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Study of the Viability of a Methanol-To-Gasoline Process for the Monetization of Stranded Natural Gas

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Abstract: Methanol-to-Gasoline Process involves the chemical transformation of Natural gas into usable gasoline range products. The objective of this work was to conduct a techno-economic analysis of Methanol-to-Gasoline Process, identifying heat integration, recycle and cost saving opportunities in the Process, and determining the Present-day Profitability of the Process. Aspen Hysys v8.6 was used in the model simulation, with an Auto-thermal Reformer being Used in modelling Synthesis Gas Manufacture, and a Plug Flow Tubular Reactor used in the methanol synthesis, with kinetic data similar to that of the commercial $Cu/ZnO/Al_2O_3$ Catalyst. The Gasoline synthesis reactor was modelled as a conversion reactor, with 94% conversion based on the CuO/ZnO/HZSM-5 zeolite conversion yield. It was also discovered, that starting with 10.02MMscfD of natural gas, we obtained 1462 Barrels/day of Gasoline, 82 Barrels/day of Methanol and 147 Barrels/day of Di-Methyl Ether. The total Capital Cost came to $172,360,500, the Operating Cost of $21,808,945 annually, and Gross annual revenue came to $26,575,626, with annual savings of $4,766,681. After Heat Integration and product recycle, a savings of $7,303,009 was realized (74% reduction). The simple payback period of 36.2 years and a Net-present value of -$94million after 20 years, indicating that the MTG process is not viable under the present economic situation. The results of the sensitivity analysis show that the MTG process will be profitable within the 1st 20 years when the price of natural gas falls $500/MMscf or is completely free, or when the interest rate falls 5% or when the inflation rate rises above 20%. The reason for its non-profitability was discovered to be its water to hydrocarbon volume distribution, with water being 53.32% and Gasoline was 46.68%.

Keywords: Natural gas, Stranded, Monetization, Profitability

INTRODUCTION

Stranded natural gas is a class of natural gas that cannot be recovered at the time of exploration due to physical or economic reasons. According to [1], over 40 % of Nigeria's Oil & Gas Reserves are stranded. On the other hand, in our country Nigeria the demand for refined products of crude oil, such as gasoline, diesel, and kerosene are exponentially growing, with an inadequate supply to meet the this demand, Mainly caused by the poor efficiency of the national refineries. A reason why there are not enough refineries is due to the Large "Capital Cost" and long "payback period" that come with its setup, hence the idea of small scale modular refineries. So, what do we do with a growing demand for transportation fuels, limited amounts of crude oil, high cost of setting up a conventional refinery, and an abundance of stranded natural gas? The solution to these can be found in the utilization of a small-scale gas to liquid (GTL) plant. Gas-to-liquids (GTL) is a process that converts natural gas to liquid fuels such as gasoline, jet fuel, and diesel. GTL can also make waxes. The most common technique used at GTL facilities is Fischer-Tropsch (F-T) synthesis [2]. Another GTL process is the methanol to gasoline process (MTG), which converts natural gas first into methanol and then methanol into gasoline. The processes include The Production of synthesis gas, (H2, CO, and CO2), from natural gas, Conversion of Syngas to methanol by passing it over a catalyst, the methanol obtained is reacted over a catalyst and dehydrated and converted to DME, DME is reacted over a zeolite catalyst to get hydrocarbons with the carbon number ranging from 6 to 10, consisting of alkenes, aromatics, cycloalkanes etc. The aim is to provide an economic means to produce gasoline from Natural gas. For GTL to become competitive, the process must operate optimally as possible, in terms of efficiencies and economics, and making this process as optimal as possible is one of the objectives this work seeks to achieve.

METHODOLOGY

The MTG plant was modelled and simulated using the ASPEN HYSYS V8.6 software. In setting up the model, two fluid packages were chosen, Peng-Robinson for the syngas section, and SRK-TWU for the methanol and gasoline synthesis section. Unit operations used include: Heater, Cooler, Equilibrium reactors, Heat Exchanger, Separators, PFR reactor, Compressor, Expander, Mixer, Pump, Recycle, Component Splitter. The temperature, pressure and composition used was the same as that used in [3] ,[4], and [5]. The composition and conditions for the natural gas feed is shown in table 1. The Feed conditions for steam and oxygen are shown in table 2. The gas was assumed to the free of Sulphur and acid gases. Hence the negation of gas treatment facilities.

