA contactor relative to the tray position. As can be observed, the liquid flow in the contactor is greater than the vapour flows. The molar flow increases with increasing tray position from the top for both vapour and liquid component flows. The vapour phase in the contactor is the natural gas while the liquid phase is the DEA. Similarly, the molar flow for the fluids in the DEA regenerator column is given in Figure 6.

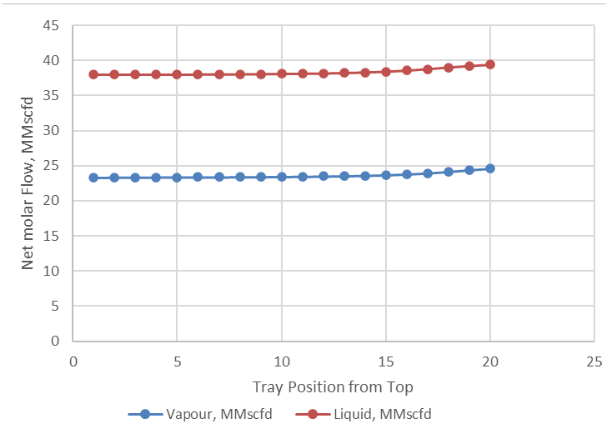

Figure 5. Net molar flow for DEA contactor.

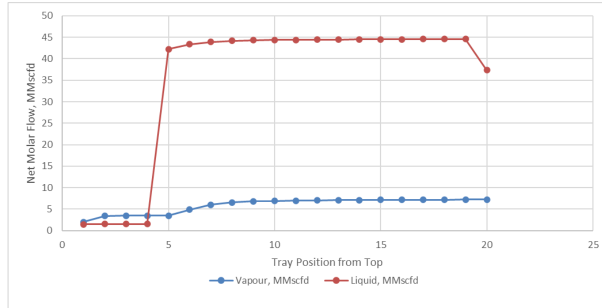

Figure 6. Net Molar flow for DEA regenerator.

The regenerator column is where the DEA is recycled to be reused. The regenerator comprises the condenser and the reboiler. The condenser is at the top of the Regenerator while the boiler is at the bottom of the regenerator. The vapour phase in the DEA regenerator unit is the acid gas component while the liquid phase is the rich DEA.

4.2. GTL plant modeling results

The GTL plant modeling results comprise the results from the GTL products for the standalone GTL process without the addition of an electricity-generating unit and the results for the integrated GTL-Electricity unit retrofitted for the production of electricity.

GTL premium transport fuels were produced during the GTL plant modeling process. The products gotten are gasoline and diesel. The GTL plant was scheduled to favour the production of this lighter ends product because they were majorly in higher demand in the market when the market analysis was conducted. The products volumes produced from the GTL plant during the modeling process are given in Table 3.

Table 3. GTL plant modeling results.

Component	Volume
Diesel Product, b/d	1315
Gasoline Product, b/d	1219
Steam from Synthesis unit, MMscfd	50
Steam from F-T unit, MMscfd	170
Electricity produced from the turbine, MW	4

As can be seen from Table 3, 1315 b/d of diesel was produced and 1219 b/d of gasoline was produced. The total product of GTL transport fuels is 2534b/d of GTL fuels. Note that by the rule of thumb, 1 b/d of GTL product is produced by 10,000scf of natural gas inlet to the GTL plant. Thus, 23.29 MMscf of treated natural gas by rule of thumb ought to produce 2329 b/d of GTL product. It can be seen that the integrated GTL-power production modeling gave more output GTL products than that estimated by rule of thumb. The GTL product recovered in this work is 8.8% percent higher than that estimated as a rule of thumb for conventional GTL plants. This is due to a conscious effort to optimize the GTL units. The H_2/CO ratio realized for the GTL plant modeling in the synthesis gas unit is 2.2.

Furthermore, from Table 3, it can be observed that the electricity produced from the turbine system is 4MW. This electrical power results from the use of medium pressure steam generated during the GTL products productions in the main GTL plant from the syngas unit and from the F-T units as shown in Table 3.

4.3. Economic analyses results

The results of economic analyses are given in this section. A total of 2534b/d of GTL products was produced as GTL fuels together with the additional generation of 4MW of electricity by adding a steam turbine to the GTL unit. The economic analyses results are given in Table 4.

Table 4. Economic analyses results.

