EFFECTS OF BIODIESEL TOWARDS CI ENGINE PERFORMANCE AND EMISSION: A BRIEF REVIEW

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ABSTRACT: Biodiesel is a biofuel that has great potential to become an alternative fuel as it can be directly used in the Compression Ignition (CI) engine with very little or without any modification needed. From this review, it is identified that the quality of the biodiesel produced and the final performance of the engine is mainly depending on biodiesel feedstock, biodiesel production and engine technology. Different feedstock has a different composition, hence will produce biodiesel with different fuel properties that contribute to engine performance and emission. Nevertheless, proper production process and advanced engine technology can overcome the biodiesel drawback.

KEYWORDS: *Biodiesel; Biofuel; Compression Ignition; Engine Performance; Engine Emission*

1.0 INTRODUCTION

The National Energy Policy (NEP) of Malaysia 1979 has identified three objectives which are supplied, utilization and environment. The global energy supply is currently very much dependent on fossil fuels (crude oil, natural gas, coal). These non-renewable resources are acquired from fossilized remains of a buried dead organism, including plants and animals, which have been undergoing natural processes in the Earth's crust over hundreds of millions of years. As these processes required a very long period, the rate of the consumption of these fossil fuels is very much faster than new ones that are being formed. This high depletion rate of the reserve fossil fuel demands us to find other alternative resources to ensure the sustainability of energy. One of the renewable energy resources that is suitable for vehicle application is the biofuel. Biofuel can be defined as a fuel that is derive from natural (non-fossil) materials such as plants, animals, or digested organic waste such as manure or matter contained in wastewater [1]. Biofuel can be in a form of solid biomass, biogas, or in liquid form (bioethanol derived from plant crops or biodiesel from plant or animal oils). Along the lines of the Five Fuels Diversification Policy, the government of Malaysia had introduced the National Biofuel Policy to ensure a dynamic and healthy development of biofuel industry in this country. The sight of the National Biofuel Policy 2006 is as follows [2]:

i. Use of environmentally friendly, sustainable and viable sources of energy to reduce the dependency on depleting fossil fuels; and
ii. Enhanced prosperity and well-being of all the stakeholders in the agriculture and commodity based industries through stable and remunerative prices.

This biofuel policy was designed in 5 strategic thrusts which are biofuels for transport, industry, technologies, export and for a cleaner environment. Nevertheless, this review is only focusing on the biodiesel as fuel for internal combustion engine as it has the potential to become as an alternative for the petroleum diesel.

British petroleum has reported that the world proved reserves for oil, natural gas, and coal at the end of 2013 only sufficient to meet Reserve-to-Production(R/P) ratio of 53.3, 55.1 and 113 years respectively [3]. The high demand has caused the oil reserve of seems to not enough for long term and become unsustainable energy resources for sectors that consume oil such as transportation, power generation, domestic fuel, industrial fuel, petro chemicals, and other sectors. Biodiesel is a type of the liquid biofuels that is the second most abundant renewable liquid fuel after bio-ethanol. Although bio-ethanol is the predominant biofuel at the moment with 90% of total biofuel usage, the main advantage of biodiesel is because it can be used with minor or without any change that need to be done to the existing engines, vehicles and infrastructure [4]. Biodiesel can be used purely, or blended with petroleum diesel fuel in any percentage. In addition, the requirement for biodiesel storage, pumping and burning are identical to petroleum diesel fuel [5].

Therefore, this contains a brief review of the biodiesel influence to the engine performance and emission. The basic parameters that indicate engine performance are the power, torque, and fuel consumption. In addition to that, the emission is produced by the engine, especially from the exhaust that contains pollutant gas such carbon monoxide (CO), carbon dioxide (CO_2) and mono-nitrogen oxides (NO_x), unburned hydrocarbons (HC), and particulate matter (PM) are also needed to be analyzed. These to ensure that the use of biodiesel will not sacrifice the engine reliability at the same time it is harmless to the nature and to guarantee its compliance towards the regulation set by the authorities.

Facts, theories and previous researcher's findings that are associated with the performance and emission of a CI engine that were fuelled by biodiesel were gathered. From this information, the core contributors to the engine performance and emission were identified. Next, the effect of each of these elements to the engine performance and emission were briefly discuss and summarized. Finally, potential areas to be explored and improved were suggested.