Table 1: Composition and inlet conditions of the feed gas used in the modeling the MTG plant

Conditions	
Molar Flow	500kgmole/h
Temperature	40^0C
Pressure	3000KPa
Composition	
Component	Mole fraction
Methane	0.955
Ethane	0.036
Propane	0.005
Butane	0.004

Table 2: Feed conditions for oxygen and Steam

Name	T^0C	Pressure kPa	Molar flow(kmol/h)
Steam	252	4045	345.2
oxygen	200	3000	300

The reactions were added in sets for the main unit operations, the Pre-reformer, the Auto-thermal Reforming Unit, the Methanol Reactor, the DME reactor, and the Gasoline Synthesis Reactor. The specifics are further described in the following sections:

The ATR: The ATR was modelled as two equilibrium reactors, the 1st for methane and the second the steam reforming catalyst bed. The exothermic reaction heat given off in the 1st will be used to drive the reaction in the second reaction. The steam to hydrocarbon ratio was modelled as 0.7, using a spreadsheet, and the oxygen to carbon ratio was modelled at 0.6.The cost of natural gas was extracted from literature as $2260/MMscf. Oxygen was taken as N800 per gallon.

The Methanol Reactor: The methanol reactor was modelled using a plug flow reactor. The reactor specifications are: Total Volume: $0.53m^3$, Length: 7.0m, Diameter: 4.0e-002m, Number of Tubes: 60, Wall Thickness: 5.0e-003m, Void fraction: 1. The Kinetic parameters are shown in table 3 below using the following equations:

$CO+2H_2=CH_3OH$ $\Delta H^O 298$ = -90.70KJ/mole ………………………………………………… (1.1)

$CO_2+3H_2 = CH_3OH+H_2O$ $\Delta H^O 298$=-41.39KJ/mole ……………………………………………….(1.2)

$CO+H_2O=CO_2+H_2O$ $\Delta H^O 298$ =-49.31KJ/mole …………………………………………………..(1.3)

$2CH_3OH= CH_3OCH_3 +H_2O$ $\Delta H^O 298$ = -11.71KJ/mole …………………………………………………..(1.4)

Table 3: Estimated kinetic parameters of the methanol reactor

Equations	**A**	**E_a**
1.1	$2.14 * 10^4$	-114,000
1.2	$4.18 * 10^8$	-127,000
1.3	8.06	-68,000
1.4	$3.07*10^{13}$	-124,000

The DME reactor was modelled as an equilibrium reactor. This unit was modelled as a conversion reactor, with 94% conversion based on [6], CuO/ZnO/HZSM-5 catalysts and Gasoline was defined a hypothetical component. The Methanol and gaseous streams where recycled in a second Hysys simulation file into the methanol synthesis reactor and ATR respectively for increased yield of Products. Pinch analysis was used in carrying out the heat integration.

Economic evaluation

The capital cost of this plant was calculated using a mathematical relation derived from the graph plot of barrels/day versus capital cost in Billion $. The data for this graph was obtained from ADI analytics. The obtained equation is as follows:

Y = 7E-16x4 - 1E-11x3 + 8E-08x2 + 2E-05x - 4E-12, where Y= Capital cost in billion $, X= barrels/day.

The operating cost of the plant was estimated using the Energy consumption, cost of raw material feedstock, labour and other miscellaneous cost, as equations used where taken from [7]

Economic tools used in the economic evaluation of the process include the discounted flow sheet, the net present value, Life cycle analysis and a sensitivity analysis. The Price of Gasoline, methanol, and DME was used in calculating the revenue for the company. All cost where calculated on a yearly basis, and the calculation was carried out on the Microsoft excel spreadsheet. The straight-line depreciation method was used in calculating the depreciation of the plant, with a salvage value of $50million after five years. Capital cost expensed in the 1st year, was taken as 30% of capital cost. Income tax was taken 35% of taxable income, and State tax was taken as 20% of net revenue. The Net present value of the plant was calculated for the 1st ten years of its operation. An interest rate of 12%, and the inflation rate was taken as 10%, in order to calculate the PV of the Plant. A life cycle analysis was carried out to determine the comparative profitability between an MTG plant and an LNG plant. A sensitivity analysis was conducted varying the price of natural gas, the interest rate and the inflation rate.

