Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 158 (2019) 3325–3330

Energy Procedia

www.elsevier.com/locate/procedia

10th International Conference on Applied Energy (ICAE2018), 22-25 August 2018, Hong Kong, China

Impact of biodiesel application on fuel savings and emission reduction for power generation in Malaysia

E.S. Tan[a*], Kumaran P [a], T.M.I. Indra[a], K. Tokimatsu[b], K. Yoshikawa[b]

[a]*Universiti Tenaga Nasional, Jalan Ikram-Uniten, Kajang, 43000 Malaysia*
[b]*Tokyo Institute of Technology, Japan*

Abstract

The objective of this paper is to assess the impact on fuel saving and emission reduction of biodiesel for power generation, using a wide range of economic indicators. There are many benefits that countries, especially developing ones can gain from renewable fuels like biodiesel. Apart from the possibilities that opens for economic growth and development across the country, especially for rural communities; opportunities are available for independent power producers to generate power to off-grid users and local businesses. This is only achievable from engines and fuels with good economic performance. This paper analyse the impact of Callophyllum inophyllum (CI) biodiesel on the fuel saving and the carbon dioxide (CO_2) emission reduction, focusing on the application of CI biodiesel in two different systems, namely internal combustion engines in the transport sector and gas turbines in the power sector. The results showed that application of CI biodiesel in the power sector is able to have more significant savings in fuel and reduction in the CO_2 emissions.

Keywords: Biodiesel; gas turbine; properties; emission; power generation

Nomenclature

CI	callophyllum inophyllum
CO_2	carbon dioxide
CHP	combined heat and power
GHG	greenhouse gas
ICE	internal combustion engine
NO_x	nitrogen oxide

* Corresponding author. Tel.:+60-389212020; fax: +60-389212116.
E-mail address: eesann@uniten.edu.my

10.1016/j.egypro.2019.01.969

1. Introduction

The economics of any power plant depends on the capital costs, but emphasis is always on the operational and maintenance costs. These costs are constituted by fuel cost, which in turn is a function of fuel market price, engine specific fuel consumption and the residual energy per kilogram of fuel. Furthermore, the economic performance of power plants depends greatly on specific site and other local conditions such energy demand, upfront capital cost of alternatives, carbon costs, electricity prices and fossil fuel prices. The cost of production of biodiesel fuels is much higher than that of conventional diesel fuel [1, 2]. These costs have limited the use of biodiesels in gas turbines and for power generation, as they increase the cost of the energy generated.

It is expected that the outcome of this study would further broaden the perspectives on the use of biofuels in gas turbines, and much more, creating additional knowledge on the implications of the use of biodiesel fuels in Malaysia and other similar developing countries. This information could assist policy makers, end-users, investors, financiers, plant operators and equipment manufacturers. More importantly, some of the economic measures can be used to reject, accept or estimate the risk associated with biodiesel-fired power plant projects.

2. System boundary

Despite the many benefits that are perceived with the use of biodiesel as substitute for petroleum derived fuels, if their use in power plants is not economically sustainable and quantifiable, the migration from conventional to renewable power generation could be impeded. The following section shows the assumptions used to the comparison of biodiesel impact. The system boundary is shown in Fig.1. The boundary includes feedstock farming, crude oil extraction and biodiesel processing.

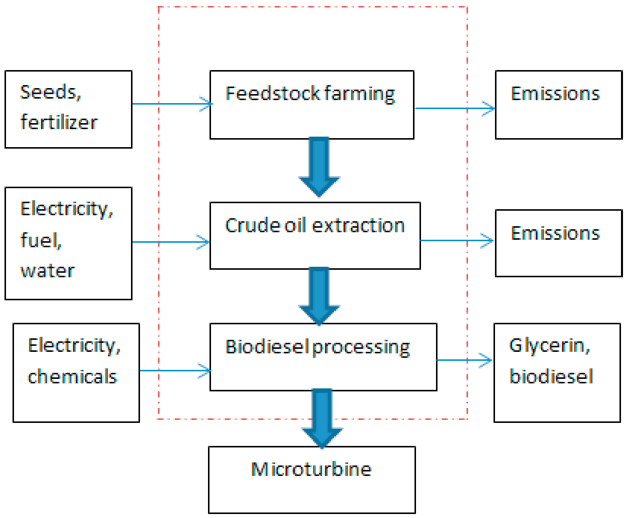

Fig.1: System boundary for biodiesel production cost analysis

Distillate and biodiesel fuel’s properties such as calorific value, density, and related conversion yield are shown in this section. The production cost analysis of biodiesel fuel includes the production of the feedstock, transesterification process as well as the combustion phase of biodiesel fuel. All the input data for this study are summarized in Table 1.

