A CASE STUDY OF PRODUCTION OF VALUE-ADDED LIQUID PRODUCTS FROM NATURAL GAS OF MELLITAH GAS PLANT USING GTL TECHNOLOGY: A TECHNO-ECONOMICAL STUDY

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Abstract: Natural gas (NG) has assumed an extremely important status worldwide as both a source of clean energy and a major feedstock for a number of petrochemicals. Its global value can be assessed by the economic, environmental, and sometimes political future of countries being dependent on their possession or lack of natural gas for domestic and global demand. This paper analyzes the economic aspects of natural gas. It presents a study on the economic and profitable utilization of natural gas by its conversion into value-added products. There are four most important conversion options to convert natural gas into liquids: (a) Ammonia Production, (b) Fuels Production using GTL Technology (Fischer-Tropsch Process) or Dimethyl Ether (DME) Production, (c) Liquefied Gas Production, and (d) Methanol Production.

This paper presents an economic study of conversion of natural gas of Mellitah Gas Plant in Libya into value-added liquid products using Gas to Liquid (GTL) technology. The important GTL technology is conversion of natural gas into liquid products by Fischer-Tropsch synthesis process. It provides good and promising means to meet the energy needs with cleaner fuels. Development of GTL technology in Mellitah complex allows for more value of natural gas by production of readily transportable liquid products such as diesel and naphtha. The produced diesel is free of sulfur, contains no aromatics and polycyclic aromatics and having high cetane number. The combustion of FT diesel results in virtually no emissions of SO2, NOx and unburned hydrocarbons. Another product, F-T naphtha, is considered to be an ideal feedstock for ethylene production as compared to naphtha produced from crude oil due to the lack of aromatics. Absence of aromatics gives rise to higher ethylene yield as compared to ethylene from conventional naphtha. GTL technology is a downstream value added industry (economic enhancement) of natural gas. At present Libya is exporting natural gas which can be converted to value added liquid products. The installation of GTL plant in Mellitah complex will give employment opportunity to young Libyans. Another advantage is the produced diesel will help to reduce the import of diesel for local consumption and it will be a step towards self dependency of the country on fuel. At present Libya imports more than 50% liquid fuels for local consumption. GTL plant in Libya can also be a strategic new export industry. The capacity of GTL plant and its re-payback value has been calculated. The quality of liquid products have also been discussed.

Keywords: GTL technology, Conversion of natural gas to liquid products, F-T products.

INTRODUCTION

Libya had natural gas reserves of an estimated 1,505 billion cubic meters (bcm) as of 2016, at which point recent new discoveries and investments in natural gas exploration were expected to raise estimates of these reserves (World Oil Review, 2017). As with oil, Libyan natural gas production was almost entirely shut-in for sustained periods in 2011, but has since recovered quickly. Libya's natural gas production has grown substantially in recent past. According to EIA (U.S. Energy Information Administration), Libya natural gas production is 11.53 billion standard cubic meter in 2017.

The Western Libya Gas Project (WLGP), which is operated by Eni and NOC through the Mellitah Oil & Gas joint venture, accounts for most Libyan natural gas production growth since 2003. The

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WLGP includes Wafa and Bahr Es Salam fields. The vast majority of the gas produced from WLGP is exported via the Green Stream Pipeline. Most other natural gas in Libya is produced by NOC and its Sirte Oil Company subsidiary in the onshore Sirt Basin. Following is the description of Wafa and Bahr Es Salam fields.

Wafa Field

Wafa Field is an oil and gas field with a significant gas cap and limited quantity of recoverable oil. It is producing gas and associated condensate from the gas cap through 22 gas wells and oil with associated gas from oil zone through 15 oil wells. The production from 37 wells collected in different gathering stations (NG1, NG2, SG1, NO1 & NO2) and routed for separation and treatment at the central plant. The on specification gas is delivered to Mellitah by the 32inch diameter and 525.5km long pipeline, the average gas delivery is about 13MMSm3/day. The production of oil and condensate sent to storage tanks in Wafa, and then delivered in mixed mode with NGL coming from gas trains to Wafa Coastal Plant by 16inch diameter pipeline. Approximately 23,000bbls of NGL and 38,000bbls of oil and condensate are delivered daily to Mellitah.

