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Techno-Economic Analysis of Flare Gas to Gasoline (FGTG) Process through Dimethyl Ether Production

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ABSTRACT

It is well known that burning flare gases and releasing them into the atmosphere has become one of the problems of the oil, gas, and petrochemical industries. If these industries can produce energy or valuable materials from flare gases, it will be very profitable and less harmful to the environment. The purpose of this investigation is to design, simulation and economic evaluation the process of converting flare gas to dimethyl ether (DME) for the production of gasoline, Liquefied petroleum gas (LPG), and hydrogen by Aspen HYSYS v.11 software. The flare gas to gasoline (FGTG) process can be indirect or direct DME production (two scenarios). In the economic comparison of these scenarios, the total product sales, operating profit, total capital cost, desired rate of return (ROR), and payoff period (POP) will be calculated. The economic evaluation results show that using the FGTG process with direct DME production (second scenario) instead of the FGTG process with indirect DME production (first scenario), increases the product sales and operating profit by about 55% and 65%, and also the total capital cost and utility cost is decreased by about 30% and 50%, respectively. Finally, the desired ROR in the FGTG process with direct DME production and indirect DME production is 52 percent/year and 33 percent/year, and the POP for the second scenario is approximately 1.1 years earlier than the first scenario.

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1. Introduction

Iran is blessed with substantial energy resources, including natural gas and crude oil. In energy terms, Iran's proven natural gas reserves, approximated at about 34 billion cubic meters, are known to be considerably more than its oil resources. Crude oil consumption was more than 100 million barrels per day, according to figures released by British Petroleum Company (BP's) in 2019. However, in 2021, global crude oil consumption has reached 92 million barrels per day (Jaccard, et al. 2018). The main reason is the transition from fuels and fossil energy to reversible and clean energies such as hydropower, solar energy, wind energy, Etc. (Icaza, et al. 2021). Organization of the Petroleum Exporting Countries (OPEC) statistics show that Iran has the third-longest lifespan of oil reserves among the 140 OPEC member countries. According to these statistics, Iran's oil reserves will exist for another 138 years (Karamelikli, et al. 2017). Due to shortages of oil reserves in the future, efforts to replace synthetic fuels instead of crude oil have taken place (Puricelli, et al. 2021). Synthetic fuels can be produced from natural gas, coal, flare gases, biogas, Etc. Flaring is one of the most controversial issues dealing with today's problems of the energy industry and its environmental effects. Gas flaring poses a series of adverse health, ecological and economic outcomes. Although the purpose of the flaring system is to maintain the safety of engineers, workers, and equipment, burning in the flare tower produces some intermediate products, which are finally transformed to CO2 and H2O (Davoudi, et al. 2014). Flare gases can be used in many methods, for example, enhanced oil recovery (EOR), DME Production, gasoline production, hydrogen production, compressed natural gas (CNG) production, LPG production, ethylene recovery, combined heat and power (CHP) generation, desalinated water generation, Etc. (Iora et al. 2014; Saidi et al. 2018; Jafari et al. 2020a). Three conventional synthetic methods for gasoline production from flare gas are the Fischer-Tropsch (FT) process, the conversion of DME to gasoline (DTG), and the conversion of Methanol to gasoline (MTG) (Wan et al. 2018). The synthetic methods of gasoline production are illustrated in Figure 1. In the MTG and DTG process, the selectivity for gasoline production is approximately 80%. In contrast, in the FT process, it is approximately 30% and the remainder of the production of heavy liquid hydrocarbons (Materazzi and Holt, 2019).

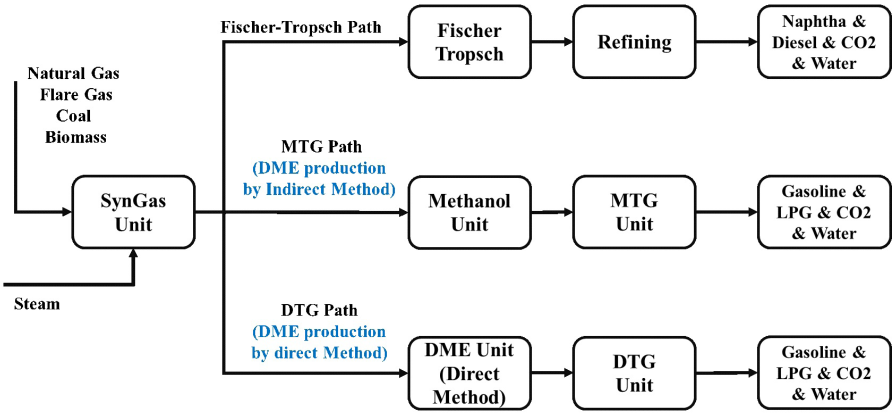

Figure 1. Gasoline Synthesis method: Fischer-Tropsch (FT), Methanol to Gasoline (MTG), and DME to Gasoline (DTG) (Wang et al. 2016)..

Few studies have been performed on the conversion of the FGTG Process. In a study by Lee et al. (1995), the technical comparison between the MTG and DTG processes has been investigated. The results showed The DTG process offers advantages over the Mobil MTG process in several areas. These include heat duty and heat of reaction, hydrocarbon product yield, synthesis gas conversion, and process efficiency. In a study by Stanley et al. (2009), the feasibility of converting flare gas to gasoline using the GTL process as a profitable method to reduce the amount of flaring in Nigeria has been investigated. Rahimpour et al. (2012) simulated and economically evaluated three different methods of flare gas recovery (FGR) (gasoline production, power generation, and gas compression). Simulation of these processes was performed in Aspen HYSYS software. The results showed that power generation has a higher ROR and faster payoff period (POP), and, finally, gasoline production has a higher annual profit. In a study by Zolghafari et al. (2017), Technical characterization and economic evaluation of FGR in various gas-processing plants have been investigated. Three methods, including GTL, gas turbines generation (GTG), and gas to ethylene (GTE), have been simulated using Aspen HYSYS. the results showed that the GTG method is one of the most economical methods and the GTE method has the higher annual profit. In a study by Hajizadeh et al. (2018), technical and economic evaluation of flare gas recovery in a Fajr-e Jam gas refinery have been investigated. Three methods for FGR were investigated, including two novel methods. The first two methods considered liquefaction and LPG production by implementing flare gases as feed for the existing LPG unit. Different parameters were studied in feed liquefaction and LPG production. The third studied option is using a three-stage compression unit to compress the flare gases. The results showed that the ROR for liquefaction and LPG methods is above 200%. In a study by Jafari et al. (2018), simulation and technical analysis of the Integrated FGTG process have been investigated. In this paper, an integrated FGTG process for converting flare gas to gasoline is simulated using the Aspen HYSYS software. The simulation results demonstrate that by recycling all gas emissions, such as off-gas from the methanol and MTG units back into the process, gasoline productivity and LPG productivity can be increased on average 55% and 10%. In a study by Jafari et al. (2020b), simulation and economic evaluation of a poly-generation system for co-production of power, steam, CH_3OH, H_2 and, CO_2 from flare gas have been investigated (figure 2). In this paper, the poly-generation system has been used for converting flare gas to energy and various products such as power, steam, methanol, H_2, and CO_2. A poly-generation system has a lower raw material cost, utility cost, and operating cost than the corresponding single-product processes. The simulation results showed that using 9690 kg/h of flare gas, 8133 kg/h methanol, 653.7 kg/h H_2, 46950 kg/h N_2, 9103 kg/h CO_2, 109850 kg/h MP steam, and 3.7 MW power have been produced. Also, the total capital cost and the operating profit of the poly-generation system are 71 million USD and 115 million USD/year, respectively, and the payoff period is 1.5 years.