Table 1: Input data for calculation of production cost analysis, fuel and emission reduction analysis

Property	Distillate	Palm biodiesel	CI biodiesel
Nett calorific value (MJ/kg)	43.4	35.0	39.3
Density (kg/m3)	837	879	869
Carbon emission factor (kg/GJ)	88.0	61.8	64.4
Yield of FAME	-	80	70
Yield of glycerin	-	10%	5%
Vegetable oil yield (kg/ha)	-	3740	4680

Source: [3]

3 Comparison of impact of CI biodiesel application in internal combustion engine and microturbine on fuel saving and emission reduction

As an alternative energy carrier for transportation and power generation; CI biodiesel is another form of alternative fuel that may be burned directly in internal combustion engine (ICE) and generators with minor or no modifications. Compared to petrol vehicles, biodiesel fueled-vehicles do not produce direct CO_2 emission during operation. One of the key factors in decision of alternative fueled-vehicles is to conduct a comparison on the energy and emission reduction. In this section, we present a comparison of fuel and emission reduction for CI biodiesel application in ICE and microturbine for power generation. The main objective is to investigate the environmental impacts of using CI biodiesel in transportation and power generation instead of conventional distillate fuels.

3.1 Impact of CI biodiesel on fuel saving

The calculation results for diesel fuel savings are based on 5% replacement of diesel fuel for both scenarios. Biodiesel and distillate fuels have different heating value or energy content. Thus, the substitution ratio of biodiesel to distillate fuel is presented by applying the following equation (1):

$$SR_w = HV_{\mathrm{d}}/HV_{\mathrm{b}} \tag{1}$$

Where SR_w = Substitution ratio by weight basis
HV_d = Heating value distillate = 43.4 MJ/kg
HV_b = Heating value biodiesel = 39.3 MJ/kg

The input data for calculation fuel and emission reduction analysis were previously shown in Table 1. As the heating value for calculation in Equation (1) is given in MJ/kg, in which the biodiesel substitution ratio is based on a weight basis. However, for the biodiesel fuel substitution based on a volumetric basis should take into account the density of distillate and biodiesel. Therefore, the biodiesel to distillate fuel substitution ratio by volume is calculated by the following equation (2):

$$SR_{vol} = HV_{\mathrm{d}}/HV_{\mathrm{b}} \bullet \rho_{\mathrm{d}}/\rho_{\mathrm{b}} \tag{2}$$

Where SR_{vol} = Substitution ratio by volume basis
HV_d = Heating value distillate = 43.4 MJ/kg
HV_b = Heating value biodiesel = 39.3 MJ/kg
ρ_b = density biodiesel = 849 kg/m^3
ρ_d = density distillate = 837 kg/m^3

The distillate fuel replacement amount is the total distillate fuel consumption by substituting biodiesel fuel with a propose replacement ratio. It is a function of annual distillate fuel consumption with a replacement ratio which is shown in equation (3) below:

$$DR_i = \eta \bullet DC_i \tag{3}$$

Where DR = distillate fuel replacement
DC = distillate fuel consumption
η = replacement ratio, set as 5%

However, the total biodiesel needed for substituting the distillate fuel is calculated by distillate fuel replacement multiply with biodiesel to distillate fuel substitution ratio as shown below:

$$BC_i = DR_i \bullet SR_{vol} \tag{4}$$

Where BC = Biodiesel consumption needed
DR = distillate fuel replacement
SR_{vol} = Substitution ratio by volume basis

Finally, the total distillate fuel saving is the distillate fuel savings multiplied by the energy content of distillate fuel. The distillate fuel savings can be defined as the following equation:

$$TDS = \Sigma DRi \bullet SR_w \tag{5}$$

Where TDS = Total distillate savings
DR = distillate fuel replacement
SR_w = substitution ratio by weight basis

In Malaysia, it is expected that the distillate fuel consumption in the transportation sector will increase to 8,629 kton in year 2017 [4] and 9,377 kton for energy sector [5]. Thus, the CI biodiesel needed for distillate replacement for both sectors are presented in Table 2.

