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Biodiesel as alternative fuel for marine diesel engine applications: A review

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ABSTRACT

Transportation and shipping activities are major contributor to air pollution at sea where most of it occurs as a result of exhaust emissions from ships. Stringent emission limitations enforced by the International Maritime Organization have hastened the need to find a new alternative fuel for marine diesel engines. Thus, biodiesel fuel was chosen as one of the environmentally friendly alternative energy that can reduce ship toxic gas emissions and at the same time reduces dependence on petroleum-based fuels. Therefore, the purpose of this paper is to provide a comprehensive review of biodiesel as an alternative fuel for marine diesel engine applications. This review covers the biodiesel fuel background, engine performance, history, recent progress, engine warranty, issues, challenges, and possible solutions on using biodiesel for marine applications. A significant number of literatures from indexed journals were cited accordingly. The results of previous studies had shown that the use of biodiesel would mostly increase the amount of brake specific fuel consumption and nitrogen oxide gas while conversely reducing other toxic gas emissions. Although a number of issues and challenges arise, most marine engine manufacturers give conditional warranty against the use of biodiesel in the engines. The study concluded that biodiesel and its blends have a bright future in the marine sector, provided some of the highlighted issues can be solved.

1. Introduction

Marine transportation activities are mostly driven by marine diesel engines due to their efficiency compared to gasoline engine. Exhaust gases from marine engines can be considered as one of the major causes of air pollution at sea [1,2]. The most crucial seaborne emission released from the combustion of marine fuels consists of nitrogen oxides (NO_X), sulphur oxides (SO_X), carbon monoxide (CO), carbon dioxides (CO_2), and particulate matter (PM). The presence of these gases will adversely affect the environment and human health with lung cancer, cardiopulmonary deaths, bronchitis, pneumonia and global warming [3]. International Maritime Organization (IMO) reported that the annual shipboard CO_2 emissions in 2012 were 938 million tons, which constituted about 2.6% of global human-made emissions of the same substance. This scenario is expected to rise three folds by 2050 if no action is taken. Meanwhile the emissions of NO_X and SO_X were 15% (19 million tons) and 13% (10.2 million tons) respectively, from their global emissions [4]. In order to cope with this issue, a more stringent regulation is necessary. The latest Marine Pollution (MARPOL) in Annex VI revision recommends limiting the sulphur level from the current 3.50% to 0.50%, effective January 1, 2020. For NO_X emissions, it was reduced to Tier II and Tier III for global and North American Emission Control Areas, respectively since January 2016.

On the other hand, the shortage and rising cost of fossil fuels has made renewable energy more popular [5]. In addition, the petroleum-based fuel resources are limited to certain countries [6]. Therefore, there is a need to look for new alternative fuels to cater to the existing market. Based on previous findings, biodiesel was identified as one of the potential resources that fulfil the world's energy demand and can be a prominent candidate as alternative to petroleum-based fuels [7,8]. Nowadays biodiesel, biofuel and biogas are a form of alternative energy which is rapidly gaining interest among consumers. It is an environmentally friendly energy, non-toxic and has properties similar to diesel fuel [9–11]. Biodiesel can be applied in diesel engines without requiring any changes to the engine systems as their combustion characteristics are almost similar to the conventional diesel. Biodiesel fuel was discovered by Rudolf Diesel in 1912 and concluded that the use of vegetable oil would be preferred in the future [12]. Biodiesel can be processed from multiple feedstocks. In Europe and the United States, rapeseed and soybean oil are typically used for the production of biodiesel. Tropical countries including Malaysia, Thailand, Indonesia, Nigeria and Colombia extract biodiesel from palm oil. Palm biodiesel that

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is also referred as Palm Fatty Acid Methyl Ester (PFAME), is produced through the transesterification process. Palm oil has low production cost and is economically viable for biodiesel production [13–15].

Various engine studies using biodiesel were conducted and the results have shown that the engine performance was on par with conventional diesel. Furthermore, the emissions from biodiesel engine indicate better results compared to fossil fuels [16–33]. However, previous results are mostly derived from laboratory experiments conducted on land-based diesel engines. There are very few investigations related to marine engines that were reported so far, especially concerning the practical applications of biodiesel in the marine sector. It is therefore in the great interest of the authors to provide a comprehensive review on biodiesel fuel used for marine diesel engine. This study examines the past findings, history, current issues, challenges and potential solutions of biodiesel used as an alternative fuel in marine diesel engines. The aim of this work is to share useful information with researchers, engineers, ship owners and anyone interested in biodiesel as an alternative to fossil fuels.

