Mechatronics, Electrical Power, and Vehicular Technology 05 (2014) 51-58

Mechatronics, Electrical Power, and Vehicular Technology

e-ISSN:2088-6985
p-ISSN: 2087-3379
Accreditation Number: 432/Akred-LIPI/P2MI-LIPI/04/2012

www.mevjournal.com

TECHNO-ECONOMIC ANALYSIS OF BIOGAS UTILIZATION AS AN ALTERNATIVE FUEL

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Received 21 October 2013; received in revised form 03 June 2014; accepted 03 June 2014
Published online 23 July 2014

Abstract

This paper will discuss the feasibility and economic analysis of biogas energy as a supply for the diesel engine generator. The techno-economic analysis was performed by using three parameters which are Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) as the feasibility indicators of the biogas power plant project. Calculation of substitution was obtained from the comparison between data of diesel engine using diesel fuel and dual-fuel with biogas. Economic calculations include the substitution percentage of diesel fuel by biogas for dual-fuel. Meanwhile, the calculation of savings was based on the ratio of energy content between diesel fuel and biogas. The eventual outcome is determined using economic comparison between the use of diesel fuel and dual-fuel mode. Feasibility shows that the pilot plant of 1 to 6 kWh using diesel fuel and dual-fuel are not feasible while techno-economic parameter analysis shows that NPV<0, IRR<MARR, while PP is undefined. The biogas power plant project is feasible in some conditions such as there is no labor cost, and 5 and 6 kWh will be feasible under the assumption that expenses for machine maintenance is eliminated. However, even when applying both conditions where biogas is feasible, diesel fuel is still not.

Keywords: techno-economic, feasibility, biogas, diesel fuel, dual-fuel.

I. INTRODUCTION

Indonesia as a developing country highly depends on oil consumptions for business and commerce. Demands for fossil fuels are increasing year over year, so that fossil fuels are being imported from other oil-producing countries. This condition caused by excessive usage of fossil fuel produces decline in oil reserves and environmental quality. The facts that oil supply is decreasing while population continues to grow and climate change happens globally push society to find alternatives for ready to use energy like electricity and gasoline as stated by [1] in [2].

The utilization of alternative energy source that is renewable and environmentally friendly becomes an inevitable choice for the Government of Indonesia [3]. Renewable energy sources are relatively simple and suitable for rural areas [3]. Renewable energy produced from farm organic waste, such as manure, crop residues, and organic residues from food and agro-industry processed, through the anaerobic digestion process is much in demand today as [4] and [5] said in [6]. One of the projects to realize the availability of electrical energy that is currently being piloted in several regions in Indonesia is the biogas power plant. Biogas is produced from anaerobic fermentation of organic material such as animal waste, waste water, and food waste. Its composition varies depending on the material source of biogas. However, it typically contains 50 to 70% CH_4, 25 to 50% CO_2, 1 to 5% H_2, N_2, and H_2S from 0.3 to 3% [7].

Along with the growth of the economy, a variety of enterprises or projects sectors are emerging. The existing enterprises or projects do not only aim to fulfill people's needs but also aim to be economical which means those projects will save operational costs either from electricity cost, water cost or others. Energy independent is a goal of this project by generating their own electricity, but techno-economic and feasibility study of this project becomes something interesting to be analyzed. Research on dual-fuel (diesel biogas fuel) has been done before, including research conducted by Sotharia and Yadav. The research of Sotharia and Yadav only focuses on the

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doi: 10.14203/j.mev.2014.v5.51-58

phenomenon of the combustion chamber and simulation performance [8], unlike the case in this study which performs calculations and analyzes techno-economic costs between diesel fuel and dual-fuel for the scale of 1 until 6 kWh.

This techno-economic analysis can be used as an indicator to assess the feasibility of investment in biogas power generation from the financial aspect. Moreover, it can also be used as a project planning program in a specified period of time and adjusted as desired with available resources.

