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Influence of poly(methyl acrylate) additive on cold flow properties of coconut biodiesel blends and exhaust gas emissions

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ABSTRACT

Biodiesel comprises fatty acid esters and is used as an alternative fuel for diesel engines. However, biodiesel has poor cold flow properties (i.e., CP, CFPP and PP) than mineral diesel fuel. This study aims to reduce the PP, CFPP and CP of coconut biodiesel (CB) blends using poly(methyl acrylate) (PMA) additives and investigate their effects on single-cylinder four-stroke diesel engine performance and exhaust gas emission. DSC and TGA were used to observe crystal behavior and thermal stability of the biodiesel fuel blends. Engine performance and emission were analyzed by Dynomax-2000 software and gas analyzer, respectively. Results showed that 20% of CB blended with diesel and 0.03 wt% of PMA showed significant improvement in the PP, CFPP and CP. Other properties of B20 with additives met the requirements of ASTM D6751. The BSFC of B20 with PMA was reduced by 3.247%, whereas the BTE was increased by 2.16%, compared with those of B20. Burning B20 with PMA increased the NO emission by 2.15%, whereas HC, CO and smoke emissions were 19.81%, 13.35% and 3.93% lower than those of B20, respectively. Therefore, CB20 blend with 0.03 wt% PMA can be used as an alternative fuel in cold regions without compromising fuel quality.

1. Introduction

Biodiesel can be extracted from various sources including vegetable oil, animal fat, and cooking oil waste; biodiesel is an excellent alternative to plain diesel fuel [1,2]. Biodiesel fuel (BDF) contains up to 12% oxygen, making it a clean-burning fuel that reduces CO_2, CO, particulate matter (PM), smoke and hydrocarbon (HC) emission [3]. Therefore, the use of biodiesel can enhance environmental status by reducing the level of greenhouse gasses (GHG) [4]. Given its site-specific availability, the use of biodiesel feedstock may vary with location but has no technical restrictions regarding location [5,6]. However, neat biodiesel fuel has some disadvantages. Some of the major drawbacks of using 100% biodiesel are higher NO_x emission, higher density and viscosity compare to neat diesel which affect the fuel atomization during injection and need to modify the fuel system, poor oxidation stability than that of neat diesel which produces harmful oxidation products under extended storage conditions [7], poor cold flow properties due to which the fuel supply system is clogged and creates engine starvation problem in cold weather [8]. To avoid these problems biodiesel blends are used. Biodiesel-diesel blend has improved physicochemical properties than pure biodiesel [9,10], and produces lower CO, PM and HC emission than neat/pure diesel but higher NO_x emission [11,12]. However, when the concentration of biodiesel is increased in a blend, carbon residue, viscosity and cold flow properties also increases, which can affect the fuel flow system and combustion process [13]. Malaysia BMW Group has been reported that 10% biodiesel blend with diesel (B10) has a technical challenge to run the engine. They have been obtained the corrosion, oil sludge and idling cycle stability problem of fuel flow system [14]. Recently, few studies have been carried out to solve the CFP problem of BDFs [15] including the use of additives [16–18], blending with diesel fuels [19], ozonation technique [20] and winterization process [21]. Among these, the use of additives to improve the CFP of biodiesel is the best method [22]. Although the influence of cold flow improver (CFI) in biodiesel blends on engine emission and performance has been investigated [23–25], the impact of polymeric CFI on engine emission and performance using biodiesel-diesel blend has not been reported. Therefore, the