Based on the review, three elements were identified as core contributors to the engine performance and emission which are biodiesel feedstock, biodiesel production, and engine technology.

2.0 BIODIESEL FEEDSTOCK

It is an appalling fact, as some of researchers have proven that in some of the performance parameters, biodiesel have shown a better result in comparison with the pure diesel [6]. Nevertheless, the types of biodiesel feedstock are one of the factors that influence the biodiesel quality, hence affecting the engine performance and emission.

Researches have shown that the performance and emission of an engine fueled by biodiesel is not the same for different types of biodiesel feedstock. For instance, the fatty acid profile of biodiesel does relates to the parent oil or fat and is a main factor contributing to fuel properties [7]. Table 1 shows the fatty acid composition from different feedstock.

Table 1: Cloud Point of Biodiesel from Different Feedstock as Related to Fatty Acid Composition [8]

Feedstock	Methyl Ester Composition (%wt)						Cloud Point	
	$C_{16:0}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$	Others	(K)	(°C)
Beef Tallow	23.9	17.5	43.9	2.3	0.1	12.3	286	13
Palm	35.9	4.1	43.2	10.6	0.2	2.4	283	10
Sunflower	6.1	4.2	24.0	63.5	0.4	1.8	274	1
Soybean	10.7	3.2	25.0	53.3	5.4	2.5	272	-1
Linseed	6.7	3.7	21.7	15.8	52.1	0.0	268	-5
Olive	10.7	2.6	78.7	5.8	0.7	1.5	268	-5
Sunflower	6.4	2.2	13.9	76.0	0.2	1.3	267	-6
Rapeseed	4.3	1.9	61.5	20.6	8.3	3.1	267	-6

By referring to the three objectives of the NEP, the feedstock of palm, jatropha, and algae seems to have potential and practical to be used in Malaysia. Palm oil and jatropha agriculture, for example, are very ideal to be planted in tropical areas with hot and humid weather along the year, like Malaysia [9]. Palm oil has advantages as the production of oil is continuous and uninterrupted regardless if annual production has its seasonal peak and down cycle. In addition, palm plantation has the highest oil yield in terms of oil production per hectare of plantation [10]. Malaysia already uses B5 biodiesel that is based on the Palm oil as its feedstock with 5% Palm oil methyl ester and 95% diesel fuel. The usage of this B5 in a diesel engine is safe and has been used without any engine modification [11]. Jatropha also one of the Malaysian government focus where a total of 1712 hectares of land has been recognized as a start for jatropha primary production and most likely to increase to 57,601 hectares by 2015 [12]. For Algae, numerous studies were conducted to identify the best algae species to be the feedstock for alternative fuel. Nevertheless, the use of algae as an alternative fuel are still in its early stages in Malaysia. A lot of effort has been done with the aim of producing biodiesel from this feedstock mainly in Sabah and Sarawak. Like other non-edible oil resources, algae is also a favorite source of alternative fuel as it will not compete with the food supply, feedstuffs and other products derived from crops [13].

Researchers have investigated palm-jatropha blended biodiesel in terms of its properties, performance, exhaust emission and noise in an unmodified diesel engine [14]. Seven sets of fuel, which are diesel fuel (D100), palm biodiesel 10% and 20% (PB10 and PB20), jatropha biodiesel 10% and 20% (JB10 and JB20), mixed palm-Jatropha with each 5% (PBJB5) and mixed palm-jatropha with 10% each (PBJB10).

The results show that brake specific fuel consumption (BSFC), for PBJB5 and PBJB10 are higher than D100 and also higher than PB10 and PB20. But it is lower than JB5 and JB10. Output Power for PBJB5 and PBJB10 are lower than D100 and also lower than PB10 and PB20, but it is higher than JB5 and JB10. It's caused by higher density, but lower calorific value properties of biodiesel. HC and CO emission for PBJB5 and PBJB10 are lower than D100 and also lower than JB10 and JB20, but it is higher than PB5 and PB10. Biodiesel has additional O2 that help complete combustion. NOx emission for PBJB5 and PBJB10 is almost the same with JB10 and JB20 where it is higher than D100, but lower than PB5 and PB10. The sound level is lower for all biodiesel than D100. But it's slightly varied with RPM. Higher viscosity of biofuel provides more damping and lubricity thus reduce noise. From their research, it is shown that, mixing different types of biofuel from different feedstock can change the fuel properties, performance and the emission produced by the engine.