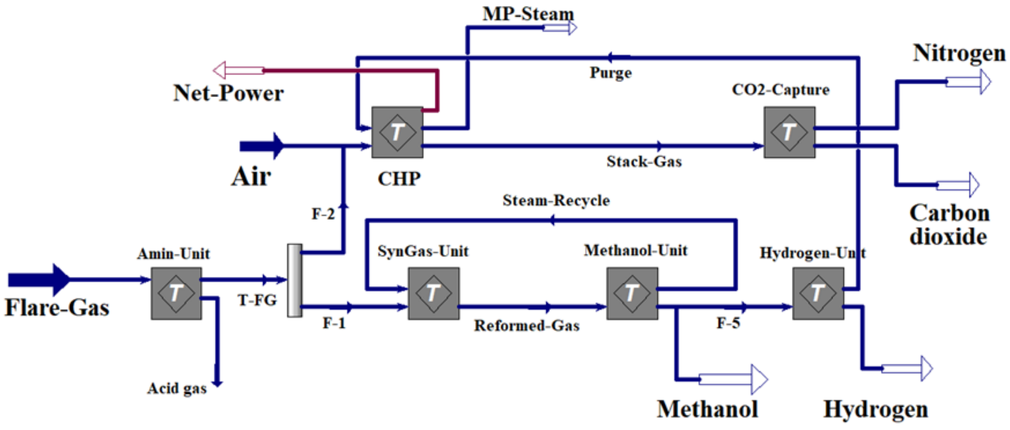

Figure 2. Block Flow Diagram (BFD) of conversion of flare gas into products in a poly-generation system (Jafari et al. 2020b).

The difference between the MTG and DTG processes is that the DME is produced indirectly in the MTG path, but in the DTG path, the DME is produced directly. In the Chemical Industry, the indirect method of DME producing is more than the direct method. The indirect method involves two synthesis steps: Methanol production from synthesis gas and dehydration of the methanol. Whereas the direct synthesis converts synthesis gas to DME using a hybrid of bi-functional. Considering the potential of producing various products from flare gases and preventing environmental pollution, in this project, an attempt is made to techno-economic analysis for the FGTG process using conventional processes. In articles published in previous years, no detailed studies have been conducted on the economic evaluation of the FGTG method. The innovations of this paper are the simulation of the conversion of flare gas to dimethyl ether (direct and indirect DME production method) with the aim of co-production of LPG, gasoline, and hydrogen and economic comparison of these processes. In the economic comparison of these processes, the total capital cost, operating profit, total utility cost, desired ROR, and the POP will be calculated.

2. Materials and Methods

South Pars and the Asaluyeh region are some of the country's largest sources of flare gas producers. Flaring is one of the most controversial issues dealing with today's problems of the energy industry and its environmental effects. Although the purpose of the flaring system is to maintain the safety of engineers, workers, and equipment, burning in the flare tower produces some intermediate products, which are finally transformed to CO_2 and H_2O (Jafari et al. 2020b). Currently, in the South Pars area, 45 burners are burning a huge volume of flare gases. 25% of all flared gas in Iran burns in the Asaluyeh region. The properties of Asaluyeh flare gases are given in Table 1.

Table 1. Characteristics of gases sent to Asalouyeh flare (Ziyarati at al. 2019).

Mole fraction	Component
Methane	0.851
Ethane	0.050
Propane	0.019
Ethane and C_4^+	0.018
CO_2	0.022
N_2	0.035
H_2S	0.005

On average, 8100 tons of flare gas is produced per day. This massive volume of burnt flare gases and their pollutants can certainly cause environmental problems in the Assaluyeh region and seriously impact human health. Therefore, planning for the collection and use of flare gases will have an excellent economic justification. Flare gas in the Asaluyeh region mainly contains methane, which is an excellent opportunity to produce valuable products such as gasoline and LPG. Simulation of conversion of flare gases into desired products was performed in Aspen HYSYS v. 11 software. The thermodynamic equation used in this simulation is PRSV, but some units require a different fluid package to be performed with very high accuracy. The fluid packages used in the various units are given in Table 2 (Lopez et al. 2017). The economic evaluation of this process was carried out using specialized economic evaluation software called Aspen Process Economic analyzer v. 11 or APEA. Features of this software include the possibility of connecting to simulation software such as Aspen HYSYS, Aspen Plus, PRO/II, mapping of various process equipment in simulation models, dimensioning of equipment, and cost estimation.

Table 2. Describe the specific fluid packages for each unit (Attary et al. 2018; Hajilary et al. 2020; Moradi et al. 2021 and Nejat et al. 2018).

Fluid Package	Description
Acid-Gas:	This fluid package is used for the Amine Treatment Unit. This new ability to purify acidic gases in Aspen HYSYS allows this to remove the acidic contaminant in the simulation with very high precision by choosing this thermodynamic equation; there is no need to define the reactions of amine and acid gases per unit of amine.
PRSV:	This fluid package is used for the Synthesis Gas Production Unit. The PRSV model is a two-fold modification of the Peng-Robinson equation of state that extends the application of the original Peng-Robinson method for moderately non-ideal systems. It is successfully expanded to handle non-ideal systems giving results as good as those obtained using excess Gibbs energy functions like the Wilson, NRTL, or UNIQUAC equations.
UNIQUAC:	This fluid package is used for the Methanol and DME Synthesis Unit. This equation presented by Abrams in 1975 uses Guggenheim's statistical mechanics and quasi-chemical theory to illustrate the fluid-structure. This equation, like the equation, NRTL can predict the behavior of LLE and VLE systems.
Peng Robinson:	This fluid package is used for the Hydrogen purification and Gasoline production unit. The Peng-Robinson (PR) model is ideal for VLE calculations for hydrocarbon systems. Several enhancements to the original PR model were made to extend its range of applicability and to improve its predictions for some non-ideal systems. For oil, gas, and petrochemical applications, the Peng-Robinson equation is usually recommended.