II. Engine Set Up and Procedure

The experiments were carried out on a naturally aspirated; water cooled, 3-cylinder direct injection diesel engine. The specifications of the engine are shown in Table 1.

The first procedure that follows techno-economic analysis of biogas utilization is modifying the engine. A conventional diesel engine was modified by adding a gas mixer and several sensors, and then connected with the bulb type load bank for performance test. The second step was doing some performance tests. Engine performance test was taken to determine how a generator set performs in terms of responsiveness and stability under a particular workload [9]. Performance test was obtained from 1,500 rpm and 0 kW (no load) up to 10 kW (full load) with gradually increasing load about 1 kW. Schematic experimental setup is shown in Figure 1.

Table 1.
Engine specification

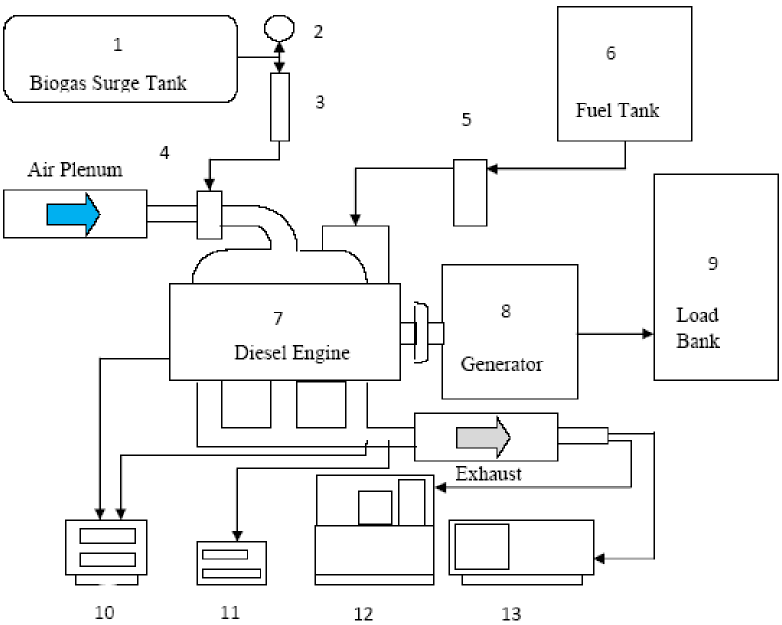
Parameter	Spesification
Engine Model	Yanmar 3TNE78
Type	4 Stroke Direct Injection Diesel Engine
Filling System	Naturally Aspirated
Cooling System	Water cooled
Displacement	1,445 cc
Net Output	19.9 kW
Compression Ratio	19:1

The performances data were analyzed to determine the performance and emission of the engine. Performance test results show that 60% of diesel fuel can be replaced as a maximum. Load versus fuel consumption (sfc) graph (Figure 2) shows that there are savings when using a dual-fuel mode, which reaches 40% of diesel fuel and 60% biogas in each load.

The fuels consumption for a day was calculated by the following equation.

$$V_f = P_i \cdot \dot{m} \cdot t \qquad (1)$$

Where V_f is fuels consumption (litre), P_i is Power (kW), $\dot{m}$ is specific fuel consumption $[\frac{\text{litre}}{\text{hour}}]$, t is operating time (hour). Therefore in one day the fuel consumption needed to generate 1 kWh is shown in Table 2. The volume of biogas that should be produced in one day is equivalent to 4.64 litres of diesel fuel in one day.