3.0 BIODIESEL PRODUCTION

Subsequent to the selection of high quality feedstock, the quality of the biodiesel produced is very much dependent on the production process and the other materials used in this process. Currently, among the most recognized standard to measure biodiesel quality is the European standard for biodiesel is EN 14214 and the ASTM International D 6751.

There are four main ways to produce biodiesel, which are direct use or blending, micro emulsions, thermal cracking (pyrolysis), and transesterification. Micro-emulsification is a process to produce microemulsions (co-solvency) which is a solution to solve high viscosity problem in vegetable oil. Thermal cracking or Pyrolysis on the other hand is the conversion of an organic substance to another through a heating process with the present of catalyst. Among these methods, the transesterification of vegetable oils and animal fats is the most common methods is widely being used [15-16].

Transesterification is a process to change the chemical properties of triglycerides and fatty acid that present in oil [17]. Transesterification process generally starts when the oil together with the alcohol (usually methanol) and catalyst are put into a reactor followed by a separator to split the methyl esters from glycerol. The methyl ester is then neutralized and methanol (by-product) is removed. The methyl ester is then washed and dried to produce finished biodiesel [18]. The process can be modeled by the Equation (1) such as

$$\text{Triglyceride} + \text{Alcohol} \quad \leftrightharpoons \quad \text{Esters} + \text{Glycerol} \qquad (1)$$

There are few important points in biofuel production. First, the reaction needs to be complete because incomplete reaction will cause triglycerides, diglycerides, and monoglycerides that contain glycerol molecules that has not been released still left in the reaction mixture. These compounds known to bind glycerol when added to the free glycerol, will produce total glycerol. Next, it is also important to ensure that the free glycerol, residual alcohol and residual catalyst were completely removed. In addition to that, the facilities in biodiesel production, including the laboratory need to be available so that the quality monitoring for the feedstock as well as the biodiesel product can be done.

The properties of Palm, jatropha, and algae biodiesel that has undergone the transesterification process which consists of kinematic viscosity, cetane number, calorific value, cloud point, pour point, flash point and density as seen in Table 2. Among all, the most important properties of the CI engine fuel are the viscosity, which is also vital for lubricants. It can be seen that the viscosity and other parameters are different from one biodiesel to another. Generally, the viscosity of biodiesel is far higher than pure diesel originated from fossils.

As the chain length of fatty acid, alcohol moiety, aliphatic hydrocarbon or fatty ester increase, the kinematic viscosity also increases. Nevertheless, the increase of kinematic viscosity is smaller in aliphatic hydrocarbons compared to fatty compounds [19]. The high value of viscosity and density of biodiesel could disturb the atomization and volatilization processes, and further weaken the combustion process in engine [20]. Other problems that might be occurred to the engine that use biodiesel, including engine lubricant degradation, injector coking, filter plugging, piston ring sticking and breaking, and seal swelling/hardening/cracking. Special treatment is also required for low temperatures operation to avoid an excessive increment in viscosity and loss of fluidity of biodiesel [21]. The effect of other properties of the diesel engine can be seen in Table 3.

Currently, one of the temporary measures to overcome the weaknesses of biodiesel is to blend it with fossil diesel. Researches that were conducted found that the engine that run on biodiesel have a higher value of the brake-specific fuel consumption (BSFC), lower engine torque, and also have lower brake power in comparison with diesel.