3. Process description of FGTG unit

This section describes the simulation of the process of converting flare gas to gasoline (FGTG). DME is the intermediate product of this process and will convert to gasoline. There are two scenarios (figure 3 & figure 4) for the production of DME:

1. FGTG Process with Indirect DME Production (first scenario).
2. FGTG Process with Direct DME Production (second scenario).

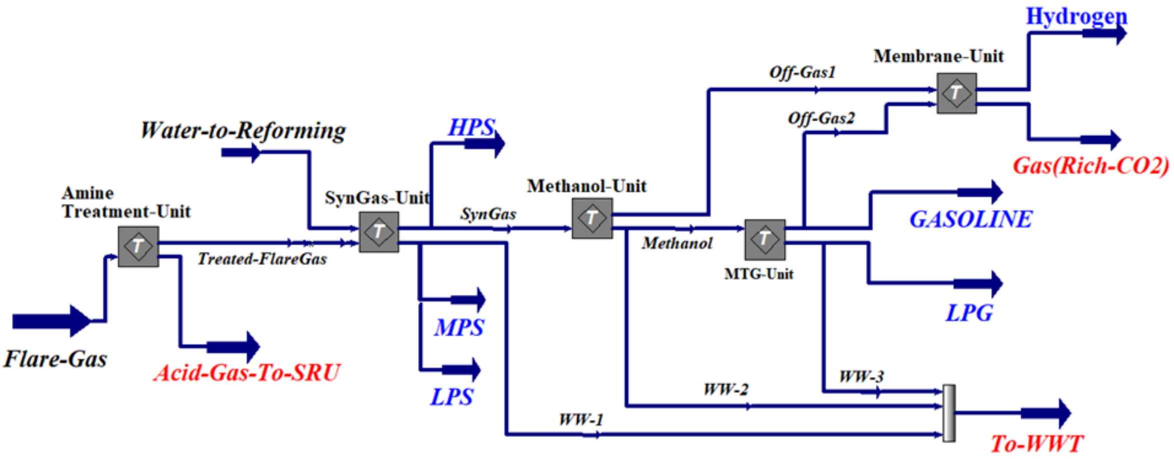

Figure 3. BFD of FGTG Process with Indirect DME Production

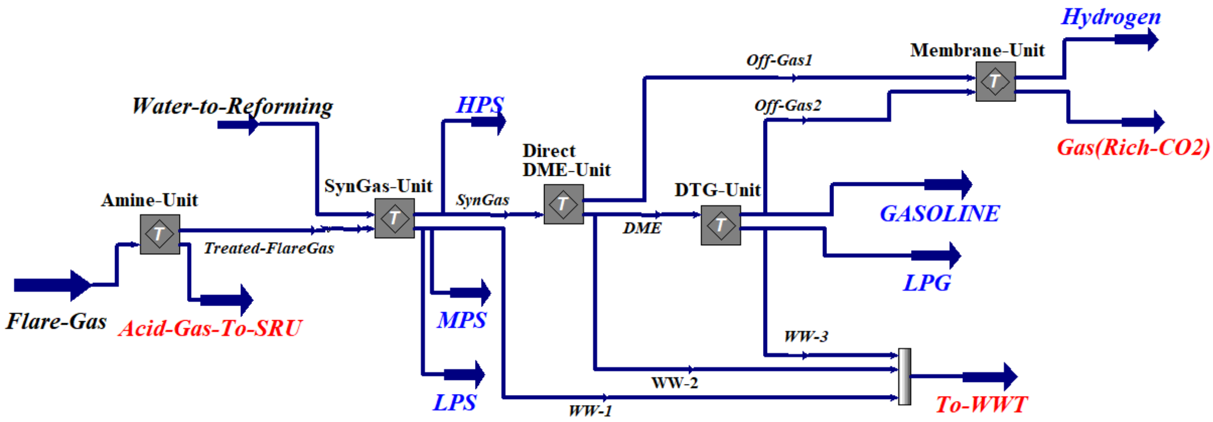

Figure 4. BFD of FGTG Process with Direct DME Production

The initial stage in the FGTG process is Amine Treatment Unit (figure 5). The flare gas enters the amine treatment unit with the specifications given in table 1, at a volume flow rate of 188500 m^3/h (Mass flow rate: 148.1 Ton/h) at 30 °C and a pressure of 100 kPa. The H2S in the flare gas is first separated in the Amine Treatment Unit and then sent to the synthesis gas production unit in these two scenarios. Many factors are involved in choosing the proper process for sweetening the gas; the most important are feed inlet temperature and pressure, selectivity, the mass fraction of acidic gases, final characteristics of treated gas, process economics, and environmental issues that influence. H2S is highly toxic and also acidic, which can cause corrosion. The solvent used in this process is MDEA, and the process pressure is 30000 kPa (Luo et al. 2014).

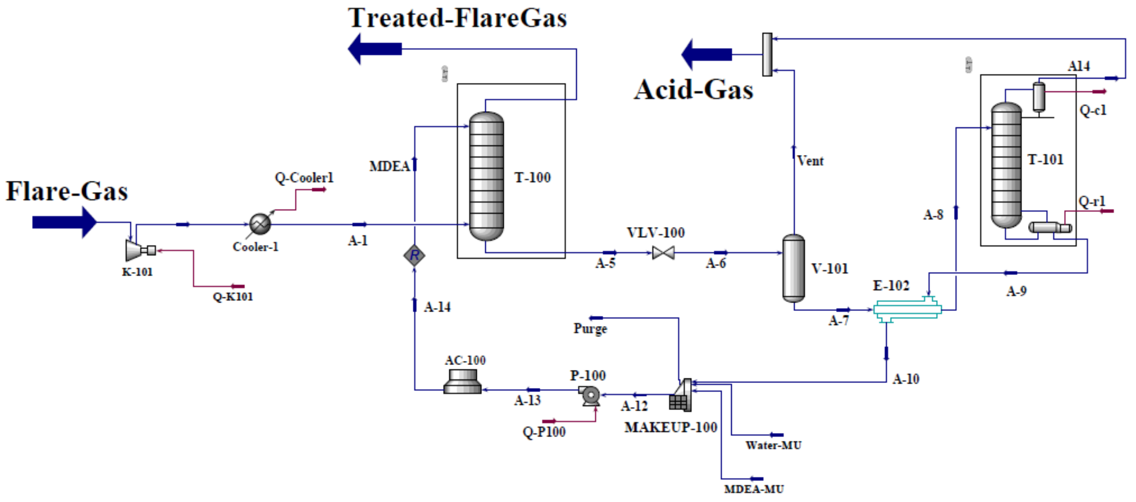

Figure 5. Schematic of Amine Treatment unit as configured in the Aspen HYSYS software environment (Luo et al. 2014).

