Techno-economic Analysis of DME Plant Based on Gasification of Palm Empty Fruit Bunch

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Abstract: Biomass from EFB is considered as potential renewable energy sources to be developed in Indonesia. EFB can be efficiently converted into valuable and useful fuel products through gasification. Gasification is a process of biomass conversion into syngas. Syngas is a raw material for most other chemical products, such as Methanol, Ammonia, and DME. One of the biomasses that has big potential and available abundantly is palm EFB waste. Research about DME synthesis from various biomass has been done. Although little research about DME production based on EFB gasification was carried out, there is no research yet being conducted on techno-economic analysis of DME Plant construction based on EFB gasification. The aim of this research is to find feasibility of small scale DME plant model based on gasification of palm EFB with 6.16 tons per hour EFB feed. Method encompasses step to perform simulation of the model and DME plant design, to do equipment sizing, to conduct costing, to calculate investment cost estimation, to calculate operating cost estimation, calculation of profitability estimation in term of BEP, and calculation of economic feasibility parameters. The model predicts yield of DME product in agreement with published real DME plant operation. The result shows flow rate of DME produced is 50% of EFB feed flowrate and 73% energy efficiency obtained for pre-treated EFB. Electric power requirement has been investigated at 3683 kW and can be fulfilled by DME Plant through waste heat steam generation cycle and internal combustion engine fuelled by off-gas. Economic analysis calculated that the total investment to build DME plant in this study was USD 104,291,799. NPV calculated was USD -42,393,967, and IRR at 4.4%. Based on NPV, IRR, PBP calculated, DME plant construction based on gasification of EFB is not feasible. Feasibility can be attained, if discount rate lower than 4.4% applied. It was estimated that 4 times increase in capacity makes DME construction process feasible. This study further will be used as the base for the bigger scale techno-economic analysis of DME Plant construction based on gasification of EFB.

Keywords: EFB, cost, DME, feasibility, profitability, simulation

1. Introduction

The need for renewable energy in Indonesia is a necessity. From various renewable energy alternatives available, renewable energy from biomass has great potential to be developed in Indonesia. The biomass potential in Indonesia is about 32 GWe, and recent utilization was only around 1,740.40 GWe or 5.4% of the total potential [1]. It was estimated by [2] that biomass potential in Indonesia at 146.7 million tons per year equivalent to 470 GJ/y.

Utilization of biomass to be used as one of energy source can be done through gasification process. Gasification is a thermochemical process that converts biomass into a gas called a producer gas or synthetic gas (syngas). Syngas is a fuel-based mixture consisting mainly of Hydrogen (H_2), Carbon Monoxide (CO), and Methane (CH_4) [3]. Syngas is a raw material for most other chemical products, such as Methanol, Ammonia, and Dimethyl Ether (DME). One of the biomasses that has big potential to be utilized is palm empty fruit bunch (EFB) waste. On year 2014 in Indonesia, total EFB waste generated was 17.43 million tons per year [4] and on year 2015, it was 30.6 million per year [5]. Based on [6]Indonesia is currently the world's largest producer of palm oil and in line with this, it can be said that the waste generated is also very large, including EFB. Every kg of Crude Palm Oil (CPO) produced, it will produce 4 kg of dry biomass. One-third of this biomass is EFB and the rest are palm leaves and stems [7]. Abundant EFB resources has potential to be used as raw material for further chemical synthesis through gasification route.

In this study, EFB is gasified and further processed to obtain DME. DME itself is the simplest ether and it chemical formula is CH_3OCH_3 [8]. The physical properties of DME are similar with Liquefied Petroleum Gases (LPG) and can be used as substitute due to the similarity in characteristic [9]. The DME burns with a clear blue flame, and unlike natural gas or LPG, DME does not require the addition of odors because it has a sweet-etheric [8]. DME can be used as fuel for Diesel engines, because DME has higher cetane number than regular diesel fuel and self-ignition characteristics that make it suitable to be used as fuel for Diesel engines, with some modifications to the fuel distribution system, since DME is a gas at room temperature [10].

Research related to the utilization of EFB as a renewable energy source of biomass has been done. Some of these are studies related to the manufacture of biomass pellets to be utilized as feeds of gasifier and boiler reactors by.[11], [12] research related to the utilization of EFB into bio-oil products is conducted by [13] which discusses the conversion of EFB to bio-oil through pyrolysis pathway, conversion of EFB into bio-syngas by using fluidized bed reactors performed by [14], and research by combining pyrolysis catalytic cracking method to produce bio-syngas with gasification by [15]. Some of the research related with the techno-economic analysis of chemical and fuel products based on gasification of EFB were conducted by [16] on utilization of EFB to generate electricity, [17]) which analyze the techno-economic of bio-oil production, [18] that was discussed about techno-economic analysis of EFB conversion into bio-ethanol, and jet-fuel, conversion into power, and fast pyrolysis and bio-oil upgrading.

Although research related to the utilization of EFB as a source of energy has been done, but so far only one research related to EFB conversion into DME through gasification route found. The research was conducted by [19] which discussed about parametric analysis of bio-DME product. There is still no research or study pertinent to Techno-economic analysis of DME production based on EFB gasification yet been found, therefore this study arises to provide an economic analysis of DME production plant based on EFB gasification. In conducting economic analysis, the calculation of the sales and demand for DME was based on the demand of LPG and DME FOB price.