Table 2: CI biodiesel needed for distillate consumption in transport sector and power sector.

Sector	Distillate consumption (kton)	Distillate savings (ton)	Biodiesel needed (ton)	Biodiesel needed (liter)
Transport (IC engine)	8,629	476,461	458,916	528 million
Power (gas turbine)	9,377	517,763	498,697	574 million

The total distillate fuel savings is 476 kton for the transport sector while 517 kton diesel can be saved when used in power sector in the year 2017. The scenario is calculated when 5% of diesel is replaced with CI biodiesel. The amount of biodiesel needed for power sector is 498 kton, and it is 8% more compared to the biodiesel needed for transport sector. This is because the gas turbine operates in a continuous combustion and would require more fuel to maintain full time running of the turbines in order to ensure stability in the combustion. Interestingly, this means that it is possible to use biodiesel in Malaysia, because the country produces around 800,000 to 900,000 tonnes in the year 2017 [6]. This amount required to use CI biodiesel in the power sector is within the production capacity of the country.

3.2 Impact of CI biodiesel on emission reduction

The environmental impacts such as potential emission reductions for biodiesel plant are discussed in this study. Biodiesel is known as a cleaner fuel compared to diesel/distillate fuel because it emits less emission and pollutant into the environment. Thus, the potential carbon emission reduction is the difference between the total carbon emitted by biodiesel and the produced carbon emission by distillate fuel. Consequently, the total potential carbon reduction is shown by the following equation (6):

$$TCS_i = TC_{di} - TC_{bi} \quad (6)$$

Whereby, the terms of equation can be calculated by the following equations (7) to (8):

$$TC_{di} = DRi \bullet EF_d \bullet HV_d \quad (7)$$

$$TC_{bi} = BCi \bullet EF_b \bullet HV_b \quad (8)$$

Where TCS = Total carbon reduction

TC_d = Total carbon reduction for distillate

TC_b = Total carbon reduction for biodiesel

DR = distillate fuel replacement

BC = biodiesel needed

EF_d = emission factor for distillate =88 kg/GJ

HV_d = heating value for distillate = 43.4 MJ/kg

EF_b = emission factor for biodiesel = 64.4 kg/GJ

HV_b = heating value for biodiesel = 39.3 MJ/kg

Table 3: Impact of CO_2 reduction for the transportation sector at different replacement rates.

Distillate replacement rate (%)	Distillate replaced (ton)	Biodiesel needed (ton)	Total carbon distillate (ton)	Total carbon biodiesel (ton)	CO_2 emissions reduction (ton)
1	86,290	91,783	329,559	232,296	97,263
5	431,450	458,916	1,647,794	1,161,480	486,314
10	862,900	917,832	3,295,588	2,322,960	972,628

Table 4: Impact of CO_2 reduction for the power generation sector at different replacement rate.

Distillate replacement rate (%)	Distillate replaced (ton)	Biodiesel needed (ton)	Total carbon distillate (ton)	Total carbon biodiesel (ton)	CO_2 emissions reduction (ton)
1	93,770	99,739	358,126	252,432	105,694
5	468,850	498,697	1,790,632	1,262,162	528,470
10	937,700	997,394	3,581,264	2,524,324	1,056,940

Table 3 presents the impact of CO_2 reduction for the transportation sector at different replacement rates of 1%, 5% and 10% in the year 2017. The potential CO_2 emission reduction is reported to be up to 972 kton for 10% of distillate fuel replacement by CI biodiesel. Meanwhile, Table 4 presents the impact of CO_2 reduction for the power sector at different replacement rates of 1%, 5% and 10% in the year 2017. The potential reduction of the CO_2 emission is 1,057 ktons when 10% of distillate is replaced by CI biodiesel. This shows that CI biodiesel have the potential of approximately 8% more CO_2 reduction when it is used in power sector compared to the transportation sector. About 97% of the global warming greenhouse gas (GHG) occurs during combustion of the fossil fuel used in the plant [7]. The substitution of biodiesel, a carbon neutral alternative energy into the microturbine system will considerably mitigate the intensive effect of GHG that occurs in the power generation sector. Furthermore, CI biodiesel is from non-edible feedstock thus, CI biodiesel has no conflict between food and fuel competition. The CI plant can tolerate various kinds of soil and it can grow in degraded and marginal soil.