Information
1. Biomass Surge Tank
2. Pressure Gauge
3. Methane RotaMeter
4. Mixer
5. Fuel Flow Meter
6. Diesel fuel Tank
7. Diesel Engine
8. Generator
9. Load Bank
10. Temperature sensor
11. NOx Meter
12. Smoke Meter
13. 4 Gas Analyzer

Figure 1. Schematic diagram of experimental set up

Quantification of the biogas required to supply the generator, was started by calculating the Low Heating Value (LHV) of 4.64 litres of diesel fuel. LHV is the amount of heat released during the combustion of a specified amount of substance without calculating the amount of energy to adjust it to initial condition [10]. The energy required to substitute diesel fuel per day can be calculated using the following equation:

$$E_f = V_f \cdot LHV_f \quad (2)$$

where E_f is energy required to substitute the fuel energy (MJ), V_f is fuel consumption (litre), LHV_f is LHV of fuel (MJ/litre). LHV of diesel fuel is 35.9 MJ per litre [11], while the energy that must be substituted by the biogas is equivalent to 4.64 litres of diesel fuel so the energy that should be produced by biogas is 166.58 MJ.

Biogas LHV is 21 MJ per m^3[11]. The biogas required in one day to replace 4.64 litres of diesel fuel can be calculated using the following equation:

$$V_g = E_f / LHV_g \quad (3)$$

where V_g is Volume of biogas (m^3), Ef is energy required to substitute the fuel energy (MJ), and LHV_g is biogas Low Heating Value (MJ/m^3). So biogas required in one day to replace the 4.64 litre diesel is 7.93 m^3.

Table 3 shows the amount of gas produced from manure per cubic. One cow produces as much as eight kilograms of manure per day. Each kilogram of manure produces 0.04 m^3 of biogas as in the Table 3. Number of cows required to produce certain amount of biogas can be found using equation 4.

$$n_{Cow} = V_g / m_D \cdot \delta_D \quad (4)$$

where n_{Cow} is sum of cow required (number of cow), m_D is weight of dung for every cow (kg), and δ_D is specific of gas produce for every kg of dung (m^3/kg). So to produce a biogas volume equivalent to 4.64 litres of diesel (in one day), manure that is required is at least from 25 cows. One assumption of this research is that the manure can be obtained for free. The biogas project is a cattle farm where cow dung is available for free. Manpower needed for maintenance of cattle (cleaning cow and cage, feeding, etc.) is one person for every eight cows. Hence, it takes 4 workers to keep 25 cows. With the biogas digester, the workers were given an additional task to input manure into the digester. Based on Figure 2, it is known that the biggest amount of power is 6 kWh. Thus, for the calculation of techno-economic analysis, comparative data to generate 6 kWh electricity was used.

Table 2.
Fuel consumption on several operating mode

Operating Mode	Fuels Type	*m* [l/h]	*t* [hour]	*V* [litre]
Diesel mode	Diesel	1.08	8	8.64
	Biogas	0	8	0
Dual Fuel mode	Diesel	0.50	8	4.00
	Biogas	0.58	8	4.64

Table 3.
Manures and their gas product amount [6]

Manure Type	Produce Gas/kg (m^3)
Cow	0.023 to 0.040
Pig	0.040 to 0.059
Chicken	0.065 to 0.116
Human	0.020 to 0.028

III. Techno-Economic Analysis

There are many aspects on project feasibility review such as market, technical, environmental, human resources, law, and financial. Feasibility analysis of a project will depend on the investments and costs that are spent, because the financial aspects become one of the most important aspects in determining the appropriateness of a project. This paper will discuss specifically about financial aspect of the biogas power plant. Financial aspects of the biogas power plant cover investment costs, operating costs which include fixed costs and variable costs, depreciation costs, and others in it.

The investment cost of the biogas power plant includes the purchase cost of the engine generator, including installation, which was IDR 40,000,000, the purchase cost of biogas digester which was IDR 16,000,000, and dual-fuel modification cost which was IDR 2,000,000. Economic life is 20 years. Salvage value of the equipment is 30% of the new price and Minimum Attractive Rate of Return (MARR) is 10%.