RESULTS AND DISCUSSIONS

The MTG plant was simulated on two different flowsheets in three sections, the ATR, the Methanol synthesis, and the gasoline synthesis. The 1st flowsheet was without recycle and heat integration, and the second flowsheet with recycle and heat integration, shown in figure 1 and 2 respectively:

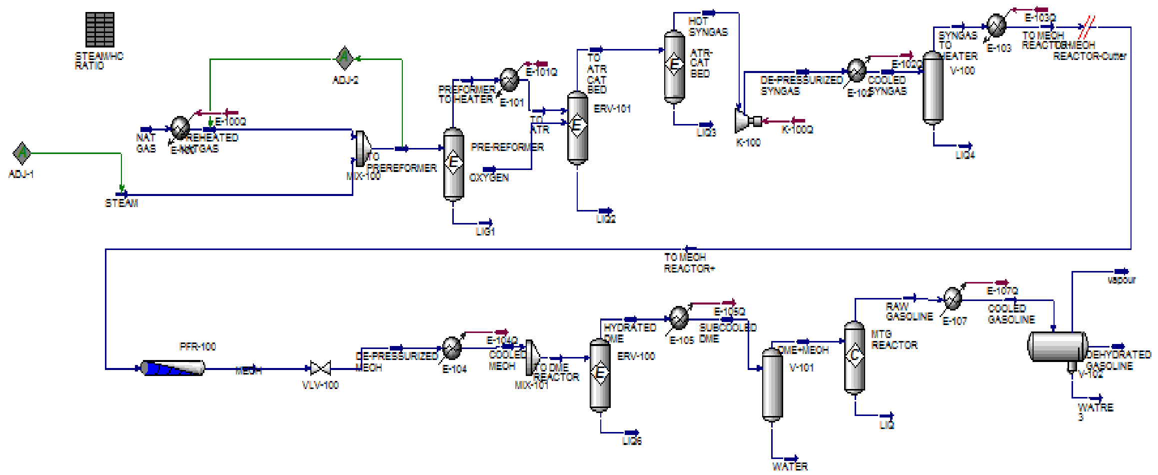

Fig-1: MTG plant without products recycle and heat integration

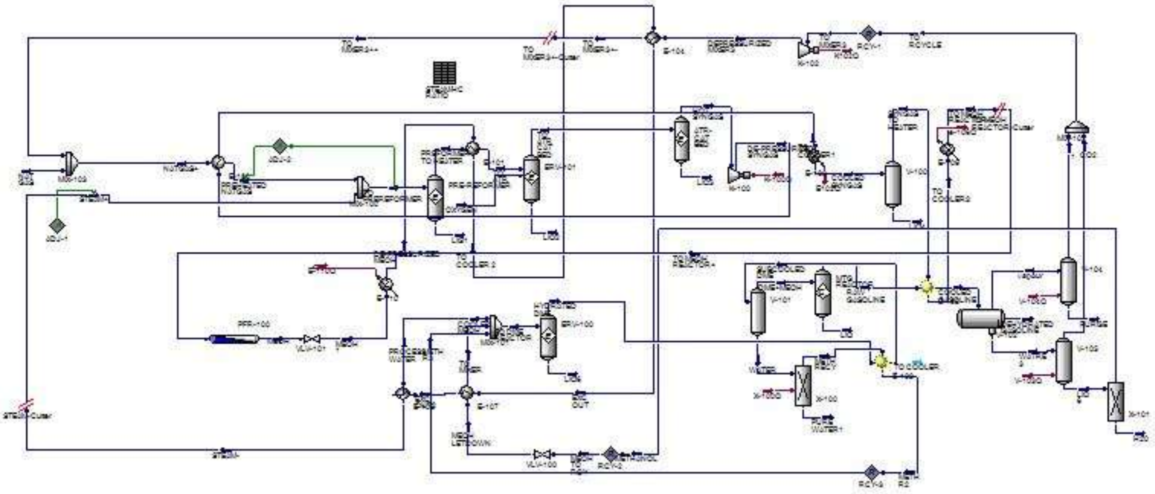

Fig-2: MTG plant with products recycle and heat integration

Overall Reaction Results

Table 4: The overall feed and products of the MTG process

FeeD Component	Amount	Products	Amount (Without recycle & HI)	Amount (With recycle & HI)
Natural Gas	10.02MMscfD	Gasoline	1098 Barrels/day	1462 Barrels/day
Steam	6220Kg/hr	Methanol	63 Barrels/day	82 Barrels/day
Oxygen	96000Kg/hr	DME	108 Barrels/day	147 Barrels/day

A General observation about the Process was the large amount of water obtained from the DME reactor and the Gasoline reactor in which methanol was very soluble.