2. Theory Background

2.1 Gasification

Gasification is a process that converts biomass into a gaseous fuel called producer gas (CO, H_2, CH_4, etc.) using a little air or oxygen/steam. Reaction occurs is incomplete combustion. According to the reference [15], gasification reactions involve several series of chemical reactions such as: drying, pyrolysis, combustion processes, gasification processes, and auxiliary processes such as gas and water phase displacement reactions.

2.2 DME Synthesis

The process of producing DME using biomass as raw material was divided into 4 stages: gasification, water-gas shift, gas purification, and DME synthesis [19].

The basic reaction for single-stage DME synthesis consists of several reaction steps shown in Table 1.

According to [20], there are two routes of the overall reaction of single-stage DME synthesis from syngas, those are reactions (a) and (b) in the table 1. The reaction (a) which is the overall reaction consists of 3 reaction steps that is, methanol synthesis reaction (c), dehydration reaction (d), and water-gas shift (WGS) reaction (e). The overall reaction (b) consists of reaction step (c) and (d). The single-stage DME synthesis reaction of JFE technology follows the overall reaction (a), while the Haldor Topsoe A/S technology and other technologies follow the overall reaction (b).

The technology used for simulation purposes on the model developed was adopting JFE technology combined with research results done by [21] about the techno-economic analysis of torrefied biomass and process configuration described on [22], which was describing about the potential of DME as an alternative to conventional fossil fuel. Reference [22] was made by EPCM consultant based on south Africa. The description of the process and reaction between [21] and [22] was quite similar with reference from [20] with topic about pilot plant 5 tons per day DME production through single-stage synthesis route. Those references were based on technology developed by JFE, and transparently provides detail information about the process.

2.3 Techno-economic Analysis

To prepare techno-economic analysis, a process simulation is conducted to know the balance of mass, balance of energy, physical property estimation, design calculation, costing, process optimization, accurate description of physical properties of pure components and complex mixtures, models for various reactors and operating units, numerical techniques to solve large systems of algebraic and differential equations [23]. The simulation conducted in this study was using Aspen Hysys process simulator.

Table 1. Reaction of Single Stage DME Synthesis

Reaction	Heat of reaction (kJ/mol)
(a) $3CO+3H_2 \rightarrow CH_3OCH_3+CO_2$	-246
(b) $2CO+4H_2 \rightarrow CH_3OCH_3+H_2O$	-205
(c) $2CO+4H_2 \rightarrow 2CH_3OH$	-182
(d) $2CH_3OH \rightarrow CH_3OCH_3+H_2O$	-23
(e) $CO+H_2O \rightarrow CO_2+H_2$	-41

For techno-economic analysis, equipment sizing to find equipment cost is important, and the sizing can be done by Aspen Hysys for most of the equipment, while for other equipment which could not be sized using Aspen Hysys, the cost and sizing can be found through estimation by six-tenths rule. Six-tenths rule is approximation of cost that developed over years and gives very satisfactory results when only an approximate cost within 20% accuracy is required [24].

Some of the equipment cost available only valid at the time they were developed, and prices may have changed with time due to changes in economic conditions. To update the cost data applicable at present, cost indexes can be used [25]. The most common cost indexes used were Marshall and Swift all-industry and process-industry equipment indexes, the Engineering News Record construction index, the Nelson-Farrar refinery construction index, and the Chemical Engineering plant cost index (CEPCI) [25], which the latter is used in this study.

Techno-economic analysis is a feasibility analysis of a project from a technical and economic point of view. To analyze an investment feasibility, it is necessary to know first the cost components of DME plant construction based on EFB gasification. Costs that need to be known are divided into costs for ISBL (inside battery limit) and cost for OSBL (Outside battery limit), as well as start-up and working capital costs. ISBL costs are directly related to the process, equipment purchases, and installation of equipment. While the OSBL costs include the costs of supporting facilities and other non-process costs [26]. The cost of supporting facilities consists of buildings and non-process facilities that should be provided such as health care facilities, fire brigades, cafeterias, and so on ([27]. The parameters used in the investment feasibility analysis based on [25] are as follows.

1. Net present value (NPV) or net present worth, defined as the difference between cash inflows and outgoing cash flow at present. If the cash flow is not the same each year, then the NPV is calculated as the sum of the discounted cash flow each year. A project is declared feasible if its NPV is positive (NPV> 0).
2. Internal Rate of Return (IRR) is the discount rate that will cause the NPV of a project to be equal to zero. The IRR value of an economically viable project is always higher than the cost of capital or the discount rate used. An investment project is considered feasible if the investment IRR value is greater than the minimum

acceptable rate of return (MARR). The MARR value is determined based on the bank interest rate or bank interest rate plus the risk level of the project plus the expected profit level of the investor.

2.4 DME Market Opportunities for LPG Replacement

In conducting economic analysis, the calculation of the selling price and the demand for DME is based on demand of LPG and DME FOB price. The use of LPG as household fuels can be seen in almost all areas of Indonesia, especially after the government's policy to replace kerosene fuel with LPG in 2007 [28]. The development of this market creates a great opportunity for the LPG processing industry, including DME. Figure.1 is a graph that illustrates the need for LPGs in Indonesia up to 2016, data from reference [29].