Operating costs include fixed costs and variable costs. Fixed costs include depreciation costs and overhead expenses include engine maintenance costs. While the variable costs include fuel costs, and labor costs. Total fixed cost varies every year because of the depreciation cost. While variable cost varies because it is affected by fuel needs obtained from the ratio of diesel fuel to biogas for each kWh. While the operation cost calculation for the diesel fuel consumption results are as follow: 1.70 litres/hour x 8 hours x IDR 8,000/litre x 30 days = IDR 3,264,000/month. The calculation of the dual-fuel consumption results are as follow: 0.82

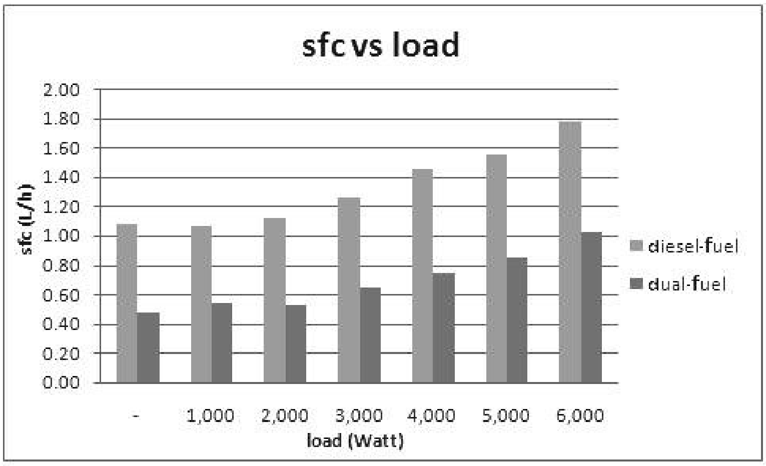


Figure 2. The result of the performance test

litre/hour x 8 hours x IDR 8,000/litre x 30 days = IDR 1,574,400/month. Inflation will affect all aspects of costs including the operating expenses that in the end will cause fluctuation in the operating costs calculation.

The overall cost calculation for techno-economic analysis is influenced by the inflation that occurred since 2011, the first year when the project began. The inflation data of 2011-2018 were obtained from IMF data [12]. From those data, inflations for year 2019-2030 were forecasted using regression method.

The inflation data are presented in Table 4. The depreciation method used in economic analysis is the Sum of the Years Digit (SYD) method. The SYD method is appropriate for assets such as trucks, machines, and equipment that have a depreciation of value or greater benefits in the beginning years of usage, another case with the building of assets that have a similar value or benefit for each year [13]. This method is chosen because continuous machine usage causes impaired usability of the machine. From Table 5 it is known that salvage value of IDR 28,000,000 is obtained by assuming a residual value of 30% from the machine purchase price and lifetime of 20 years. The SYD depreciation calculation can be seen in Table 5 and Table 6.

Net income of 6 kWh diesel fuel as well as 6 kWh dual-fuel were obtained through a detailed calculation that can be seen in Table 7 and 9. The usage of diesel fuel means there was no biogas needed. This is why there is no revenue contained in Table 7. Net cash flow can be obtained through diesel fuel generating cash flow for 6 kWh (used as an example) of electricity as contained in Table 8. Revenues contained in Table 9 are obtained from the calculation of biogas equivalence to diesel, using the ratio of dual-fuel to diesel fuel contained in Figure 2. Calculation results were obtained from the multiplication of biogas equivalence to the usage of diesel fuel with number of days (30), number of months (12) and diesel fuel price per litre (IDR 8,000).Whereas net cash flow for dual-fuel to

Table 4.
The inflation data of 2011 – 2030

Year	Inflation (%)	Year	Inflation (%)
2011	5.357	2021	4.693
2012	4.259	2022	4.556
2013	7.257	2023	4.420
2014	7.542	2024	4.283
2015	5.753	2025	4.147
2016	5.236	2026	4.010
2017	4.729	2027	3.873
2018	4.505	2028	3.737
2019	4.966	2029	3.601
2020	4.829	2030	3.464

Table 5.
The SYD depreciation method for diesel fuel

Year	Salvage Value	Depreciation	Book Value
1	28,000,000	2,666,667	37,333,333
2	28,000,000	2,533,333	34,800,000
3	28,000,000	2,400,000	32,400,000
⋮	⋮	⋮	⋮
20	28,000,000	133,333	12,000,000