2. Marine diesel engine

Marine diesel engines are nearly identical to land-based automotive engines. Generally, they are larger in size and equipped with fairly complicated systems and operate at a higher efficiency. Marine engine consists of four-stroke and two-stroke diesel engines, which represents 75% and 25% respectively. [34]. Four-stroke engines are primarily used in container ships and bulk carriers, while large two-stroke engines are typically installed for slow speed ships. Generally marine engines can be classified into three main categories: slow speed, medium speed and high speed engines. The selection category is based on the size, engine speed and the purpose of their operation. Slow speed engines normally operate below 350 rpm and have very minimum fuel consumption. In terms of size, slow speed engines are the biggest engines in the world which uses heavy fuel oil (HFO) for combustion. On the other hand, medium speed marine engines running with speeds between 350 and 750 rpm are generally used as main propulsion or auxiliary engine onboard ships. Meanwhile, high speed marine engines have revolutions of more than 750 rpm [35]. They are designed to provide high power output with minimum weight and size, usually used on speed boats and smaller ships. Marine internal combustion engines are normally equipped with a turbocharged system to reclaim more power.

3. Marine fuels

Marine fuels are processed from petroleum crude oil in refineries. Before being used, it is usually stored at bunker stations located in port areas. In today's shipping industry, heavy fuel oil is mostly used to power the main engine during voyage while marine diesel oil and marine gas oil are normally used for auxiliary engines and operation in harbours. There are five types of marine fuels which are categorized based on their blends and viscosity, namely:

a) Marine Gas Oil (MGO) – It is identical to the automotive diesel fuel which is used in land vehicles.
b) Marine Diesel Oil (MDO) – It contains a mixture of heavy fuel oil and marine gas oil, has low viscosity and does not require preheating before use.
c) Intermediate Fuel Oil (IFO) – Almost similar to marine diesel oil, a mixture of residual oil or HFO with MGO.
d) Marine Fuel Oil (MFO) – Almost similar to HFO. It is a mixture of HFO with MGO but contains less gas oil than IFO.
e) Heavy Fuel Oil (HFO) – The lowest grade of marine fuel. It is a residual oil, having a high-viscosity residual oil and requires preheating before use.

Marine fuel also can be grouped and graded into three basic types namely distillate, intermediate and residual, as listed in Table 1. Besides viscosity, density is also an important attribute for marine fuel grading because it is purified before use in order to remove water and dirt. Most marine fuel products are manufactured according to ISO 8217 standards. Currently, this standard does not permit the composition of biodiesel, but there are plans to do so in the future. On the other hand, the ASTM D975 standards allow blends of 5% biodiesel known as B5 fuels which are currently available in the market of most countries. Table 2 lists the basic properties of biodiesel, automotive, marine and heavy oil fuels.

Table 1
Marine fuel type and grades [12].

Fuel type	Fuel grades	Common industry name
Distillate	DMX, DMA, DMB, DMZ	Gas oil or marine gas oil, marine diesel oil
Intermediate	IFO 180, 380	Intermediate fuel oil
Residual	RMA-RMK	Fuel oil or residual fuel oil

Table 2
Properties comparison of biodiesel, automotive and marine fuels [12].

Property	Biodiesel EN14214	Automotive diesel EN590	Marine diesel ISO 8217	Heavy fuel oil ISO 8217
Density/15 °C, kg/m^3	860–900	820–845	< 900	975–1010
Viscosity/ 40 °C, cSt	3.5–5.0	2.0–4.5	< 11	< 700/50 °C
Flashpoint	> 120	> 55	> 60	> 60
Cetane no.	> 51	> 51	> 35	> 20
Ash content, %	< 0.01	< 0.01	< 0.01	< 0.2
Water content, ppm	< 500	< 200	< 300	< 5 000
Acid no. (TAN)	< 0.5	–	–	–
Sulphur, ppm	< 10	< 350	< 200,000	< 50,000
Calorific value, MJ/kg	37.5	43	42	40

4. Global energy trends

Hydrocarbon or fossil fuels are accounting for more than 80% of today's world total supplied energy. Fossil fuel resources are becoming less day by day and approximately 65.5% of world oil reserves come from Middle East countries [36]. Fig. 1 shows the forecasts of world oil production based on present demand scenario. The maximum

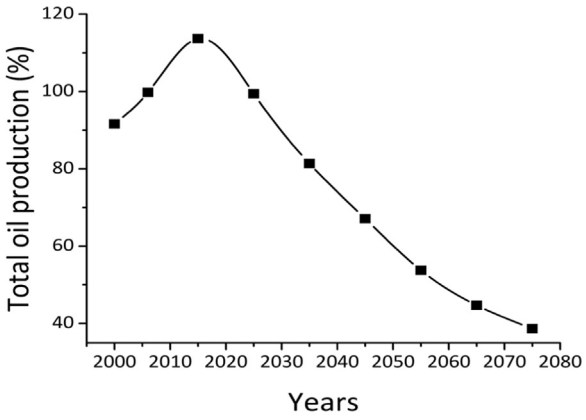

Fig. 1. World oil production forecast based on current scenario [8].