At present, most LPG needs in Indonesia are met through 35% domestic supply, while 65% of the demand is obtained through imports [30]. There is potential for import reduction through the utilization of oil palm EFB to become DME as LPG substitution.

3. Methodology

3.1 DME Plant Design

3.1.1 Simulation Tools

The simulation was done by using Aspen Hysys process simulator. Aspen Hysys has been used in several studies to simulate biomass gasification [12][32] and DME production [19] . The various components that comprise Aspen Hysys provide an extremely powerful approach to steady state process modeling.

The user describes the process in terms of pieces of equipment interconnected by process stream, and the program solves all the mass/energy/equilibrium equations, taking into consideration the specified design for the units [33]. Feedstock EFB is not a default component in Aspen Hysys and must be put manually as Solid Hypothetical component. The input of EFB as hypothetical solid component was based on ultimate analysis of EFB measured feedstock based for simulation is dry ash free (daf) base. From weight percentage of components C, H, O, N, S. Process Flow Diagram (PFD) of DME Plant was shown on figure 2. PFD developed come with detail energy flow.

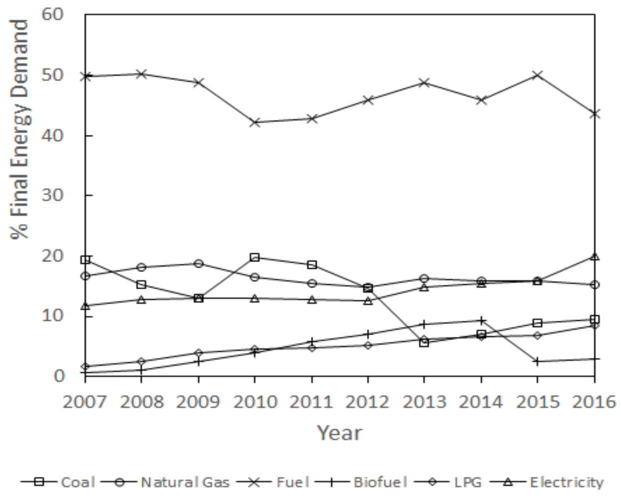

Figure 1. Final energy demand percentage

3.1.2 Biomass Feedstock

Feedstock used was Empty Fruit Bunch (EFB). The composition of the EFB was based on dry ash free base (daf) taken from [12]. Based on ultimate analysis chemical formula can be determined [32]. In 100 grams of biomass, there is 51.67 grams of carbon. Mass in grams divided by carbon molecular weight (12 g/mol) will give result of 4.306 mol of carbon. The same is applied to other elements which lead to the following chemical formula for EFB Biomass: $C_{4.306}\,H_{6.176}\,O_{2.587}\,N_{0.048}\,S_{0.003}$, and this chemical formula is used as an input to Aspen Hysys as hypothetical solid component. The input of EFB is at 6.16 tonnes per hour, based on [34].

3.1.3 Biomass Pre-treatment

Before the gasification process, raw biomass in any form needs to go through pre-treatment process. This pre-treatment process was consisting of several parts, such as granulator, dryer, hammermill, and pelletizer [12]. In the form of pellets, EFB has a greater energy density, reducing the bridging problem in gasifiers that use biomass with non-uniform sizes [12]. According to [35], with pelletizing, bulk density of EFB increases almost three times after the pellet-making process. Energy required for EFB pellet making is 210 kWh/dry long fiber[36]. It was assumed that dried EFB is the same with dry long fiber (DLF).

3.1.4 Gasification

The process of gasification occurs in Circulating Fluidized Bed (CFB) gasifier. Gasifier used Steam–Oxygen as an oxidant. Oxygen supplied by cryogenic air separation process. The electricity consumption of air separation unit was based on [21] at 1.0 MWe/ kg O_2/s. The composition of the syngas as result of gasification was calculated based on equilibrium reaction at 900 °C, and the process assumed isothermal during the gasification reaction [37]. Waste heat from reactor used as heat for steam generation, since reactor cooled using water, and water will turn into steam (steam generator I) for gasification oxidant supply. Some of the steam generated flow into steam turbine and combined with other steam generated by waste heat generate electricity. From the CFB gasifier, syngas outlet cooled to 400 °C, before entering Water Gas Shift (WGS) reactor to adjust for the H_2 to CO ratio (H_2/CO) equal 1 for DME synthesis requirement [38]. Raw syngas outlet was filtered using bag house filter to remove particulates.

3.1.5 Water Gas Shift

Water gas shift reaction takes place to adjust for the composition of H2/CO equal 1 [38]. Temperature of the reaction is at 400 °C and pressure 1000 kPa based on [32]. Prior to acid gas removal process, syngas cooled to 25 °C [39]. Gibbs reactor was used to simulate the reaction and amount of steam supplied to WGS reactor to get H2/CO = 1 was 130 kg/h. Type of WGS used is High Temperature WGS, because it favors WGS reaction with a greater reaction rate [32]. WGS reactor volume was obtained by using (1) which is ideal reactor formula [40], residence time value taken was 1.8 m/s [32] .

$$V = t_R \cdot Q \quad (1)$$

Where, V is volume of reactor in m^3 and t_R is residence time in seconds and Q is reactor flow rate in m^3/s.