The second stage in the FGTG process is the synthesis gas production unit (figure 6). The treated flare gas enters the synthesis gas production unit at a temperature of 50 °C and pressures 3000 kPa with water at a temperature of 25 °C and pressure 100 kPa. In the synthesis gas production unit, the ratio of H_2/CO is 4(Ghasemzadeh et al. 2016 and Jones et al. 2009). The amine treatment unit and synthesis gas production unit are the same in both scenarios. The first reactor is operated as a pre-reformer for reforming the heavier hydrocarbon components. Reactions 1 to 6 occur in the pre-reforming reactor. The conversion value in all reactions is 100%~~-the~~ second reactor reforms methane. Reactions 7 and 8 occur in the reforming reactor. Low-pressure steam (LPS), medium-pressure steam (MPS), and high-pressure steam (HPS), produces from the hot synthesis gas leaving the pre-reforming reactor.

In the first scenario, the synthesis gas is sent to the methanol unit, and methanol is produced. The produced methanol is then sent to the MTG unit. In this unit, methanol will first be converted to DME and then convert to liquid hydrocarbons. The process of methanol synthesis (figure 7) involves several steps, including compression of the synthesis gas, synthesis cycle, synthesis reactions and catalysts, and the purification of methanol. The synthesis gas can be converted to methanol by an exothermic reaction at an average temperature of 210-270 ºC and a 50 - 100 bar pressure in the presence of a copper alumina catalyst. The main reactions involved in methanol reactors are exothermic for an equilibrium model involving two reactions (Eq. 8 & 9).

$$C_2H_6 + 2H_2O \rightarrow 2CO + 5H_2 \qquad \text{Reforming ethane} \tag{1}$$

$$C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2 \qquad \text{Reforming propane} \tag{2}$$

$$i\text{ - }C_4H_{10} + 4H_2O \rightarrow 4CO + 9H_2 \qquad \text{Reforming i-butane} \tag{3}$$

$$n\text{ - }C_4H_{10} + 4H_2O \rightarrow 4CO + 9H_2 \qquad \text{Reforming n-butane} \tag{4}$$

$$i\text{ - }C_5H_{12} + 5H_2O \rightarrow 5CO + 11H_2 \qquad \text{Reforming i-pantane} \tag{5}$$

$$n\text{ - }C_5H_{12} + 5H_2O \rightarrow 5CO + 11H_2 \qquad \text{Reforming n-pantane} \tag{6}$$

$$CH_4 + H_2O \leftrightarrow CO + 2H_2 \qquad \text{Steam Methane Reforming} \tag{7}$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \text{Water Gas Shift} \tag{8}$$

$$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O \qquad \text{Methanol Synthesis Reaction} \tag{9}$$

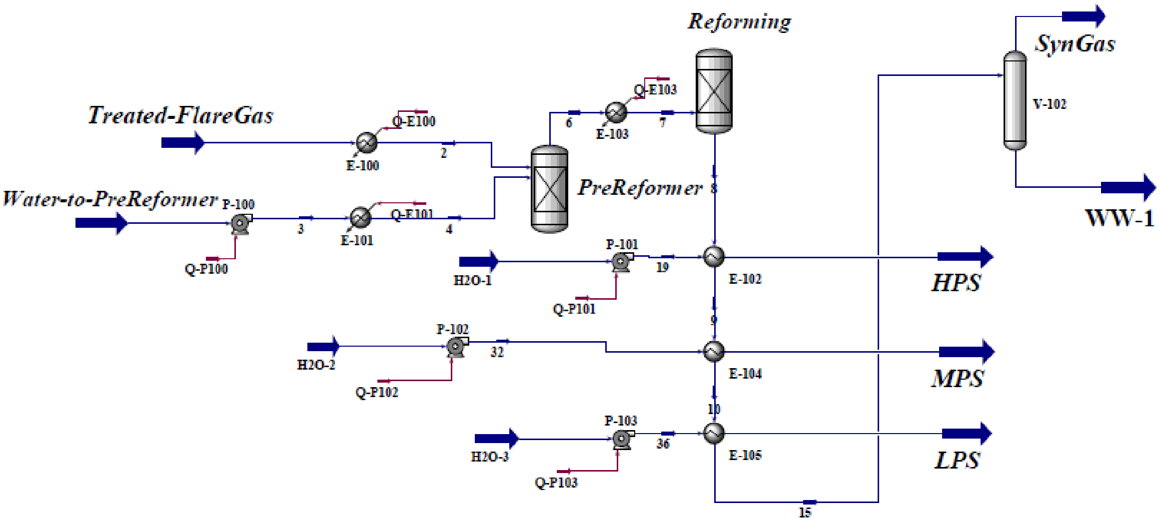

Figure 6. Schematic of synthesis gas production as configured in the Aspen HYSYS software environment (Ghasemzadeh et al. 2016).

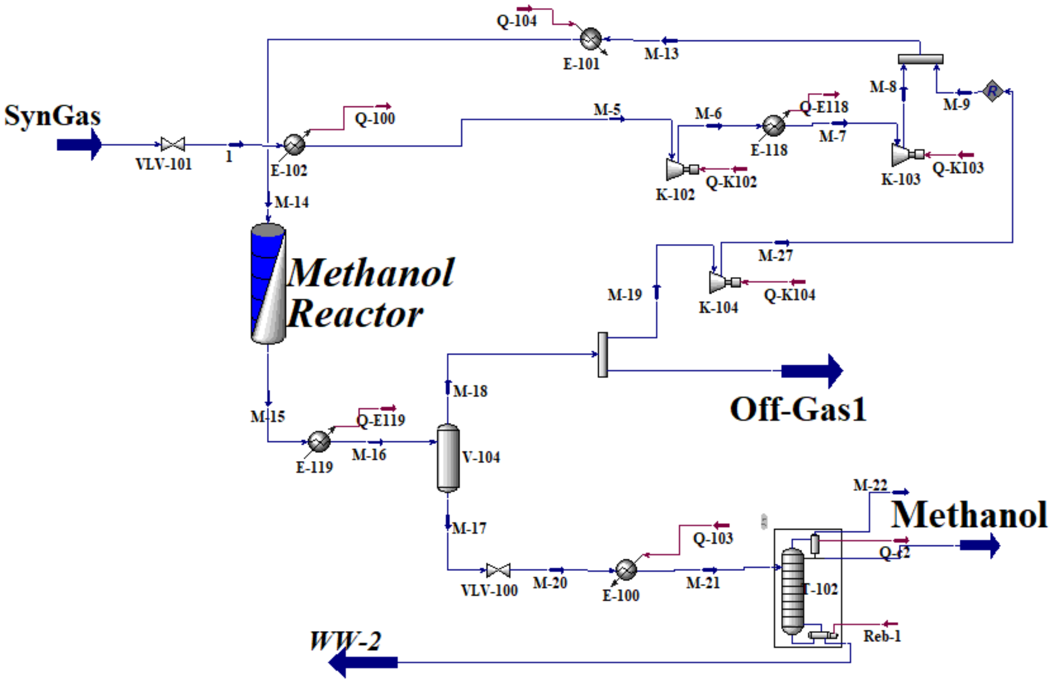

Figure 7. Schematic of methanol production unit as configured in the Aspen HYSYS software environment (Sunny et al. 2016).

