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Compression Ignition Engine Performance as a Function of the Fuel Properties

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Abstract. Compression ignition engines have wide application in the transportation, agricultural, construction and industrial sectors which are critical for the economic sustainability of any nation. These engines are powered with petroleum diesel which is however, been threatened by the reality of crude oil going into extinction in some couple of years if new reserves are not discovered, and also the need to reduce global warming; a consequence of the effect of its combustion products. Biodiesel is a renewable fuel with similar properties to petroleum diesel, and can be used purely or in blends without the need for modifying the existing engines. The thermal efficiency of an engine is a very important performance indicator, and researchers would stop at nothing to ensure its improvement. The kinematic viscosity is one of the fuel's properties which contribute to an engine thermal efficiency. This work is thus designed to review some past studies on the use of biodiesels and its blends in engines and find a correlation between the kinematic viscosity and the thermal efficiency. A correlation was established to exist between the fuel kinematic viscosity and the engine thermal efficiency.

Keywords: biodiesels, kinematic viscosity, calorific value, pure biodiesel properties, thermal efficiency.

1 Introduction

The rapid dwindling rate of the world fossil energy reserves has continued to be unmatched by new discoveries. However, the comfortable existence of the present age mankind has been tailored towards his large dependence on generated energy used in transportation from a location to another (air, land, and marine), powering of construction and agricultural equipment, and for electricity generation utilized in powering of household equipment and industrial machines/ equipment.

To meet this energy requirement, the dwindling fossil energy reserves are being continually called into play, as the bulk of the generated energy consumed by man is produced from it and only a fraction, about 13% of the whole is generated from nuclear, wind, solar and hydraulic sources. The generation of energy from fossil energy resources however also comes with an attendant cost of environmental pollution asides the possibility of it getting into extinction in a couple of years if new reserves are not discovered.

The transportation sector and agricultural and construction equipment generate its energy largely from crude oil, while a small fraction of the world's electricity is also generated from it. The major process of converting the inherent energy of crude oil utilized in these sectors employs basically the use of internal combustion engines. Crude oil forms about 38% of the amount of fossil energy used in generating energy for the use of mankind, and is a major contributor to the much talked about climatic change caused by global warming.

In order to continue to meet the huge demand of energy for transportation, agricultural and construction equipment, and electricity generation placed on internal combustion engines while placing a premium on the maintenance of a cleaner environment, alternative energy sources to crude oil are been sought for, and one of such is the use of renewable and bio-degradable biofuels.

Compression ignition engines are known for their heavy-duty applications, and are the preferred engine of choice for agricultural and construction earth moving equipment, marine and rail transportation devices, and electricity generation. These engines rely on the combustion of Automotive Gas Oil (AGO) generally known as diesel for the generation of its energy. In a quest to reduce the environmental impact and maintain a high thermal efficiency with the use of these engines, biodiesels are now increasingly used as a source of fuel because of its applicability to already existing engines without the need for modifications [1].

Researchers are thus busy carrying out studies on the production and use of biodiesels in compression ignition engines, its desired properties and the impact of its combustion products on the environment.

The impact of some of the properties of fuels, biodiesels inclusive such as calorific value on thermal efficiency [2–4] flash point on storage of fuels [5], cetane number on the fuel auto-ignition [6], and viscosity on flow rate and thermal efficiency [7–13].

This study is thus designed to review the literature and find a correlation between the kinematic viscosities of biodiesels / biodiesel blends and engine thermal efficiency.

2 Literature Review

2.1 Kinematic viscosity and thermal efficiency

Kinematic viscosity is the ratio of the fluid dynamic viscosity to its density and has a significant impact on fuel delivery and power output. It determines the rate of flow of the fuel, and too high a value can lead to pumping issues and atomization in the injection system [14].

Thermal efficiency is the fraction of the heat input that is converted into useful work by the device, in other words, it is the percentage of fuel energy converted into useful power output [11, 15]. The thermal efficiency of an engine has a direct relationship to its power output and is inversely proportional to the rate of mass of fuel consumption, hence a high value of thermal efficiency is an indication of better fuel economy and by extension reduced spending and lower exhaust of emission products.