Bahr Es Salam Field

It is a field where gas and associated condensate are produced from (26) wells; (15) platform wells and (11) sub-sea wells. The production is gathered on the platform where the gas is primarily dehydrated and approximately 20MMSm3/day of sour gas delivered to Mellitah gas plant for further treatment by 36 inches diameter and 110km long sea-line. The un-stabilized condensate is delivered to Mellitah process plant by the 10inch diameter sea-line for stabilization.

The National Oil Corporation (NOC) announced intentions to significantly increase the country's natural gas production. New or expanded projects to support this goal include associated oil and gas fields in various stages of development. Increased natural gas production would facilitate an expanded use of natural gas in the power sector, while maintaining and expanding existing pipelines and liquefied natural gas exports. However, like all prospective oil and gas plans in Libya, greater development of the natural gas sector is contingent upon support and certainty from the new political order. Table 1 presents the production of natural gas in Wafa Field and Bahr Es Salaam Field and its export from the Mellitha Gas Plant.

GAS TO LIQUID (GTL) TECHNOLOGY

Another important use of natural gas is to convert it into liquid products. Recently a new technology, Gas to Liquid (GTL) Technology, has been developed to convert natural gas into liquid products which can be transported easily by road tankers or pipelines. Gas to Liquid (GTL) Technologies provide good and promising means to meet the energy needs with clean fuel (Ahmad *et al*, 2002). The products are free of sulfur, metals, aromatics and asphaltenes. The two important GTL technologies are described below:

(a) Conversion of natural gas into liquid products by Fischer-Tropsch synthesis process. It is one of the leading GTL technologies to convert natural gas into high value, clean burning fuel.

(b) Another important GTL technology is the process to convert natural gas into DME (dimethyl ether). DME is a clean fuel and it can be used as a substitute for power plant fuel. DME can be used as good diesel substitute/ diesel volume extender since it has high cetane number.

GTL products will also provide significant environmental benefits (CONCAWE, 1999; El Missirie, 2000 and De *et al*, 2000) as compared to other conventional liquid fuels.

Fischer-Tropsch (FT) Synthesis Products Process

Fischer-Tropsch technology is a process that rearranges carbon and hydrogen molecules present in the natural gas. Conversion of natural gas into F-T products involves three main processing steps such as:

(a) Synthesis gas manufacture
(b) Fischer-Tropsch conversion
(c) Product upgrading

A block diagram indicating production of FT liquid products from natural gas is given in (Fig.1).

Synthesis Gas Manufacture

Synthesis gas is a mixture of hydrogen (H2) and carbon monoxide (CO). It is produced by incomplete combustion of natural gas. In addition to hydrogen and carbon monoxide small amount of carbon dioxide is also produced in synthesis gas production. The technology for making synthesis gas is a known process which has been used in many commercial

Table 1. Production and Marketed Natural Gas of Mellitah Oil and Gas B.V.

Year	Natural Gas at Mellitha Complex ($MMSm^3$)		Natural Gas Marketed ($MMSm^3$)	
	NGL from Wafa Field	Dehydrated Natural Gas from Bahr Es Salaam Field	Natural Gas Marketed in Local Market	Natural Gas Exported
2007	4,552.557	7,199.714	0	8,784.985
2008	4,569.607	7,977.396	0	9,381.145
2009	4,009.956	7,888.998	0	8,753.173
2010	4,415.734	8,185.830	501.361	8,991.064
2011	3,648.387	2,378.242	2,040.325	2,152.126
2012	4,569.708	8,128.668	2,613.495	6,252.582
2013	3,688.646	8,331.319	2,979.290	5,354.704
2014	4,200.242	8,888.807	3,127.644	6,356.750
2015	4,775.971	9,680.922	3,596.604	1,422.543
2016	4,755.913	9,703.459	5,012.205	4,635.901
2017	4,444.689	9,994.788	5,080.731	4,536.411