Table 6.
The SYD depreciation method for dual-fuel

Year	Salvage Value	Depreciation	Book Value
1	40,600,000	3,866,667	54,133,333
2	40,600,000	3,673,333	50,460,000
3	40,600,000	3,480,000	46,980,000
⋮	⋮	⋮	⋮
20	40,600,000	193,333	17,400,000

Table 7.
Net income of 6 kWh diesel fuel

Descriptions	Year				
	0	1	2	...	20
Revenues	0	0	0	...	0
Operating Expenses	0	257,572,926	213,084,162	...	180,872,352
Depreciation	0	16,952,000	14,024,000	...	11,904,000
Gross Profit	0	0	0	...	0
Interest Loans	0	0	0	...	0
Earnings Before Income Taxes	0	0	0	...	0
Income Taxes	0	0	0	...	0
Net Income	0	-274,524,926	-227,108,162	...	-192,776,352

Table 8.
Net cash flow of 6 kWh diesel fuel

No.	Descriptions	Year				
		0	1	2	...	20
1	*Cash in flow*					
	~ Earnings after income taxes	0	-274,524,926	-227,108,162	...	-192,776,352
	~ Depreciation	0	16,952,000	14,024,000	...	11,904,000
	~ Salvage Value	0				12,000,000
	Total *Cash In Flow*	0	-257,572,926	-213,084,162	...	-168,872,352
2	*Cash Out flow*					
	~ Investment :	40,000,000	0	0	...	0
	~ Loans	0	0	0	...	0
	Total *Cash Out Flow*	40,000,000	0	0	...	0
3	*Net Cash Flow* (NCF)	-40,000,000	-257,572,926	-213,084,162	...	-168,872,352
4	*Cumulative* NCF	-40,000,000	-297,572,926	-510,657,088	...	-4,696,281,370

generate 6 kWh can be seen in Table 10. Other assumption is the products that may be harvested from the cow, namely milk and meat, are not taken into calculation in this paper.

A. Net Present Value (NPV)

One of the ways to determine the feasibility of a project is the present worth analysis. Through the present worth analysis, the present worth can be calculated from the cash flows of future costs and benefits [14]. Based on calculations of 6 kWh using diesel fuel, it was acquired the NPV of –IDR 2,163,082,740 (NPV<0), which means the project is not feasible. While the calculations of 6 kWh using dual-fuel, it was acquired the NPV of –IDR 543,317,930 (NPV<0), which means the project is not feasible as well.

B. Internal Rate of Return (IRR)

Internal Rate of Return is the interest rate used when the return of the project investment worth is equal to zero [14]. Based on calculations of 6 kWh using either diesel fuel or dual-fuel, IRR of undefined was acquired. Since IRR<MARR (10%), then the project is not feasible.

C. Payback Period (PP)

The payback period is a method to determine the period of time required on a project to restore a number of investments which are used for the project [14]. Based on calculations of 6 kWh using diesel fuel and dual-fuel, the acquired PP is over 20 years. Indicator of the project feasibility is NPV>0 [15], IRR>MARR [16]. From the calculation of 6 kWh, it is known that NPV for diesel fuel is -IDR 2,163,082,740 and NPV for dual-fuel is -IDR 543,317,930 (NPV<0) and IRR<10% (IRR<MARR), based on these criteria then the biogas power plant using either diesel fuel or dual-fuel is not feasible.

Table 11 explains the result of NPV, IRR, PP for plant scales of 1 to 6 kWh. Furthermore, the calculation of 1 until 6 kWh with the assumptions that there are no labor costs was performed (see Table 12). Despite the feasibility analysis result, compared to using only diesel fuel, the studied modification with biogas-diesel fuel ratio of 60:40 will save 4.64 litres of diesel fuel per day in generating 1 kWh.