Catalyst initial fill is 60% volume of WGS reactor, and density of catalyst is 1600 kg/m^3 [32].

3.1.6 Water Removal and Syngas Cleaning

Water removal was modelled using separator as a dryer. and acid gas was removed by Amine process [32]. The removal process modelled by water separator that removes water content until below 1 % mol, though 1 % mol is still acceptable [32] . After water removed, syngas entering Acid removal modelled as component splitter. CO_2 and H_2S assumed removed at 90% and 100% [32].

3.1.7 DME Synthesis

Sweet syngas is compressed into 5000 kPa, according to the operating pressure of JFK process [20]. The reactor used is Gibbs reactor to simulate the synthesis of DME and reactions involved is equilibrium reaction based on [41]. The operating temperature of the reactor was based on JFK process [20] at 260 ^oC. The temperature maintained at 260 ^oC throughout the reaction. Water jacketed cooler is used to maintain temperature of DME reactor, and water as a cooler will turn into saturated steam by absorbing heat of DME synthesis reaction. Steam produced was a part of steam integration at steam generator II. Product gas was cooled to 15 ^oC [21], then separated by Gas – Liquid separator where unconverted syngas recycled back to DME synthesis reactor. On this simulation, 95% of unconverted is recycled and 5% is sent to off-gas line and further used as fuel of gas engine for electricity generation [21]. Liquid outlet of Gas-Liquid separator flows to purification section which consist of three distillation towers.

3.1.8 Distillation

The distillation process occurred in the first tower was mainly to separate CO_2 and other light gasses with DME, Methanol (MeOH) and water. The tower has 9 stages and feed stage located on stage number 1 from condenser at the top. The gas as a top product mixed with the outlet gas from Gas – Liquid separator and sent as a fuel for steam as part of steam generator II system. Bottom product contains DME, methanol, and water entering DME Tower. The distillation in DME tower is to separate DME as top product with Methanol and water as bottom product. DME recovered from DME tower is 99.6% purity according to [14], [15]. DME tower has 10 stages and feed stage is feed number 3 from the top. The bottom product of DME Tower which were methanol and water was further separated in methanol tower. methanol tower has 12 stages, the top product of the distillation in methanol tower was methanol and its bottom product were water. Methanol was recycled, while water delivered to water treatment facility before discharged or re-utilize.

DME reactor volume was obtained by using (1) which is ideal reactor formula [40], residence time value taken was 100 seconds [20] .

Catalyst initial filling quantity was based on data provided by [20], where height data is used. Catalyst filled 7 m of reactor height, though reactor scaled-up, only diameter of the reactor changed and from volume of reactor calculated by using (1), diameter can be found and finally volume of catalyst was known. To determine how much catalyst in kg required, density of catalyst used is 650 kg/m^3 [43].

3.1.9 Steam Generation and Power Generation

Steam generation for the process and power generation was from the steam boiler fueled by waste heat from the plant. There were two steam generators available. The first. was steam generated by waste heat from CFB gasifier and was named as steam generator I as shown on figure 2.

The second was combination waste heat boiler from WGS reactor, DME reactor, and E-100, all were combined as steam generator II as shown on figure 2.

Power for DME plant was generated by using one steam turbine at steam generator I and II system. To fulfill power requirement, Internal Combustion Engine (ICE) that was utilizing off-gas as a fuel was provided.

3.2 Economic Analysis

3.2.1 Market Aspect

It was assumed that the market for DME is already available and the location is in one of palm oil mill that was near to main road. The DME treated as replacement for LPG, due to its characteristic as mentioned above. Location can be selected elsewhere in Indonesia. The price of DME will follow price of Saudi Aramco FOB price at USD 560 per ton [44]. It is understandable that the demand of LPG is increasing every year as now LPG become main fuel for household in Indonesia, since its conversion program that was started on 2007 [28].

3.2.2 Chemical Engineering Plant Cost Index

Investment was a basis to find chemical engineering plant cost index (CEPCI). CEPCI can be found by comparing cost index on present year to index of reference year. Index on reference year was used as basis cost, and new cost at project year can be found by using (2) that was obtained from [25].

$$Present\ cost = reference\ cost\ x\ \left(\frac{CEPCI\ at\ present}{CEPCI\ at\ reference\ time}\right) \quad (2)$$

Reference year for main equipment was year 2014 as a cost basis of Aspen Hysys version 8.8 [45], gasifier and high pressure feeding system was year 2011[46], EFB biomass pre-treatment was based on year 2015 [47], air separation unit was based on year 2007 [48], acid gas removal (MEA sweetening) was based on year 2010 [49], and the rest of the equipment/section was based on year 2014 [50].