In the quest to investigate the effect of the utilization of biodiesels and petroleum biodiesel blends on engine performance several researchers have conducted experiments using biodiesels produced from different sources and different blend fractions. Biodiesels produced from different sources have their own characteristic physicochemical properties which are a function of the production process and have an impact on the performance of the engine.

Independent studies with the use Karanja oil biodiesel and its blend (B20) with determined kinematic viscosities of 5.35 cSt at 40 °C and 3.04 cSt resulted into engine thermal efficiencies of 32.0 % and 30.2 % respectively [16, 17]. With biodiesel/biodiesel blends of Pongamia origin, kinematic viscosity values of 5.17 (B10), 5.43 (B20), and 5.62 cSt (B30) at 40 °C, the engines thermal efficiency were 26.2 %, 26.8 %, and 26.5 % respectively [10], while with values of 4.56 cSt (B100) at 33 °C and 5.46 cSt (B20) as determined from other studies resulted into engine thermal efficiency values of 26.0 % and 28.0 % respectively [18].

Studies on biodiesels with Canola oil and Honge oil as their origin with kinematic viscosity values of 5.38 and 5.60 cSt respectively measured at 40 °C resulted into thermal efficiency values of 31 % and 25 % respectively [2–8].

Jatropha oil is commonly used as a source of biodiesel in many parts of the world because of its ease of propagation [19]. Several studies have been conducted on the performance and emission characteristics of compression ignition engines using biodiesels produced from Jatropha and its blends with petroleum diesel, some of interest to the authors have been selected. Kinematic viscosity values of 4.38 (B100), 5.84 (B100), 5.21 (B10), 5.64 (B20), 5.97 (B30), 6.61 (B100), and 4.84 cSt (B100) measured at 40 °C as determined by some researchers for Jatropha biodiesel and its blends used in fuelling of an engine resulted into thermal efficiency values of 24.0, 24.0, 26.5, 26.3, 27.2, 22.0, and 31.0 % respectively [7, 8, 10, 15, 20].

Biodiesels with Soybean, Manhua and Palm oil as sources have also been worked upon by researchers. With Soybean oil as source, the use of its biodiesel with kinematic viscosity values of 3.34 (B20), 3.68 (B40), and 4.25 cSt (B100) measured at 40 °C in compression ignition engine resulted to thermal efficiency values of 31.3, 30.5, and 29.5 % respectively [3].

Manhua oil biodiesel with a kinematic viscosity of 5.58 cSt measured at 40 °C gave a thermal efficiency value of 27 % when used to fuel an engine [21]. Studies on biodiesel derived from Palm oil with kinematic viscosity values of 4.56 (B100), 2.82 (B20), and 3.40 cSt for petroleum diesel-palm oil blend in the ratio 1:4 measured at 40 °C resulted into thermal efficiency values of 25, 28 and 27 % respectively [22], while with kinematic viscosity of 4.70 cSt (B100) measured at 30 °C during another study, the thermal efficiency of the fuelled engine was 27 % [23].

Working with biodiesel produced from used and fresh Corn oil, the kinematic viscosity values measured at room temperature were gotten to be 4.70 and 5.86 cSt gave engine thermal efficiency values of 25.5 and 22.5 % respectively [24]. With Neem oil biodiesel having a kinematic viscosity value of 3.20 cSt, the engine's thermal efficiency was found to be 23.0 % [25], and as reported by Tutak et al., the use of B100 as fuel in their test engine with kinematic viscosity value of 4.51 cSt measured at 40 °C gave thermal efficiency value of 27.0 % [26].

A summary of the literature values of kinematic viscosities and the corresponding engine thermal efficiencies is as shown in Table 1 below.

Plots of thermal efficiency against kinematic viscosity values of biodiesel and some of its blends are as depicted in Figures 1–2.

Figure 1 is a plot of the thermal efficiency values against the kinematic viscosity values of some biodiesels and biodiesel blends. The thermal efficiency values can be seen to be indirectly proportional to the kinematic viscosity values, although this cannot be said to be applicable in some instance given an indication that other fuel properties will have an impact on the engines thermal efficiency.