Mobil operated the first MTG plant in New Zealand, producing gasoline of approximately 92-RON (Research Octane Number) quality, based on a process developed in the 1970s (Nian et al. 2013). The basis of the process of MTG is to convert methanol to DME and then to other hydrocarbons. The reaction is the strongly exothermic conversion of methanol to hydrocarbon products, and adiabatic temperature increase to about 600 ºC is associated. MTG reaction paths are summarized by Eq. 10 to 14:

$$2CH_3OH \leftrightarrow DME + H_2O \tag{10}$$

$$DME \rightarrow Light\ Olefins + H_2O \tag{11}$$

$$Light\ Olefins + DME \rightarrow Heavy\ Olefins + H_2O \tag{12}$$

$$Heavy\ Olefins \rightarrow Aromatics + Paraffin \tag{13}$$

$$Aromatics + DME \rightarrow Higher\ Aromatics + H_2O \tag{14}$$

The first step is the dehydration reaction of methanol, resulting in the equilibrium mixture of DME, methanol, and water. DME is then converted to light olefins. DME then converts light olefins (mostly propylene and butene) into heavier olefins, which can then react with each other to form aromatics and paraffin. A schematic of the MTG process configured in the Aspen HYSYS software environment is illustrated in Figure 8. This is applied to an integrated plant-wide FGTG process for converting flare gas to hydrocarbon fuel products, including gasoline and LPG.

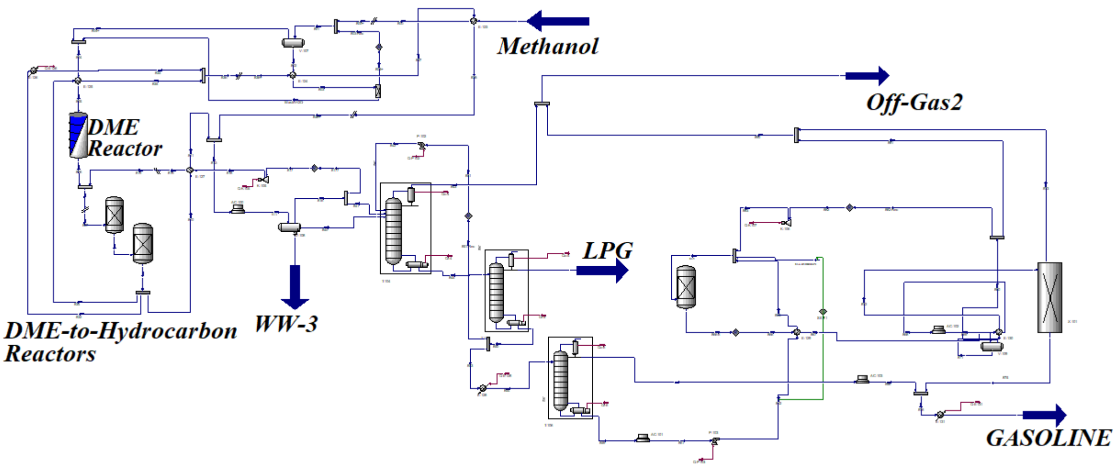

Figure 8. Schematic of MTG unit as configured in the Aspen HYSYS software environment (Hindman et al. 2013).

In the Second scenario, the synthesis gas is directly converted to DME. The produced DME is then sent to the DTG unit. In this unit, DME is converted to liquid hydrocarbons. Recently, a combination of the methanol co-production and dehydration of the methanol process for the direct synthesis of DME from the syngas at one reactor has been developed. The direct synthesis of DME from the syngas follows the three significant reactions 15, 16, and 17 and generally reaction 18. The reactions take place in the DME production, namely:

$$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O$$ Methanol synthesis (15)

$$2CH_3OH \leftrightarrow CH_3OCH_3 + H_2O$$ Methanol dehydration (16)

$$CO + H_2 \leftrightarrow H2 + CO_2$$ Water gas shift: (17)

$$3CO + 3H_2 \leftrightarrow CH_3OCH_3 + CO_2$$ Overall reaction: (18)

The schematic of the DME production (direct Method) process and DTG process configured in the Aspen HYSYS software environment is illustrated in Figures 9 & 10.

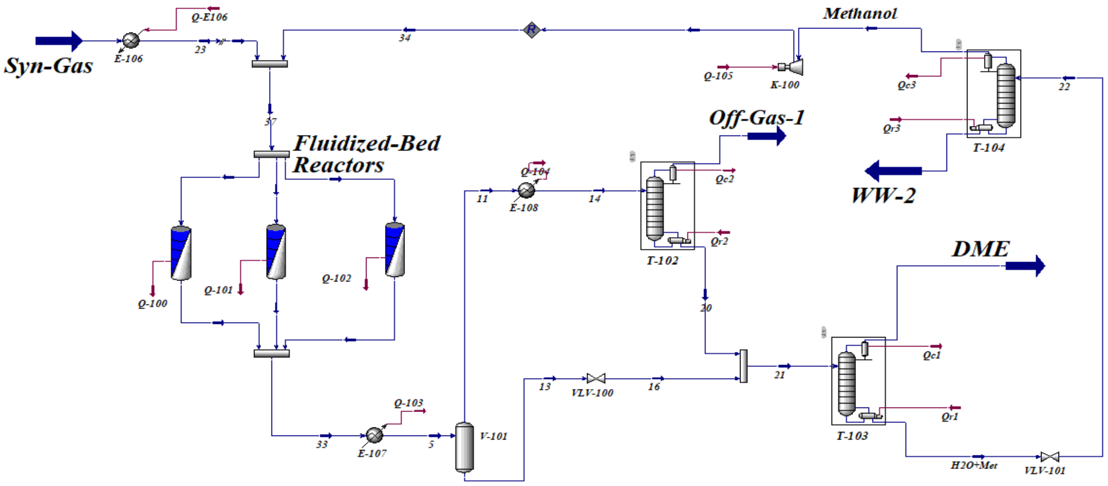

Figure 9.Schematic of DME production (direct method) as configured in the Aspen HYSYS software environment (Jones et al. 2009).