3.2.3 Rule of Six-tenths

Cost for equipment such as gasifier, high pressure (HP) feeding system, air separation unit, and acid gas removal was obtained by using rule of six-tenths. Basic equation expresses

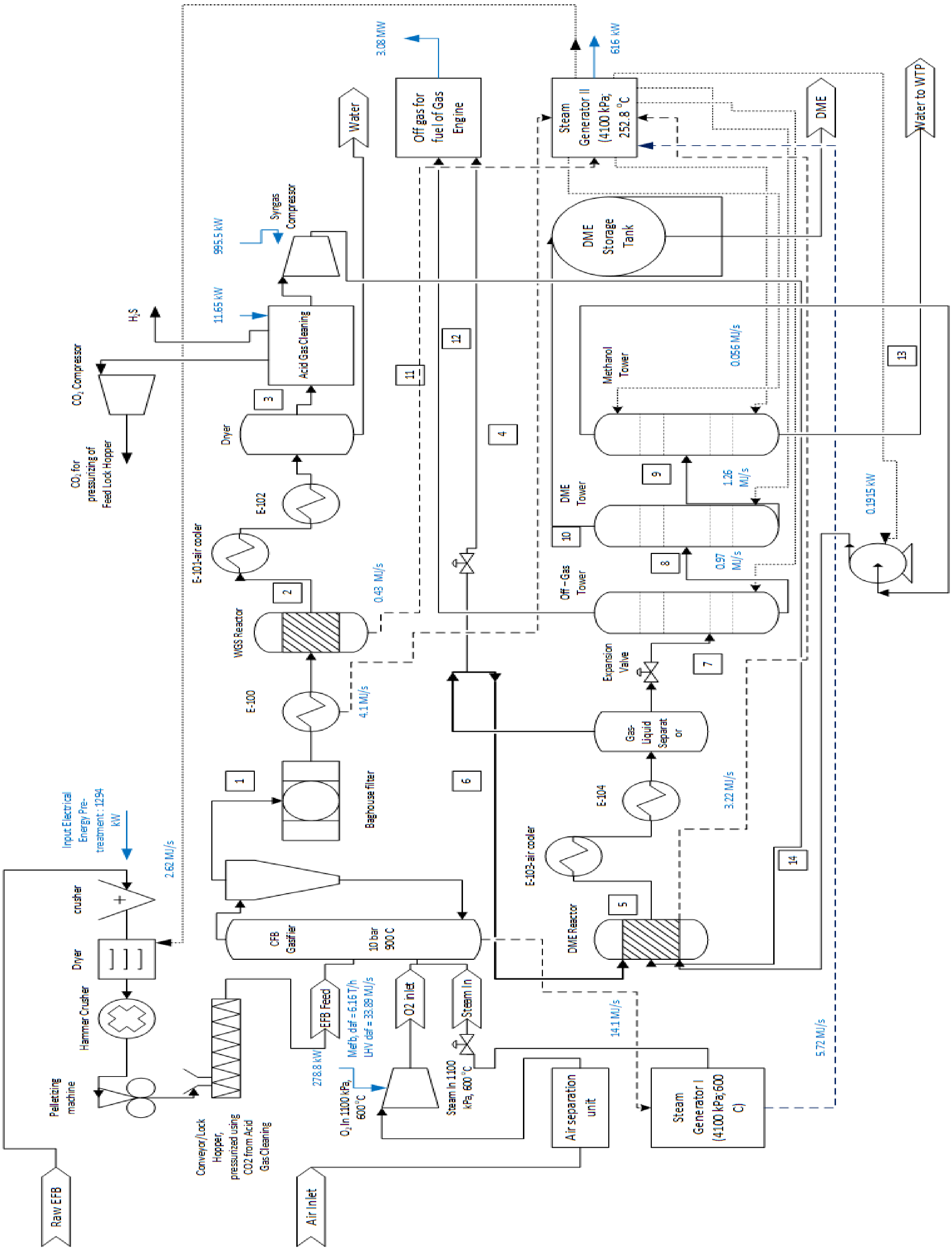

Figure 2. Process Flow Diagram DME plant based on EFB gasification

the rule of six-tenths shown by (3), that was obtained from [24].

$$C_B = C_A\left(\frac{S_B}{S_A}\right)^{0.6} \tag{3}$$

Where, C_B is the approximate cost of equipment having size S_B (could be any unit) and C_A is the known cost of equipment having size S_A (same unit with S_B).

3.2.4 Estimation of Fix Capital Cost

The basic components in the DME manufacturing plant are the cost of equipment, overhead costs, administrative costs of doing business, and profits. From the list of existing equipment and acceptable raw specifications, estimates can be made. The most important thing is to make a base of the process equipment used from the equipment list. Equipment installation costs can be searched as a percentage of the total equipment cost [25]. In this study the method used to estimate fix capital cost was the percentage method of total plant installation cost [25].

3.2.5 Estimation of Variable Cost

Complete cost estimates covered many things. Estimated variable costs covered are as follows: raw material; utility costs, including: steam, compressed air, refrigeration, electricity; water treatment or water treatment costs; labor costs; maintenance cost; insurance and taxes; factory overhead costs, all fees on process facilities that cannot be charged into other costs; expenses related to sales and marketing; research and development costs; and administrative costs [25].

3.2.6 Profit Measurement

Profit is a clear goal and it is something that can be quantified in an economic evaluation. The measurement by considering time value of money are [51]:

1. NPV, the value can be obtained from NPV function of Microsoft excel.
2. IRR, the value can be obtained from IRR function of Microsoft Excel.

4. Result and Discussion

4.1 Process Simulation Result

The simulation result on every stream number shown on figure 2 was tabulated on table 2. Results showed the total mass and molar flow, operating temperatures, operating pressures, heat flow, and composition of each substances produced.