Economic evaluation of Heat integration (HI) & products recycle

Table 5: Economic evaluation of (HI) & products recycle

	Non-Integrated plant	Integrated plant
Operating Cost(million $)	$(36.60)	$(21.81)
Capital Cost(million $)	$165.4	$172.36
NPV @ the 20^{th} year	$(420.03)	$(94.70)

The heat integrated system was found to be better in terms of energy spending. Integrating the system, leads to a cost savings of $7,303,009.46(74% reduction). The number of heat exchangers and heaters in the integrated plant, are more than the former, entailing an increase in investment cost, but the yearly savings of the value stated above will cover the initial investment cost over time. This shows the integrated plant is more economical for the process. If the project was estimated at the twentieth year, the integrated project is lesser than zero in its value, and the un-integrated project was also less than zero. Due to the economic guideline, a project with NPV greater than zero should be invested in, and a project with NPV less than zero should be neglected. This is then to say that for this project both options would not be feasible to invest in for these present conditions.

Simple payback period

The simple payback period was calculated for the integrated plant with an annual savings of $4.77 MILLION YEARLY. The result showed that it will take 36.2 years to recover the initial funds in the investment.

Table 6: Life Cycle Cost analysis between an LNG and MTG plant

million $	**LNG**	**MTG**
Capital Cost	$ 172.36	$ 68.25
Operating Cost	$ 21.81	$ 10.24
NPV @ 10th year	$ 230.40	$ 333.69

Using capital cost and operating cost alone, the NPV for both LNG and GTL monetization options were calculated and the results are given in the table above. From table 3, it can be seen that the MTG option will have consumed more money after 10 years, showing that the LNG option is a better monetization option for natural gas.

Table 7: Effect of changing Natural Gas Prices on Project Profitability

NAT. GAS PRICE/MMscf (@DF=12%, IF= 10%)	**NPV**	**REMARK**
1000	$ (24.18)	DON'T INVEST
1500	$ (52.17)	DON'T INVEST
2260	$ (94.70)	DON'T INVEST
3000	$ (136.13)	DON'T INVEST
500	$ 3.81	INVEST
0	$ 31.80	INVEST

The results from varying the price of natural gas is shown in table 7 above. From the table, that MTG becomes a profitable venture only when natural gas prices fall below $500/MMscf, and will be most profitable if the natural gas comes free.

Table 8: Effect of changing Interest Rate on Project Profitability

DF (@ $2260/MMscf, IF = 10%)	**NPV**	**REMARK**
1	$67.20	INVEST
5	$ (23.51)	DON'T INVEST
0	$100.65	INVEST

It can be noted from table 5 that even at an interest rate of 5% from 12%, the Profit will remain not feasible, and only if the interest rate falls as low as 1% can the project be considered feasible.

Table 9: Effect of changing Inflation Rate on Project Profitability

IF(@ $2260/MMscf, DF = 12%)	NPV	REMARKS
5	$ (117.46)	DON'T INVEST
10	$ 94.70)	DON'T INVEST
20	$ 10.40	INVEST
30	$ 328.43	INVEST
40	$1,292.74	INVEST
50	$4,144.75	INVEST

The effect of changing inflation rate on the Profitability of the project was also investigated keeping all other factors constants. The results are shown in table 6. From table 6, above it can be seen that from an inflation rate of 20%, the project can be will become feasible and profitable.

Table 10: Reason for Non-Profitability

	Water Produced (m^3/h)	**Hydrocarbons Produced (m^3/h)**	**Total Volume Produced (m^3/h)**
Total	14.61	12.79	27.41
%	53.32	46.68	

It can be observed from table 10 above that the process produces more water than hydrocarbons, unlike the Fischer-Tropsch process. This single factor alone hinders the profitability of the process.

CONCLUSION

Based on the results from this paper, a framework for testing the viability of the MTG process as a monetization option for associated stranded natural gas, has been established.

Starting with 10.02 MMscfd of Natural gas, this process obtained a yield of 1462 Barrels/day of Gasoline, 82 Barrels/day of Methanol and 147 Barrels/day of di—methyl ether, which fits our category of a small-scale plant

A Life cycle analysis between the LNG monetization option and the MTG monetization was conducted, and results show that the LNG monetization was better with the economic conditions in the analysis

Pinch Analysis for heat integration was carried out and the total operating cost per year was reduced with about 74%, while a discounted flow sheet was used to calculate the NPV of both plant configurations. It was observed that the integrated plant with recycle would be more viable.

From the NPV analysis conducted, it was deduced that the project will not be profitable under the economic conditions used in the analysis, as the NPV after 20 years, remained negative. The reason for its non-profitability was discovered to be its water to hydrocarbon volume distribution, with water being 53.32% and Gasoline was 46.68%. A sensitivity analysis was carried out showing that the MTG process will be viable within the 1st 20 years when the price of natural gas falls below \$500/MMscf or is completely free, or when the interest rate falls below 5% or when the inflation rate rises above 20%.

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