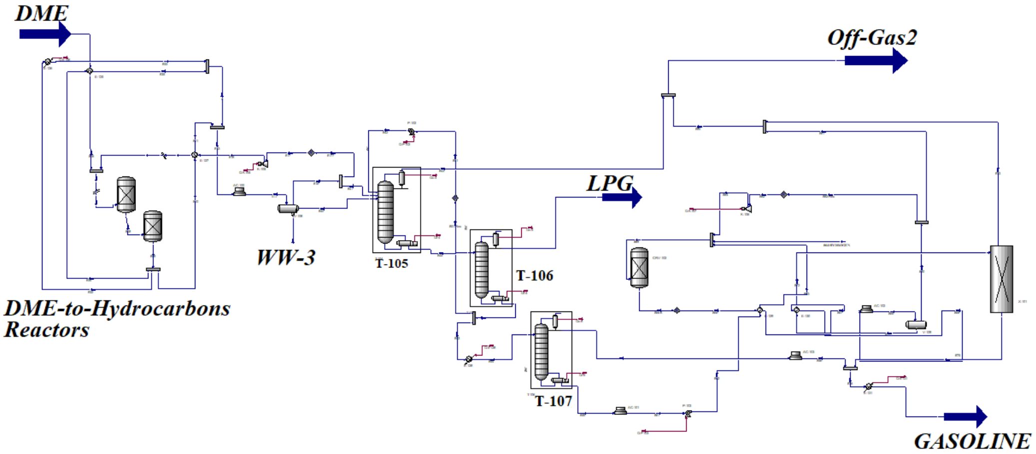

Figure 10. Schematic of DTG unit as configured in the Aspen HYSYS software environment (Hindman et al. 2013).

The off-gases produced from the methanol production unit, DME production unit, MTG unit, and DTG unit are rich in H_2. Pure H_2 can be one of the essential products along with gasoline and LG. Selling pure hydrogen and gasoline, and LPG can significantly impact the overall profit of the process and ROR. Membrane processes have been used to purify hydrogen. A schematic of the Membrane process configured in the Aspen HYSYS software environment is illustrated in Figure 11. In this process, two-stage silica membranes are used in series. The permeance and pressure gradient of silica membranes are given in Table 3.

Table 3. Properties of hydrogen permeance and selectivity of silica membrane (Saebea et al. 2019).

Specifications	Values
Stream pressure (kPa)	1300
Pressure gradient (kPa)	1200
Permeance of $H_2 \frac{m^3}{m^2.hr.pa}$	0.0003225
Permeance of $CH_4 \frac{m^3}{m^2.hr.pa}$	6.45×10^{-8}
Permeance of $C_2H_6 \frac{m^3}{m^2.hr.pa}$	8×10^{-8}
Permeance of $C_2^+ \frac{m^3}{m^2.hr.pa}$	5×10^{-9}

Since there is no membrane simulation in Aspen HYSYS software, another simulator software is needed. Since the PRO/II software can simulate a membrane system, this membrane is first simulated in this software and, then using the PRO/II software output, the same performance of the membrane in Aspen HYSYS software component splitter equipment has been implemented (Ghasemzadeh et al. 2017).

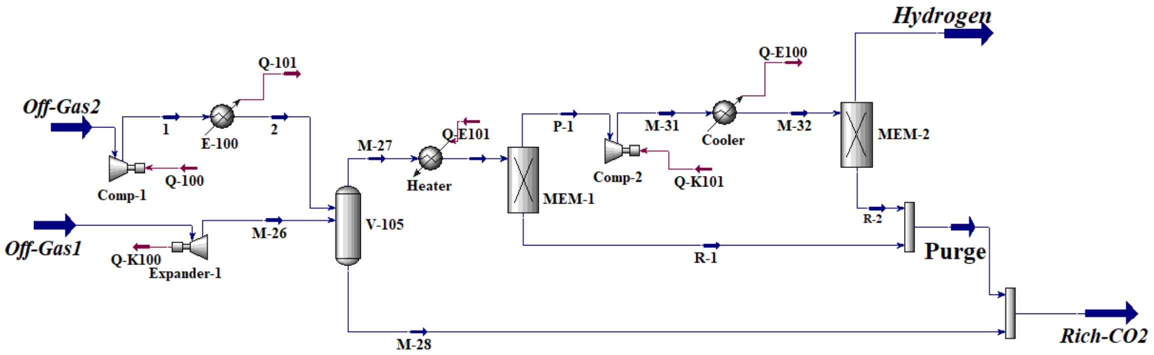

Figure 11. Schematic of Membrane Process for Hydrogen purification unit as configured in the Aspen HYSYS software environment (Jafari et al. 2020b).

4. Economic evaluation of FGTG Unit

In the following, it should be considered whether the production of gasoline from flare gases will be economically profitable or not. The most important issue in the economic evaluation of the chemical processes is obtaining the equipment cost, total installed cost, total capital cost, total operating cost, total utilities cost, operating profit, desired rate of return, and payoff period (POP) (Jafari and Khalili-Garakani., 2021a).

The operating profit of this process is defined as (Jafari et al. 2019):

Operating Profit = (Products Sales Price) - (Raw materials Price + Utility Cost)

Since the design of the FGTG is innovative, the design should be carefully evaluated in terms of economic. On the other hand, for the FGTG process, an accurate economic comparison shall be made between the direct or indirect production method of DME from flare gases to determine which has a higher desired ROR and an earlier payoff period. The following is a list of some commonly used terminology in economic evaluation with its description (Jafari et al. 2019):

- Equipment cost in APEA represents the cost of purchasing equipment, and total installed cost represents the total direct material and labor costs associated with the project component. Due to the items that are included in the installed cost, in APEA software, the installed cost is more than the equipment cost.
- Total utilities cost refers to the cost of cooling water, refrigerant, hot oil, steam, power, etc., annually.
- The total capital cost of this process is defined as: Total Capital Cost = Fixed Capital Cost + Working Capital Cost

  capital cost includes the following:

  - ✓ Direct costs: Equipment and setting, piping, civil, structural steel, instrumentation and controls, electrical equipment and materials, insulation, paint, etc.
  - ✓ Indirect field costs: Engineering and supervision, start-up and commissioning, construction expenses - fringe benefits, burdens, insurance, equipment rental, field services, temporary constructions, etc.
  - ✓ Indirect non-field costs: freight, taxes and permits, engineering, and material procurement, contingency, allowances for unpredictable events, other project costs, etc.
- The POP refers to the amount of time it takes to recover the total capital cost. The POP of this process is defined as: POP = Fixed Capital Cost / Net Profit
- The desired ROR of this process is defined as: ROR = (Net Profit / Fixed Capital Cost)

The right decisions made during economic evaluation operations, such as choosing the right type of equipment and utility, will significantly impact the correct economic evaluation. At the beginning of the work, the stream price of feed and product are entered to determine if the unit design capable of profitability or not (Jafari et al. 2019). Table 4 shows the stream prices of flare gas, products, and utilities. Hydrogen fuel prices range from 12 USD to more than 14 USD per kilogram, but the most common price is 12 USD per kg.