Ratio of H_2 to CO on stream number 2,3, 4 was equal to 1, and this is required according to JFE technology [20] for direct synthesis of DME (single-stage). Raw DME product represented by stream number 5. The stream further cooled and separated in Gas-Liquid separator, where gas product consists mostly CO_2 and unreacted syngas (H2 and CO), CH_4, and CO_2.The gas product recycled at 95% mol and 5% mol of it delivered and mixed with top product of off-gas tower, further was utilized as fuel of ICE for power generation.

The liquid product of Gas-Liquid separator was expanded from 5000 kPa to 1000 kPa, to follow operating condition of DME purification section [39].

Methanol produced at stream number 9 was recycled into DME reactor. Stream number 10 was DME product with purity 99.9 %, since DME has similarity with LPG in term of physical properties, its handling and storage are similar to LPG [52]. Yield of DME over input EFB for the model developed was 50%. Table 3 shows mass of EFB input and DME output, energy of EFB input and energy of DME output.

4.2 Power Consumption and Generation

Power generated by steam turbine was 606 kW and total electrical power demand of main unit/section in DME plant was shown on table 4. Table 5 shows power generated to cater for the demand of the DME plant. Only one type of Genset-prime mover was used for power generation.

Table 2. Material stream and stream composition of DME Plant

Stream No.		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Vapour Fraction		0.9932	1	1	1	1	1	0.2532	0	0	0
Temperature	*C*	900	400	25	25	260	15	-14	49	150	43
Pressure	*kPa*	1,000	997	997	5000	5000	5000	1000	999	999	950
Molar Flow	*kgmole/h*	602	605	601	528	1,027	819	156	76	9	67
Mass Flow	*kg/h*	11,400	11,478	11,404	8,200	33,970	25,684	6,672	3,325	239	3,086
Heat Flow	*MJ/h*	-41,080	-54,627	-60,855	-28,918	-218,000	-176,900	-44,300	-15,620	-2,112	-13,520
Mole Frac (%)											
H_2		35.00	41.51	41.79	47.58	9.68	11.29	0.47	0.00	0.00	0.00
CO		48.47	41.62	41.91	47.71	17.26	20.12	1.70	0.00	0.00	0.00
CO_2		6.66	13.22	13.31	1.52	41.60	41.65	41.19	0.00	0.00	0.00
H_2O		6.46	1.02	0.34	0.39	0.31	0.05	1.80	3.71	31.95	0.05
CH_4		2.20	2.19	2.21	2.51	14.04	15.99	3.20	0.00	0.00	0.00
H_2S		0.19	0.19	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N_2		0.26	0.25	0.26	0.29	2.00	2.32	0.21	0.00	0.00	0.00
CH_3OH		0.00	0.00	0.00	0.00	0.62	0.06	3.78	7.81	68.02	0.01
CH_3OCH_3		0.00	0.00	0.00	0.00	14.48	8.53	47.64	88.48	0.04	99.94

Table 3. Energy efficiency of DME plant

Parameter	Unit	Value
Energy in from EFB	MJ	122029.6
Energy out from DME product	MJ	88969.4
Energy Efficiency	%	73

First ICE is gas engine type to be fueled by off-gas and its fuel conversion efficiency assumed at 38% [53].

Based on the result, conversion of CO on the simulation was 64% at 5000 kPa and 260 ºC. CO conversion tally with the experiment result [20], where CO conversion was higher than 50% at 5 MPa and 260 ºC. The efficiency of this model is 73% for pre-treated EFB, and this is slightly different with the result given by JFE process at 69.4% when using natural gas as the feed. Efficiency for torrefied biomass as reported by [39] was 67%, while untreated biomass only 60%. This study revealed that 50% of EFB input was converted to DME, and energy efficiency from EFB to DME was 73%. Conversion of torrefied biomass model into DME as studied by [21] was 54%, and it is quite close with the result obtained in this study. To run the plant electricity is required, and it can be fulfilled by the waste heat utilization through steam generation and genset, where genset fuel was using DME as final product.

4.3 Utilities

Besides power requirement, to run the plant, utilities were needed to support the operation of DME plant. The main utilities for operation in annual basis was tabulated on table 6.

Water consumption only for cooling on jacketed gasifier and reactors, while for the process, it was mainly steam utilized. Refrigerant used was based on calculation carried out in Aspen Hysys. The utilities listed was the utilities required for yearly demand.