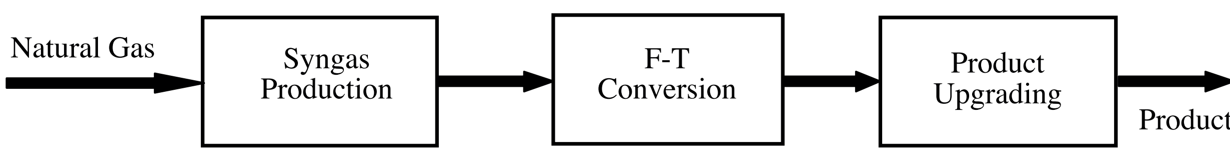

Fig. 1. Block diagram of Fisher-Tropsch process of GTL Technology.

applications as the first step for producing hydrogen, ammonia and methanol. The basic reaction is:

$$2CH_4 + O_2 \longrightarrow 4H_2 + 2CO$$

Two types of gasifiers are commonly used for the production of synthesis gas: viz. (i) partial oxidation and (ii) reforming. In partial oxidation process, natural gas is oxidized partially with pure oxygen to produce hydrogen and carbon monoxide. In case of reforming, oxygen is introduced principally through stream in presence of catalyst.

In addition to above two methods for synthesis gas production, there is one more process called autothermal reforming (ATR) which uses air directly instead of pure oxygen. Since air is directly used in this process, no dedicated oxygen generation unit like partial oxidation process is required which will reduce the plant capital cost. The process selection is based on number of factors like feedstock type, H_2 : CO ratio, etc.

Fischer-Tropsch Conversion

It converts Syngas into paraffinic and olefinic hydrocarbons of varying chain length. F-T process was first developed in 1920 by Hans Fischer and Franz Tropsch (De Klerk, 2013) for production of synthetic liquid fuel from coal. Then it was further developed by U.S. then by South Africa in 1950's due to energy security concern. GTL project based on natural gas was recently developed. F-T conversion happen at moderate temperature (200 – 300 oC) and pressure (10 – 40 bar) and uses iron or cobalt based catalysts. The simplified reaction is:

$$nCO + (2n + 1)H_2 \longrightarrow C_nH_{2n+2} + nH_2O$$

Side reactions include olefins and alcohol production. The desired H2 : CO ratio for Fischer-Tropsch reactor is about 2:1. In this step, synthesis gas flows into a reactor containing a proprietary catalyst converting into waxy hydrocarbons. Two basic types of catalysts used in the Fischer-Tropsch reactor are cobalt and iron. The hydrocarbons are synthesized by a chain growth process, with the length of the chain being determined by the catalyst selectivity and the reaction conditions.

Product Upgrading

The waxy hydrocarbons are upgraded into F-T products in this step. Product upgradation can be done by using standard hydrocracking and hydroisomerization processes.

F-T Products: F-T products are mainly middle distillates of conventional refinery. The major F-T products are naphtha, gasoline, kerosine, jet fuel and diesel. F-T products contain predominantly paraffins and olefins with very few complex cyclic hydrocarbons and oxygenates. Further, the products are totally free of sulfur, nitrogen, nickel, vanadium, asphaltenes and aromatics that are typically found in petroleum products. The properties of F-T diesel is shown in Table 2.