Table 4. Stream price for flare gas, products and utility

Stream Name	Cost	Unit	Ref.
Flare Gas (Raw material)	0.02	USD/m^3	[35, 19]
Water & cooling water (Raw material & Utility)	0.00418	USD/Ton	[19]
Gasoline (Product)	880	USD/Ton	[36]
LPG (product)	1000	USD/Ton	[37]
Hydrogen (product)	12000	USD/Ton	[38]
HP steam (product & Utility)	4.52	USD/Ton	[19]
MP steam (product & Utility)	4.36	USD/Ton	[19]
LP steam (product & Utility)	4.17	USD/Ton	[19]
Refrigerant (Utility)	2.71	USD/GJ	[19]

After determining the raw material cost, total products sales, the type of consumption utility of equipment is selected. A key step in APEA software is the mapping of equipment. For example, a distillation column in Aspen HYSYS might be mapped into several items such as a trayed or packed tower, a kettle-type reboiler, an overhead condenser, a reflux pump, etc. The default material of construction for all equipment is carbon steel. However, the materials used in the construction of the equipment can be changed according to conditions such as high temperature, high pressure, or corrosion. After mapping and sizing operations, the economic evaluation in the APEA software will be completed and the results will be reported (Meng et al. 2018).

5. Results and discussion

In these two simulated configurations (direct and indirect production of DME gases sent to flare for simultaneous production of gasoline, LPG, hydrogen, and steam at different levels), the connection between the flows in the main flowsheet and sub-flows sheet is established. In table 5 and Table 6 are compared the products produced and the rate of utility consumption in the two processes for co-generation of gasoline, LPG, and hydrogen.

The simulation results showed that using the FGTG process with direct DME production (second scenario) instead of the FGTG process with indirect DME production (first scenario) decreases the mass flow rate of gasoline and LPG produced by about 55% and 35%. The reason for the low production of gasoline and LPG in the second scenario is that the ratio of H_2/CO is high. If the H_2/CO is higher than 3, more methanol will be produced in the first scenario, resulting in more gasoline and LPG. If the H_2/CO is less than 3, the methanol will be produced less in the first scenario, and DME will be produced more in the second scenario. Also, the results show that using the second scenario instead of the first scenario increases the mass flow rate of hydrogen produced by about 100%. Since steam production is done at the same synthesis gas unit, LPS, MPS, and HPS production are the same in two processes. This table shows that the purification and separation of hydrogen from off-gas flows next to gasoline can be very profitable.

Generally, using the second scenario instead of the first scenario increases the sum of gasoline, LPG, hydrogen, and steam production at different levels by about 55%. Since hydrogen production is more expensive than gasoline and LPG, producing more hydrogen will be more profitable. Also, the total utilities cost in the second scenario in terms of power, heating, and cooling is less than in the first scenario. However, the water production of the first scenario is much more compared to the second scenario. Finally, the simulation results show that using the first scenario instead of the second scenario increases the total utilities consumption by about 50%.

Table 5. Flow rates and price of purchases of flare gas and utilities

	FGTG with Indirect DME Production (first scenario)				FGTG with Direct DME Production (second scenario)			
Feeds & Utilities	Mass flow	Unit	Cost flow	Unit	Mass flow	Unit	Cost flow	Unit
Flare Gas	148.1	Ton/h	3770	USD/h	148.1	Ton/h	3770	USD/h
Water	1361	Ton/h	5.69	USD/h	1361	Ton/h	5.69	USD/h
Power	579.1	GJ/h	9149.78	USD/h	384.4	GJ/h	6073.52	USD/h
Cooling-water	2848	GJ/h	605.2	USD/h	2544	GJ/h	540.6	USD/h
HP Steam	4119.2	GJ/h	10298	USD/h	3391	GJ/h	8477.5	USD/h
MP Steam	2204.3	GJ/h	4849.46	USD/h	658.7	GJ/h	1449.14	USD/h
LP steam	754	GJ/h	754	USD/h	131.9	GJ/h	250.61	USD/h
Refrigerant	0	GJ/h	0	USD/h	176	GJ/h	477.136	USD/h

Table 6. Flow rates and Price of Product Sales

	FGTG with Indirect DME Production (first scenario)				FGTG with Direct DME Production (second scenario)			
Products	Mass flow	Unit	Cost flow	Unit	Mass flow	Unit	Cost flow	Unit
HP steam	869.1	Ton/h	3700.19	USD/h	869.1	Ton/h	3700.1933	USD/h
MP steam	124.5	Ton/h	542.82	USD/h	124.5	Ton/h	542.82	USD/h
LP steam	227.2	Ton/h	948.37	USD/h	227.2	Ton/h	948.36915	USD/h
Hydrogen	12.51	Ton/h	150120	USD/h	25.69	Ton/h	308280	USD/h
Gasoline	76.09	Ton/h	66959.2	USD/h	49.48	Ton/h	43542.4	USD/h
LPG	15.54	Ton/h	15540	USD/h	11.46	Ton/h	11460	USD/h
Gas (Rich CO_2)	19.27	Ton/h	0	USD/h	125.5	Ton/h	0	USD/h
Acid Gas	3.95	Ton/h	0	USD/h	3.95	Ton/h	0	USD/h
to-WWT	130.4	Ton/h	0	USD/h	55.11	Ton/h	0	USD/h

Table 7, is showed a summary of the economic comparison of the FGTG process in two scenarios. The results show that both methods of FGTG can be very profitable. On the other hand, the FGTG process with direct DME production (second scenario) is better than the FGTG process with indirect DME production (first scenario). The results show that using the first scenario instead of the second scenario increases the equipment cost, total installed cost, and total capital cost by about 30%, 35% and 23%, respectively. Also, using the second scenario instead of the first scenario increases the net profit and total operating profit by about 20% and 65%. ROR of the second scenario is 52% and for the first scenario is 33%. Finally, the POP for the second scenario is approximately 1.1 years earlier than the first scenario.