Table 9.
Net income of 6 kWh dual-fuel

Descriptions	Year				
	0	1	2	...	20
Revenues	0	88,611,494	73,306,253	...	62,224,589
Operating Expenses	0	147,754,480	122,233,885	...	103,755,859
Depreciation	0	24,580,400	20,334,800	...	17,260,800
Gross Profit	0	0	0	...	0
Interest Loans	0	0	0	...	0
Earnings Before Income Taxes	0	0	0	...	0
Income Taxes	0	0	0	...	0
Net Income	0	-83,723,385	-69,262,432	...	-58,792,070

Table 10.
Net cash flow of 6 kWh dual-fuel

No.	Descriptions	Year				
		0	1	2	...	20
1	Cash in flow					
	~ Earnings after income taxes ~ Depreciation	0 0	-83,723,385 24,580,400	-69,262,432 20,334,800	... ...	-58,792,070 17,260,800
	~ Salvage Value	0				17,400,000
	Total Cash In Flow	0	-59,142,985	-48,927,632	...	-24,131,270
2	Cash Out flow					
	~ Investment :	40,000,000	0	0	...	0
	~ Loans	0	0	0	...	0
	Total Cash Out Flow	40,000,000	0	0	...	0
3	Net Cash Flow (NCF)	-40,000,000	-59,142,985	-48,927,632	...	-24,131,270
4	Cumulative NCF	-40,000,000	-117,142,985	-116,070,618	...	-1,112,514,274

Table 11.
Summary of NPV, IRR, PP for 1 - 6 kWh plant scales

Capacity	Diesel Fuel			Dual-fuel		
(kWh)	NPV	IRR	PP	NPV	IRR	PP
1	- 1,413,951,676	Undefined	>20	- 155,411,019	Undefined	>20
2	- 1,546,862,026	Undefined	>20	- 384,983,441	Undefined	>20
3	- 1,679,772,376	Undefined	>20	- 415,945,512	Undefined	>20
4	- 1,824,765,485	Undefined	>20	- 438,600,685	Undefined	>20
5	- 1,981,841,353	Undefined	>20	- 525,193,792	Undefined	>20
6	- 2,163,082,740	Undefined	>20	- 543,317,930	Undefined	>20

Table 12.
Summary of NPV, IRR, PP for 1 - 6 kWh plant scales (no labour cost)

Capacity	Diesel Fuel			Dual-fuel		
(kWh)	NPV	IRR	PP	NPV	IRR	PP
1	- 1,413,951,676	Undefined	>20	1,916,574	10.48%	8.07
2	- 1,546,862,026	Undefined	>20	13,999,333	13.48%	6.42
3	- 1,679,772,376	Undefined	>20	1,916,574	10.48%	8.07
4	- 1,824,765,485	Undefined	>20	1,916,574	10.48%	8.07
5	- 1,981,841,353	Undefined	>20	- 34,331,703	0.76%	19.98
6	- 2,163,082,740	Undefined	>20	- 22,248,944	4.17%	15.04

IV. CONCLUSIONS

The results of the calculations show that using diesel fuel or dual-fuel is not feasible to build the project. The results of economic analysis show that the diesel fuel project still not feasible, whereas biogas power plant is feasible in 1 to 4 kWh if there are no labor cost. Although the 5 and 6 kWh condition is not feasible, it may be feasible if the expenses of machine maintenance are eliminated by getting the subsidies from the local government. This ongoing project is recommended in one of regions in Bandung district as the feasible project if organized and operated by the local residents, so it can make zero to the labor cost. For further research, other revenues that can be obtained from cow such as cattle meat, milk, and compost from cow manure can be taken into account for the analysis of its feasibility.

ACKNOWLEDGEMENT

The authors wish to acknowledge Naili Huda for interesting and useful discussion and all researchers in Research Centre for Electrical Power and Mechatronics – Indonesian Institute of Sciences for assisting data collection and helping to improve this paper.

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