Advantages of F-T products: Since F-T products are free of sulfur, nitrogen and complex cyclic hydrocarbons, its combustion results in virtually no emissions of SO_2, NO_x and unburned hydrocarbons. Also F-T products can be directly used without any purification process like hydrodesulphurization in case of crude oil derived fuels. F-T products hold a great promise in meeting the stringent exhaust emission norms. F-T naphtha is considered to be an ideal feedstock for ethylene manufacture as compared to naphtha produced from crude oil due to the lack of aromatics. Absence of aromatics gives rise to higher ethylene yield as compared to ethylene from conventional naphtha.

The attraction of FT diesel in addition to its purity is its fuel quality with respect to the cetane number. F-T diesel has a high cetane number of around 75 as compared to minimum requirement of around 50 – 58 in most of the countries. A high cetane number provides fast fuel/air mixing and reduced engine delay before ignition. The other important effect of a high cetane number is the lower flame temperature which results in the reduced formation of oxides of nitrogen (NO_x).

The physical properties of F-T products are almost similar to petroleum products. It can be transported in the same ships/tankers in which petroleum products are transported. It can be stored in the conventional petroleum product storage tanks. No special ships and storage tanks are required for storage and transportation of F-T products unlike liquefied natural gas (LNG). Hence less investment is required for shipping and transportation of F-T products.

TECHNO-ECONOMICAL STUDY

This study is based on the GTL Plant of average production of 50,000 bbl/day middle distillates (Diesel and Naphtha). Actually the natural gas at Mellitah gas plant is much more than this amount. For the sake of calculation we are considering the techno-economical study of this capacity plant. The distribution of products is shown in Table 3 and the revenue collected from the sales of products is given in Table 4.

Calculation of Amount of Gas Required for GTL Plant

50,000 bbl per day of middle distillates = 8,183,000 Liters (Since 1bbl of middle distillates-163.66 Liters), or, 6,614,319kg (Considering density of middle distillates is 0.8083g/cm^3), or, 50,000 bbl of middle distillates = 6614 Tons.

Table 2. Properties of F-T diesel.

Parameters	EU Countries	California Specifications	F-T Diesel
Cetane index	51 Minimum	48 Minimum	73
Aromatics (vol.%)	35 Maximum	10 Maximum	BDL* or 0
Sulfur (ppm)	50 Maximum	50 Maximum	BDL* or 0

Table 3. Distribution of F-T Products.

Product	Percent of Natural Gas Converted to Product	Amount of Product Produced per day (in Tons)
Flue gas	5	413
Liquid Products (Naphtha + Diesel)	80	6614
Wax	15	1240

Therefore, the amount of natural gas required to produce 6614 Tons/day of middle distillates = 8268 Tons/day (Considering 80% of natural gas is converted to middle distillates in FT-Technology), or, the amount of gas required for GTL plant is 371MMSCFT/day (Density of gas = 0.04912 lb/SCFT).

Calculation of Annual Cost of Gas Processed in GTL Plant

- The amount of natural gas processed in GTL plant per day = 371MMSCF/day, or, 378,420 MMBTU per day (Since 1MMSCFT = 1,020MMBTU).
- The cost of natural gas processed in GTL plant = US$946,053per day (Considering average cost of 1MMBTU = US $2.50).

Therefore, Annual Cost of Natural Gas Processed in GTL Plant = US$ 345.308 million.

Calculation of Plant Capacity and Cost of Plant

A number of studies5 peg the cost of the various existing F-T technologies in a range of U.S.$ 20,000 to U.S.$ 30,000 per daily barrel. A feasibility study of applying Exxon's Advanced Gas Conversion for the 21st Century (AGC-21) technology to produce 50,000B/D of middle distillates and other oil based products from 500 million cubic feet of gas was completed jointly by Exxon and Qatar General Petroleum Corp. Capital costs for the project were estimated to be $1.2 billion- or $24,000 per daily barrel (DBL) of middle distillate capacity.

- Plant Capacity = 50,000bbl per day of middle distillate.
- Plant Cost = U.S.$ 1,200 million (Considering plant cost 24,000 per daily barrel of middle distillate capacity).