Table 4. Power requirement of DME plant

Plant Section/Unit	Power Consumption (kW)	Remarks
Recycle pump	0.19	Hysys calculation
Air Separation Unit	1103	From [21]
Pre-treatment EFB	1294	From [36]
MEA Acid Gas Cleaning	22	From [49]
CO2 compressor	12.35	Hysys calculation
Refrigeration system	452	From [24]
Syngas Compressor	996	Hysys calculation
Power Required	**3600**	

Table 5. Power generation of DME plant

Power Generator	Power Consumption (kW)
Steam Turbine	606
Genset Off-Gas ICE	3077
Power Generated	**3683**

Table 6. Utilities of DME plant

Utilities	Demand Per Year	Remarks
Water (m3)	135666	Based on Hysys
Steam (tons)	87709	Generated from waste heat
Refrigerant (tons)	121	Based on Hysys

4.4 Economic Analysis

4.4.1 Investment Cost

The investment for DME plant based on EFB gasification was estimated based on the components listed on table 7. The price of equipment was obtained from other works by using six-tenths rule and CEPCI adjustment. It was obviously seen that gasification equipment purchase was very cost intensive compares to other equipment purchases. To further analyze the total plant investment, approach used for the total plant cost was based on delivered-equipment cost [25] for solid-fluid processing plant. The base for production capacity was based on 24 hours per day and 328 days per year (90%) [25]. The lifetime of the plant was assumed at 30 years [54] . Purchase equipment cost was marked up at 10% value to compensate for the delivery, since price quoted usually in Free on Board (FOB) basis [25]. Total Plant Cost (TPC) based on delivered-equipment cost of solid-liquid plant [25] was USD 104,291,799. From that total cost, equipment cost was USD 16,687,087 and working capital was USD 12,515,315. Detail of plant investment cost is shown in table 8.

Table 7. Cost estimation for Equipment and Plant section

Equipment/Section	Reference Cost*	Ref. Size	Ref. CEPCI	Cost year 2017 *+
Main Equipment	2,744 (Hysys, cost basis 2014 [45])		576.1	2.728
Genset DME	0.128 [55]			0.128
Genset Off-gas	0.512 [55]			0.512
Steam Turbine	0.568 (Hysys, cost basis 2014 [45])		576.1	0.565
Refrigeration 1 (E-103)	1.124 [50]		576.1	1,118
Refrigeration 2 (E-101)	0.348 [50]		576.1	0.346
Air Cooler E-102	0.199 [50]		576.1	0.198
Air Cooler E-104	0.393 [50]		576.1	0.390
WGS Reactor			576.1	
WGS catalyst (initial filling)	0.027		556.8	0.026
DME Reactor			576.1	
DME catalyst (initial filling)	0.790		576.1	0.0785
CFB Gasifier complete	28.171 [46]	42 kg/h	585.7	8.750
Air Separation Unit	82.700 [48]	2202 O_2 , tons/day	525.4	16.210
Acid Gas Removal (Amine)	6,050 [48]	0.5 kg/s CO_2	550.8	5.733
HP Biomass Feed system	24.550 [46]	42 kg/h	585.7	0.759

* Cost in Million USD

\+ CEPCI 2017 = 572.8

Table 8. Investment Cost and Components

Component	Estimation	Cost (USD)
Equipment Cost Plus delivery	**110%E**	**16,687,087**
Installation	**39%E**	**6,507,964**
Piping	31%E	5,172,997
Electricity	10%E	1,668,709
Instrumentation	26%E	4,338,643
Yard improvement	12%E	2,002,450
Service facilities	55%E	9,177,898
Building	29%E	4,839,255
Total Direct Cost (DC)		**50,395,002**
Engineering and Supervision	32%E	5,339,868
construction expenses	34%E	5,673,609
Legal expenses	4%E	667,483
Contractors Fee	19%E	3,170,546
Contingency	37%E	6,174,222
Total Indirect Cost (IC)		**21,025,729**
Total main Plant Cost (TPC)		**71,420,731**
Total Cost of ASU		**11,499,253**
Total Cost AGR		**8,832,000**
Biomass Pre-treatment		**24,500**
Fix Capital Investment		**91,776,484**
Working capital	12% TPC	**12,515,315**
Total Plant Cost (TPC)		**$104,291,799**

4.4.2 Operating Cost

Operating cost is a cost that directly related to production process cost. Operating cost consist of fix cost and variable cost. Operating cost was estimated based on [25], except for cost of raw material, utilities, operators, and depreciation. Cost of raw material was assumed 0 because EFB used is a waste and directly attained from palm oil mill, since the location of DME plant was assumed integrated with palm oil mill. Operating cost was calculated based on the minimum factor available [25]. Total operating cost per year is USD 5,753,259. Total operating cost consists of variable cost amounted USD 2,654,041, and fix cost amounted USD 3,099,219. Details of the operating cost is shown in table 9.

4.4.3 Break Event Point

BEP can be achieved with minimum production quantity of DME at 6726 tons/year. Decent margin can be obtained if production quantity higher than minimum production quantity. Figure 3 shows BEP analysis of DME plant, from that figure, sales line slope must be steeper than slope line of variable cost and fix cost. Based on the graph, BEP analysis is the early analysis to determine whether the project is profitable or unprofitable. BEP graph can be used to plan for the production rate to avoid negative profit margin during normal operation.

4.4.4 Economic Feasibility Analysis

Feasibility analysis was conducted to know the profitability of this DME plant project. Discount rate used assumed the same with corporate loan interest rate in Indonesia at 10.25 % [56].