There are limited studies on life cycle assessment (LCA) for biodiesel in microturbines, however, there was a recent study [8] that states jathropa biodiesel power plants can reduce CO_2 emissions by 22-76%. From this analysis conducted, it is more significant to use CI biodiesel in a microturbine as compared to ICE. The intermittent combustion under high pressure in a reciprocating machine such as the ICE appears more demanding than continuous combustion under lower pressure in the combustion chamber of a microturbine. The blades in microturbine are in contact with hot gases continuously throughout the operation, whereas the piston and the cylinder of an IC engine are subjected to high pressure and high temperature for a very limited period of time throughout the cycle. Hence the highest temperature in an ICE is higher than that in the microturbine. This means that the utilization of biodiesel in the microturbine would not be associated with higher nitrogen oxide (NO_x) emissions as a result of thermal NO_x formation.

Microturbines are also known to have higher efficiency compared to IC engines. This is because the system has a recuperator that recuperates hot exhaust air to be channeled back into the intake, thus enabling the users to install other Combined Heat and Power (CHP) applications. The flexibility of the microturbine, which accepts gaseous and liquid fuels of high calorific value, such as biodiesel allows the utility producer to switch between fuels based on the most economical convenience.

4 Conclusion

In summary, the potential CO_2 emission reduction for 10% of fossil diesel fuel replacement by CI biodiesel are 972 ktons for transport sector and 1,057 ktons for power sector. This show there is more significant emission reduction in the power sector. From the fuel and emission impact analysis conducted, it is more significant to use biodiesel in a microturbine as compared to Internal Combustion (IC) Engine. The substitution of biodiesel, a carbon neutral alternative energy into the microturbine system will considerably mitigate the intensive effect of GHG that occurs in the power generation sector.

Acknowledgements

The authors would like to thank Tenaga Nasional Berhad for providing the resources for the research under TNB Seed Fund, U-TG-RD-18-13.

References

[1] Wegstein, M. and Adhikari, N., 2010, Financial Analysis of Jatropha Plantations. Journal of the Institute of Engineering, Kathmandu 8(1): 1-5.

[2] Chisti, Y, 2007, Biodiesel from Microalgae. Biotechnology Advances: 25: 294–306.

[3] Sathya, S. V., Selvaraj, D. K., Kalimuthu, J., Periyaraman, P. M., & Subramanian, S., 2011, Two-step biodiesel production from Calophyllum inophyllum oil: Optimization of modified beta-zeolite catalyzed pre-treatment. Bioresource Technology, 102(2), 1066-1072.

[4] H.C Ong, T.M.I Mahlia, H.H Masjuki, D. Honnery, 2012, Life cycle cost and sensitivity analysis of palm biodiesel production in Malaysia. Fuel, 98, pp: 131-139.

[5] Malaysian Energy Information Hub, Diesel fuel consumption in Malaysia, available from: http://meih.st.gov.my/statistics, last accessed: 17 January 2018.

[6] Malaysia The Star Online newspaper, Malaysia's biodiesel production to rebound this year, available from: https://www.thestar.com.my/business/business-news/2017/03/07/malaysias-biodiesel-production-to-rebound-this-year/, last accessed: 17 January 2018.

[7] Y. Bicer, Ibrahim Dincer, 2017, Life cycle assessment of ammonia utilization in city transportation and power generation, Journal of Cleaner Production, 170 pp:1594-1601.

[8] T. Onabanjo, G.Di Lorenzo, A. J. Kolios, 2017, Life-cycle assessment of self-generated electricity in Nigeria and jathropa biodiesel as an alternative power fuel, Renewable Energy, 103, pp: 966-979.