Economics of GTl Plant was studied using annual expenses to run the plant and annual revenue obtained from sales of the products. The results are summarized in Table 5.

- GTL Plant Capacity = 50,000 bbl/day of middle distillate
- GTL Plant Cost = U.S.$ 1, 200 million (Based on U.S. $ 24,000 per daily barrel)

Annual Profit = U.S. $ 2,256.981 Million

Table 4. Revenue Collected by Sales of FT-Products.

Product	Annual Production (Tons)	Average Price per Ton (U.S. $)	Annual Revenue from Sales of Products (U.S. $)
Flue Gas	Utilized as fuel in the plant	-	-
Liquid Products (Naphtha + Diesel)	2,414,110	1065	2571.027 Million
Wax	452,600	536	242.594 Million

Table 5. Summary of Economics of GTL Plant.
GTL Plant Capacity = 50,000 bbl/day of middle distillate
GTL Plant Cost = U.S.$ 1, 200 million (Based on U.S. $ 24,000 per daily barrel)

Annual Expenses	Annual Revenue from Sales of Products
Annual Cost of Natural Gas Processed = U.S. $ 345.390 million Annual Cost of Plant Operation = U.S. $ 91.250 million *(based on U.S. $ 5 per barrel of middle distillate)* Annual Plant Depreciation Cost = U.S. $ 120 million *(based on 10% depreciation per annum)*	Revenue obtained from sales of middle distillates = U.S.$2571.027 Million Revenue obtained from sales of wax = U.S.$ 242.594 Million
Total Annual Expenses = U.S. $ 556.640 million	Total Annual Revenue from Sales of Products = U.S. $ 2,813.621 Million

$$\text{Repayback vale of the plant} = \frac{\text{Plant Cost in U.S. \$}}{\text{Annual Profit in US \$}} = \frac{\text{U.S.\$ 1,200 Million}}{\text{U.S.\$ 2,256.981}} = 0.53 \text{ years}$$

Therefore, Repayback value of the plant = Approximately 6 month

CONCLUSIONS

1. GTL technology is Downstream value added industry (economic enhancement) of natural gas. At present Libya is exporting natural gas which can be transferred to value added products. It can be a strategic new export industry.
2. F-T products are free of sulphur, nitrogen and complex cyclic hydrocarbons. Its combustion results in virtually no emissions of SO_2, NO_x and unburned hydrocarbons. F-T products can be directly used without any purification process like hydrodesulphurization in case of crude oil derived fuels. F-T products hold a great promise in meeting the stringent exhaust emission norms.
3. The attraction of F-T diesel in addition to its purity is its fuel quality with respect to the cetane number. F-T diesel has a high cetane number of around 75 compared to minimum requirement 50 - 58 in most of the countries. A high cetane number provides fast fuel/air mixing and reduced engine delay before ignition. The other important effect of a high cetane number is the lower flame temperature which results in the reduced formation of oxides of nitrogen (NO_x).
4. F-T naphtha is considered to be an ideal feedstock for ethylene manufacture as compared to naphtha produced from crude oil due to the lack of aromatics. Absence of aromatics gives rise to higher ethylene yield as compared to ethylene from conventional naphtha.
5. A techno-economical study was performed for GTL plant of 50,000 daily barrels capacity of production of middle distillates. The annual revenue obtained from the sales of GTL products is U.S.$ 2,813.621 million while the annual revenue obtained from the export of natural gas is U.S.$345.390 million. The net annual profit from the GTL plant will be U.S.$2,256.981 million.
6. The cost of GTL plant (50,000 daily bbl capacity) is U.S.$ 1,200 million. The re-payback value of the plant is calculated to be approximately six months. Set up GTL plant in Mellitah will be an economically viable plant.
7. The installation of GTL plant in Mellitah will provide employment opportunity to young Libyans. This will bring know-how of new GTL technology among Libyans.

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