Table 2: Properties of Processed Biodiesels from Different Feedstock [22]

Biodiesel	Kinematic Viscosity (mm2/s)	Cetene Number	Calorific Value (J/kg)	Cloud Point (ºC)	Pour Point (ºC)	Flash Point (ºC)	Density (kg/litre)
Jatropha	4.84	52	41.00	6	1	163	0.880
Palm	5.70	62	33.50	13	-	164	0.880
Algae	4.15	-	39.76	-	-	-	0.852
Petroleum Diesel	3.06	50	43.80	-	-16	76	0.855

Table 3: Correlation of Diesel Fuel Properties to Composition and Performance Property [23]

Property	Effect of Property on Performance	Time Frame of Effect
Viscosity	Affect fuel spray atomization and fuel system lubrication	Immediate and long
Density	Affect heating value	Immediate
Heating Value	Affect fuel economy	Immediate
Cetene Number	Measure of ignition quality-affect cold starting, smoke	Immediate
Cloud Point	Allow low temperature operability and fuel handling	Immediate
Flash point	Safety in handling and use – not directly related to engine	-
Lubricity	Affect fuel injection system (pump and injector) wear	Long-term (Typically)

An investigation on palm biodiesel-diesel blended fuel for instance shown that, by increasing biodiesel ratios up to 30% in biodiesel-diesel blended, the fuel reduced the engine brake power by 2.6% and increased BSFC by 3% [24]. The same pattern also reported for 20% biodiesel (palm, jatropha, and moringa) mixed with diesel, whereby the biodiesel for all samples had reduced brake power (BP) and increase BSFC than diesel fuel [25]. For engine emission, the results shown that biodiesel fuel reduces the average amount of carbon monoxide (CO) and hydrocarbons (HC) but increase nitric oxides (NO) emissions when compared with diesel fuel. This indicates that more research need to conduct to improve the biodiesel production as currently the use of biodiesel blend that is more than 5% (B5) is still not universally accepted.

4.0 ENGINE TECHNOLOGY

Currently, biodiesel is directly being used or tested in the CI Engine that was designed for diesel fuel without or with minor modification. This might be one of the causes that the output performance that is obtained from the engine has had an advantage of Diesel fuel. To develop a special engine that suits biodiesel properties is a long time process and might not worth for now. One of the technology that can be used to overcome the disadvantages of biofuel in CI engine is the Selective Catalytic Reduction (SCR) which help to reduce emissions in passenger cars and heavy-duty trucks in a more cost-effective at the same time improve fuel efficiency. A CI engines that equipped with SCR and ran on pine oil biodiesel was tested in a research [26]. Pine oil biodiesel has advantages of lower viscosity and lower boiling point, which improves the atomization and fuel/air mixing process, but the lower cetane number of the pine oil makes it likely to produce more NO_x. SCR system that using urea as reducing agent with the assist of catalytic converter was installed in the exhaust pipeline. Result shown that the brake thermal efficiency has improved about 7.5% compared to diesel in full load condition as the pine biodiesel ratio increases to B50 (50 % pine, 50% diesel). In addition, the major emissions such as CO, HC, smoke, and NO_x were also reduced compared to diesel by 67.5%, 58.6%, 70.1%, and 15.2%, respectively.

Other well-known technology to reduce NO_x emissions in CI engine is the exhaust gas recirculation (EGR) system. EGR helps to reduce oxygen concentration and the flame temperature in the combustion chamber. Though, it is reported that the use of EGR in diesel engines contribute to the increasing of smoke emissions and declining of thermal efficiency [27]. For instance, the results from an experiment on a four stroke Mitsubishi 4D68 CI engine that equipped with EGR and fuelled with palm oil biodiesel shows the drawbacks of EGR [28]. From this test that was conducted under a steady state condition, it is found that the CI engine that run on palm biodiesel and EGR had deteriorated the brake power output, the engine torque and increased fuel consumption. For the emission, although it manages to decrease the NO_x, there are slight increments in other emissions include CO_2, CO, and particulate matters when using EGR. Almost the same results were obtained by other researchers [29-30].

5.0 CONCLUSION

From this review, it is very clear that the effort of developing biodiesel technology is very crucial in order to provide an alternative energy resource that is more sustainable and reliable. It has been learned from this review that the status of the biodiesel development is still in the premature stages, although this technology has been acknowledged quite a long time ago. It can be concluded that there are three fundamental elements that influence the biodiesel properties, hence will affect the engine performance and emission which are the feedstock, the production and engine technology.

High quality of biodiesel starts with a proper selection of feedstock, selecting the most economic and effective production method and a proper design of the engine and other supporting technologies. Therefore, there a lot of research that can be conducted which involves a wide range of field, including the science of agriculture, chemical engineer and automotive.

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