Table 9. Operating Cost

Cost Type	Cost Component	Cost (USD)	Remark(s)
VC	Labour and direct SPV cost	158,571	Estimation based on Indonesia standard and [32]
VC	Laboratory charges	15,857	10% of Labour and direct SPV cost [25]
VC	Maintenance and Repair	1,835,530	2% of Fix capital investment [25]
VC	Operating Supplies	275,329	15% of maintenance and repair [25]
VC	Safety and Protection	1,714	Estimation based on Labour (self-estimation)
VC	Catalyst	106,209	Top up each year, same quantity with initial loading
VC	Solvent Top up	46,563	Based on [57]
VC	Raw Material	0	EFB waste
VC	Utilities (Water, refrigeration, water treatment)	214,267	steam/electricity from waste heat
VC	Patent and royalties	0	0% of product cost [25]
FC	Plant Overhead Cost	$11,100	7% of Labour and direct SPV cost [25]
FC	Depreciation	2,358,358	Straight line depreciation of Total Direct Cost for 25 years [25]
FC	Insurance	367,106	0.4%of fix capital investment [25]
FC	Local Tax	91,776	Based on Indonesia local tax for building and land [58]
FC	administration cost	23,786	15% of operating labour [25]
FC	Distribution and marketing cost	123,546	2% of total product cost [25]
FC	R & D	123,546	assumed 2% of total product cost
	Total Variable Cost (VC)	**2,654,041**	
	Total Fix Cost (FC)	**3,099,219**	
	Total Operating cost	**5,753,259.50**	

Parameters to analyze profitability of this DME plant was calculated and tabulated in table 10, from there, it was shown for the current capacity at 6.16 tons per hour EFB feed, the project was not feasible.

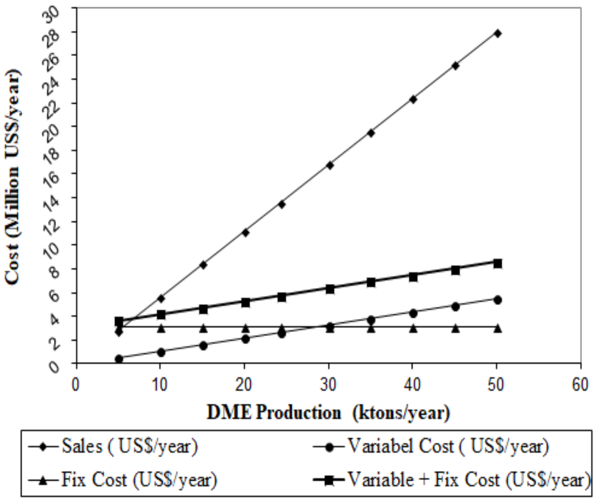

Figure 3. Break Event Point of DME plant

Table 10. Economic Feasibility Result

Feasibility Parameters	Unit	Value
NPV	USD	- 42,393,967
IRR	%	4.4%

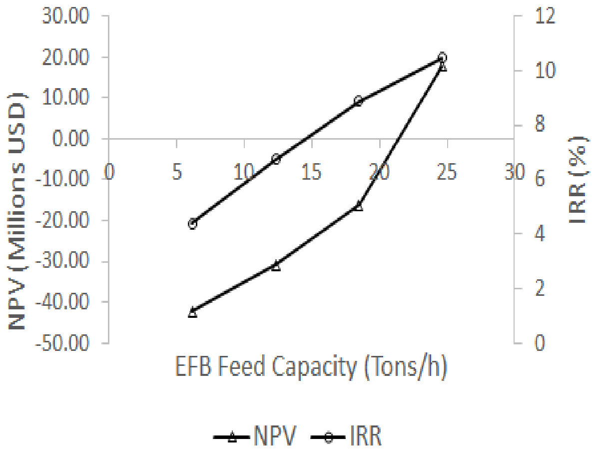

Figure 4. Scale-Up Feasibility Prediction

Small scale DME plant based on EFB gasification attached to main palm oil mill is not feasible by current interest rate at 10.25 %. To make project feasible, option for loan to finance the project of DME plant based on gasification of empty fruit bunch must be sought from other countries with lower than 4.4% loan interest rate. Some of the countries offered very low loan interest rate[59].

The rough prediction of feasible capacity of DME plant at 10.25% discount rate can be done by using sixth-tenths rule for investment cost, and percentage of investment cost for operating cost. At current study annual operating cost was 5.52%, this value was assumed constant for 30 years plant life time. Annual operating cost in percentage was used for scale-up feasibility calculation.

Based on Figure 4, feasibility can be achieved at 24.64 tons/h EFB biomass input. This feasibility needs to be analyzed and studied further, including sensitivity analysis to see the impact of changes that can affect the feasibility of the project.

5. Conclusion

The paper exhibits the thermodynamic and economic aspect of the proposed DME plant based on gasification of EFB and the model of DME plant was designed and simulated by using Aspen Hysys. Simulation of the model was based on empty fruit bunch gasification that was conducted in CFB gasifier.

Total electric power required was 3600 kW. Power requirement fulfilled by power generation from waste heat and genset fueled by off-gas at 3683 kW.

The performance of the DME plant shown by energy efficiency at 73%, and 50% conversion of EFB mass to DME mass.

Based on economic analysis, DME plant at 6.16 tons/h EFB Feed was not feasible to be built at 10.25% discount rate. At 6.16 tons/h rate, discount rate must be below 4.4% to make project feasible.

Rough predictions for feasibility based on production capacity have been made and it was found that a fourfold increase in capacity makes the project feasible.

This study further will be used as the base for the bigger scale techno-economic analysis of DME Plant construction based on gasification of EFB.

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