Biodiesels despite having similar properties to petroleum diesel posses some characteristics such as oxygen content, fatty acid composition, and moisture content which differs from that of petroleum diesel and thus can impact the performance characteristics of an engine fuelled with it [27–29].

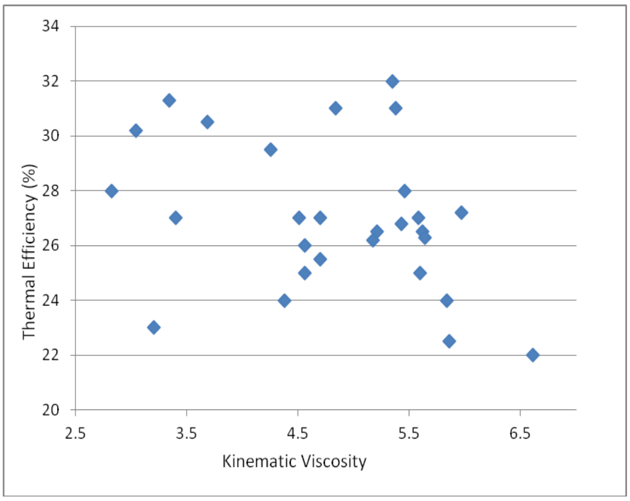

Figure 1 – Thermal efficiency kinematic viscosity plots of biodiesels and its blends

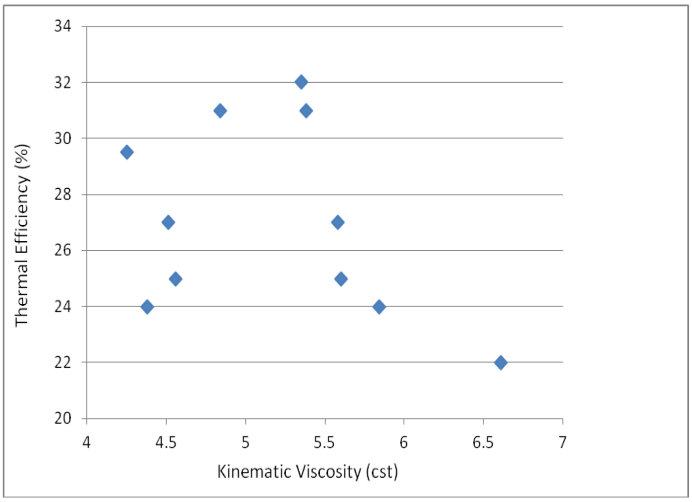

Figure 2 – Thermal efficiency kinematic viscosity values at 40 °C plots of biodiesels

Table 1 – Summary of thermal efficiency values

Kinematic viscosity, cSt	Thermal efficiency, %	Biodiesel source	Reference	Kinematic viscosity, cSt	Thermal efficiency, %	Biodiesel source	Reference
5.35	32.0	Karanja	[16]	6.61	22.0	Jatropha	[17]
3.04	30.2	Karanja	[17]	4.84	31.0	Jatropha	[20]
5.17	26.2	Pongamia	[10]	3.34	31.3	Soybean	[3]
5.43	26.8	Pongamia	[10]	3.68	30.5	Soybean	[3]
5.62	26.5	Pongamia	[10]	4.25	29.5	Soybean	[3]
4.56	26.0	Pongamia	[18]	5.58	27.0	Manhua	[21]
5.46	28.0	Pongamia	[18]	4.56	25.0	Palm oil	[22]
5.38	31.0	Canola	[2]	2.82	28.0	Palm oil	[22]
5.60	25.0	Honge	[8]	3.40	27.0	Palm oil	[22]
4.38	24.0	Jatropha	[7]	4.70	27.0	Palm oil	[23]
5.84	24.0	Jatropha	[8]	4.70	25.5	Corn oil	[24]
5.21	26.5	Jatropha	[10]	5.86	22.5	Corn oil	[24]
5.64	26.3	Jatropha	[10]	3.20	23.0	Neem	[25]
5.97	27.2	Jatropha	[10]	4.51	27.0	Neem	[26]