Table 7. Summary of the Economic comparison of the FGTG Process with Indirect DME Production and FGTG Process with Direct DME Production

	FGTG with Indirect DME Production (first scenario)	FGTG with Indirect DME Production (first scenario)	Unit
Total Raw Materials Cost	32.57	32.57	MUSD/year
Total Product Sales	2054.68	3183.61	MUSD/year
Total Utilities Cost	199.14	130.50	MUSD/year
Operating Profit	1822.97	3020.54	MUSD/year
Total Equipment Cost	265.00	204.00	MUSD
Total Installed Cost	301.00	223.00	MUSD
Fixed Capital Cost	1075.17	828	MUSD
Working Capital Cost	190	146	MUSD
Total Capital Cost	1265.17	974.00	MUSD
Net Profit	354.80	430.56	MUSD/Year
Desired Rate of Return	33	52	Percent/Year
Payoff Period	3.00	1.90	Year

6. Conclusions

This work has addressed simulation and economic comparison of the process of converting 148 Ton/h (188500 m^3/h) of flare gas to gasoline, LPG, and hydrogen with two scenarios (indirect or direct production of DME).

Aspen HYSYS v.11 was used to carry out the process simulation studies. Also, Comparison and economic analysis of these two scenarios for the simultaneous production of gasoline and other products were presented in APEA v.11. The H_2S in the flare gas is first separated in the Amine Treatment Unit and then sent to the synthesis gas production unit in these two scenarios. In the synthesis gas production unit, the ratio of H_2/CO is 4. The amine treatment unit and synthesis gas production unit are the same in both scenarios. In the direct process of producing DME, the treated flare gas is converted directly to DME, but in the indirect method, the treated flare gas is first converted to methanol and then to DME. The following are the main results obtained from the simulation and economic evaluation:

- ✓ The first scenario (FGTG process with indirect DME Production) produces 76.09 ton/h of gasoline, 15.54 ton/h of LPG, and 12.51 ton/h of hydrogen. But in the second scenario (FGTG process with direct DME production), 49.98 ton/h of gasoline, 11.46 ton/h of LPG, and 25.69 ton/h of hydrogen will be produced.
- ✓ Gasoline and LPG production are higher in the first scenario, but hydrogen production is higher in the second scenario.
- ✓ Total utilities cost in the first scenario increased by about 50% than in the second scenario.
- ✓ Operating profit in the second scenario increased by about 65% than in the first scenario.
- ✓ Raw material cost in the two scenarios was equal, and total product sales in the second scenario increased by about 55% than in the first scenario.
- ✓ Capital cost in the first scenario increased by about 30% than in the second scenario.
- ✓ The desired ROR in the first scenario is 33% and in the second scenario is 52%.
- ✓ POP for the first scenario is 3 years and in the second scenario is 1.9 years.

Further research is needed to increase the production of products such as gasoline and LPG, sensitivity analysis of CO_2-rich gas return to the syngas unit to increase production. Also, the wastewater stream will be returned to the process after treatment to avoid excessive water consumption in the process. Multi-objective and single-objective optimizations are also needed to reduce energy consumption, reduce capital costs, and increase valuable products such as gasoline, LPG, and hydrogen.

Nomenclature

FGR	Flare gases recovery
ROR	Rate of Return
POP	Payoff Period
DME	Dimethyl Ether
LPG	Liquefied petroleum gas
FGTG	Flare Gas to Gasoline
OPEC	Organization of the Petroleum Exporting Countries
BP	British Petroleum
FT	Fischer-Tropsch
DTG	Dimethyl Ether to Gasoline
MTG	Methanol to Gasoline
GTL	Gas to Liquids
EOR	Enhanced Oil Recovery
CNG	Compressed Natural Gas
CHP	Combined Heat and Power
APEA	Aspen Process Economic Analyzer
BFD	Block Flow Diagram
PFD	Process Flow Diagram
MDEA	Methyl Diethanolamine
LPS	Low-Pressure Steam
MPS	Medium-Pressure Steam
HPS	High-Pressure Steam
GTG	Gas Turbines Generation
GTE	Gas to Ethylene
MUSD	Million United Stated Dollars
P.O. Period	Payoff period
RON	Research Octane Number

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تجزیه و تحلیل فنی و اقتصادی فرآیند تبدیل گاز فلر به بنزین (FGTG) از طریق تولید دی‌متیل‌اتر

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چکیده

مسئله سوزاندن گازهای فلر و رهاسازی آن‌ها به اتمسفر، به یکی از مشکلات صنایع نفت ، گاز و پتروشیمی تبدیل‌شده است. اگر این صنایع بتوانند انرژی یا مواد ارزشمندی را از گازهای فلر تولید کنند، بسیار سودآور خواهد بود و همچنین محیط‌زیست هم آسیب کمتری خواهد دید. هدف از این تحقیق، طراحی، شبیه‌سازی و ارزیابی اقتصادی فرآیند تبدیل گاز فلر به دی‌متیل‌اتر به‌منظور تولید هم‌زمان بنزین، گاز مایع و هیدروژن در نرم‌افزار Aspen HYSYS v.11 است. فرآیند تبدیل گاز فلر به بنزین (FGTG) می‌تواند از دو مسیر تولید مستقیم یا غیرمستقیم دی‌متیل‌اتر صورت بگیرد (دو سناریو). در مقایسه اقتصادی این دو سناریو، هزینه فروش محصول، سود عملیاتی ، کل هزینه سرمایه‌گذاری، نرخ بازده سرمایه‌گذاری و بازگشت سرمایه محاسبه خواهد شد. نتایج ارزیابی اقتصادی نشان می‌دهد که استفاده از فرآیند FGTG با تولید مستقیم دی‌متیل‌اتر (سناریوی دوم) به‌جای فرآیند FGTG با تولید غیرمستقیم دی‌متیل‌اتر (سناریوی اول) فروش محصول و سود عملیاتی را حدود ۵۵ درصد و ۶۵ درصد افزایش می‌دهد و همچنین کل هزینه سرمایه‌گذاری و هزینه یوتیلیتی به ترتیب حدود ۳۰ درصد و ۵۰ درصد کاهش پیدا می‌کند. سرانجام ، نرخ بازده سرمایه‌گذاری در فرآیند FGTG با تولید مستقیم دی‌متیل‌اتر و تولید غیرمستقیم دی‌متیل اتر به ترتیب ۵۲ درصد در سال و ۳۳ درصد در سال است و همچنین بازگشت سرمایه در سناریوی دوم ۱/۱ سال زودتر از سناریوی اول است.

واژگان کلیدی: گاز فلر، دی‌متیل‌اتر، بنزین، هیدروژن، سود عملیاتی، عسلویه