Parameter	GTL	Electricity	GTL-Power co-production	Percentage increase (GTL-coproduction – GTL)
NPV, MMUS$	231.8	8.7	240.5	4%
POT, yrs	4.50	3.3	4.47	0.67%
IRR, %	22.07%	30.2%	22.2%	0.91%
P/$	4.554525768	6.56	4.60	0.88%
NCR, MMUS$	50.7	1.5	52.2	3%

The economic analyses results in Table 4 show that there is a 4% increase in NPV as a result of additional production of electricity alongside the GTL products in the integrated GTL plant. There was no significant reduction in the payout time; there was only a reduction of 0.03yrs corresponding to 0.67%. The internal rate of return increased from 22.07% in the GTL plant to 22.2% for co-production, an increase of 0.2%. This corresponds to a percentage increase of 0.91%. The NCR increased by 3% due to the addition of an electricity generation unit to the GTL plant.

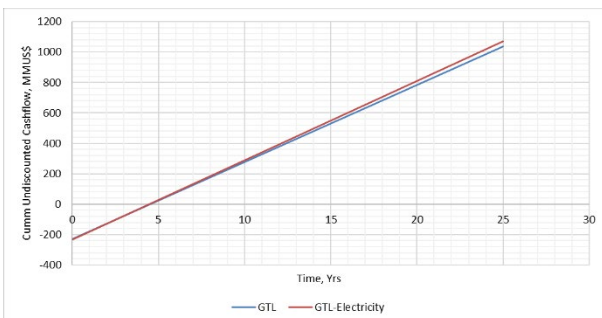

Figure 7. POT analysis for GTL and GTL-power co-production.

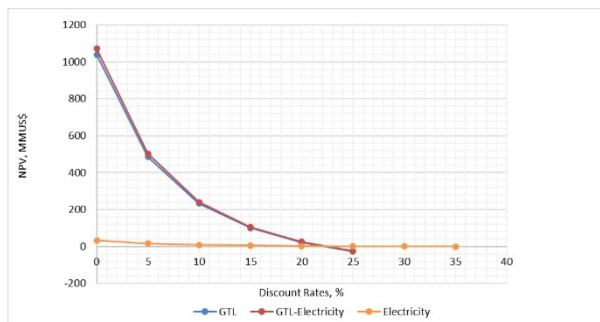

Figure 8. IRR plot for the GTL and GTL-power co-production.

Incorporating technology for commercial electricity production into the GTL plant results in a shorter time to recover the initial investment costs, as demonstrated in Figure 7. Simultaneously generating GTL products and electricity yields extra revenue for the operator, enhancing the overall profitability of the GTL process.

Figure 8 illustrates that the internal rate of return (IRR) has increased across the board. In this comparison, the blue line represents the GTL plant operating on its own, while the red line represents the GTL-Electricity production scenario, which combines the production of GTL products with electricity generated from the by-product steam stream using a steam turbine. The green line represents electricity production when considered as a standalone operation.

The profitability indices for the GTL-Electricity scenario consistently outperform those of the standalone GTL operation. This implies that the GTL-Electricity production approach proves to be more economically viable than the standalone GTL operation across all the economic indicators considered.

An integrated GTL process system has been considered in this research work. The GTL plant primarily produces premium fuels for transport. As a means to optimize the GTL plant for better performance, more returns on investment, and higher efficiency, the traditional GTL product yielding plant was integrated with electricity generation units with the inclusion of steam turbine units that harnesses the waste steam produced in the GTL process to generate electricity. The otherwise waste heat is captured and put to useful ends in the production of electricity that would be used onsite and also sold to generate additional revenue for the operator. The turbine plant does not need a boiler unit because there is already steam generated in the synthesis gas unit and the F-T units.

5. Conclusion

Investments in Gas-to-liquids technology in the production of fuels are very capital intensive and operators are deterred from venturing into it because of the huge capital cost, hence there is a dire need to seek avenues to reduce operational or capital costs in GTL ventures or increase revenue possibilities such that investment opportunities can be attractive. To enhance the profitability of GTL ventures and reduce the initial startup capital, significant facility integration, advanced configuration, and technology upgrades are required. GTL-Electricity integration provides a hybrid technology configuration that allows for optimization of the GTL plant thus improving the revenue base of GTL projects. 4MW of electricity was generated by the inclusion of an electricity-generating turbine in the GTL plant. This increased the profit of the GTL process. GTL-power co-production resulted in a 4% boost in the Net Present Value (NPV) of the GTL process, along with a 3% increase in annual cash flow. Integrating GTL and electricity generation provides a cost-efficient approach for monetizing associated gas. It offers faster payback periods and higher internal rates of return compared to standalone GTL projects.

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