To mitigate the impact of some of the differences which exist between biodiesels and biodiesel-petroleum diesel blends on its performance when used as a fuel in engines, the impact of kinematic viscosity on an engine thermal efficiency is viewed from the aspect of only pure biodiesels, also the obtained kinematic viscosity values utilized in arriving at the plot in Figure 1 were not all determined at a uniform temperature, and as it has been stated in different literature that fluid viscosity is dependent on temperature [30–32], the plot of thermal efficiency against fuel kinematic viscosity values all measured at 40°C was done and is as shown below in Figure 2.

The thermal efficiency values are seen to be a function of the fuels kinematic viscosity values except for some of the few cases where despite the relatively low values of the fuels kinematic viscosity, the thermal efficiency value was lower (4.38 cSt – 24.0 %, 4.56 cSt – 25.0 %, and 4.51 cSt – 27.0 %).

As stated earlier, literature has established that the thermal efficiency of an engine is a function of its calorific value [2–32], and as shown in Figure 2, the thermal efficiency is also a function of the fuels kinematic viscosity, except for the stated observed exceptions, it is hence imperative to examine if the reasons for the exception can be attributed to the calorific value property of the fuel. This table shows biodiesels with kinematic viscosity values of lesser than 5 cSt and the corresponding calorific and thermal efficiency values is presented in Table 2.

Table 2 – Pure biodiesel properties

Kinematic viscosity, cSt	Calorific value, kJ/kg	Thermal efficiency, %
4.25	36.2	29.5
4.51	37.1	27.0
4.56	40.6	25.0
4.84	37.2	31.0

The Biodiesel with a kinematic viscosity value of 4.56 cSt despite having a higher value of calorific value than the others listed in Table 2 gave a lower value of thermal efficiency, given an indication that the observed few exceptional cases in the thermal efficiency against kinematic viscosity value plot in Figure 2 could have been due to other factors not directly related to the properties of the fuels.

3 Conclusions

Compression ignition engines have wide application in the transportation, agricultural, construction and industrial sectors which are critical for the economic sustainability of any nation. These engines are powered with petroleum diesel which is however, been threatened by the reality of crude oil going into extinction in some couple of years if new reserves are not discovered, and also the need to reduce global warming; a consequence of the effect of its combustion products.

In this paper, research works of literature on the study of biodiesel and biodiesel-petroleum diesel blends have been reviewed, and a correlation has been shown to exist between the fuels kinematic viscosity value and the thermal efficiency of an engine operated on it.

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Продуктивність двигунів із запалюванням стисненням від властивостей біопалива

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Анотація. Двигуни із запалюванням стисненням мають широке застосування у транспортній, сільськогосподарській, будівельній і промисловій галузях, що є надважливими для економічної стійкості будь-якої країни. Ці двигуни працюють на нафтовому дизельному паливі. При цьому видобуток сирої нафти через кілька років перебуватиме під загрозою, якщо не будуть виявлені нові запаси. Також при цьому необхідно враховувати загрози глобального потепління як наслідок суттєвого збільшення викидів продуктів згорання. Біодизель є поновлюваним паливом зі схожими властивостями з нафтовим дизелем. Він може використовуватися самостійно або в сумішах. Тепловий коефіцієнт корисної дії двигуна є надважливим показником ефективності, а науковці робліть усе необхідне для забезпечення зростання цього показника. Кінематична в’язкість є однією із властивостей палива, що сприяє тепловій ефективності двигуна. Таким чином, ця робота спрямована на огляд попередніх досліджень у розробленні біодизеля та його сумішей для двигунів. У результаті знайдено зв’язок між кінематичною в’язкістю і тепловою ефективністю. Також встановлено кореляцію між кінематичною в’язкістю палива і тепловою ефективністю двигуна.

Ключові слова: біодизель, кінематична в’язкість, калорійність, властивості біодизеля, теплова ефективність.