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Nomenclature

ASTM	American Society for Testing and Materials
BSFC	brake specific fuel consumptions
BTE	brake thermal efficiency
B0	100% diesel
B20	20 vol% of biodiesel with 80% diesel
CB20	20 vol% of coconut biodiesel with 80% diesel
CB20P	20 vol% of coconut biodiesel with 80% diesel and 0.03 wt% PMA
CFPP	cold filter plugging point
CFPs	cold flow properties
CME	coconut methyl ester
CO	carbon monoxide
CO_2	carbon dioxide
CP	cloud point
DSC	differential scanning calorimetry
EVAC	ethylene vinyl acetate copolymer
FAME	fatty acid methyl ester
FP	flash point
HC	hydrocarbon
HV	heating value
NO	nitric oxide
O	oxygen
OS	oxidation stability
PM	particulate matter
PP	pour point
rpm	revolution per minute

present research selected the polymeric additive poly(methyl acrylate) (PMA) as CFI for coconut biodiesel (CB) blend, which could be a new alternative fuel for use in cold climatic conditions. A comparative study was also conducted to investigate the effects of PMA on the performance of single cylinder diesel engine and exhaust gas emission.

1.1. Literature review

1.1.1. Review on cold flow improving additives

Many researchers have explored the influence of adding CFI additives on biodiesel CFPs, emission, and engine performances [23,24]. Cao et al. [22] used ethylene vinyl acetate copolymer (EVAC) as CFI to investigate the effect of CFP on the biodiesel blend and found that 0.04 wt% of EVAC with B20 showed better CFP. Boshui et al. [16] used polymeric CFI to improve the CFP of soybean biodiesel. Joshi et al. [18] used ethyl levulinate (EL) to explore the reducing effect of CP, PP, and CFPP of cottonseed and poultry fat biodiesel. They found that 20 vol% of EL reduced CP, PP and CFPP by 4–5 °C, 3–4 °C and 3 °C, respectively. Dwivedi et al. [26] used ethanol as CFI to reduce the CP and CFPP of pongamia biodiesel by 10 °C. Roy et al. [23] improved the CFP of canola biodiesel using wintron XC30 (2 vol%) and investigated its effect on engine performance and emission. They found that B5 with additive showed better results for CP because of the temperature (6 °C) and HC. The HC and CO emissions of biodiesel blends with additives were less than those of biodiesel blends without additives at low and medium load conditions. The NO_x emission of the biodiesel blends with additives was almost the same as that of diesel at medium and high load conditions. Bhale et al. [27] used a different type of additive in MME to investigate the effect of CFPs and engine performance, as well as emission characteristics.

1.1.2. Review on diesel engine performance and emission characteristic of biodiesel blends

Previous research has been conducted on the production, characterization, and characteristics of engine performance and emission of biodiesel-blended fuels [28,29]. Habibullah et al. [28] investigated the influence of CB-diesel blend on the performance and emission of the single cylinder diesel engine at full load conditions. They found that the biodiesel blend showed high brake-specific fuel consumptions (BSFC) and low brake torque. The emission of HC and CO was 13.75%–17.97% lower than petroleum diesel, whereas NO_x emission was 5.67% higher than diesel. How et al. [30] explored the effect of CB-diesel blends on the performance and emission of a high-pressure common-rail diesel engine under several load conditions. They found that the biodiesel blends moderately affected the BSFC and BSEC of all loading conditions. The BSEC reduction rate was increased along with the percentage of biodiesel in the blend. The CO emission of the biodiesel blend was reduced as the concentration of biodiesel in the blend increased, but NO_x emission was higher than diesel. Smoke opacity was also reduced to 52.4% for B50 at 0.86 Mpa load condition. Mofijur et al. [31] explored the blend properties of 5 vol% and 10 vol% of palm and *Moringa oleifera* biodiesel, as well their effects on multi-cylinder engine performance and emission with different speeds. They found that the brake power of the biodiesels was 1.38%, 2.27%, 3.16% and 4.22% lower than that of diesel, whereas that of BSFC was 0.69%, 2.56%, 2.02% and 5.13% higher for PB5, MB5, PB10 and MB10, respectively. HC emission was reduced by 14.47%, 3.94%, 18.42% and 9.21%; CO was reduced by 13.17%, 5.37%, 17.36% and 10.60%; and NO_x emission was increased by 1.96%, 3.99%, 3.38% and 8.46% in PB5, MB5, PB10 and MB10, respectively, compared with diesel. Mofijur et al. [32] also investigated the effect of *Jatropha curcas* and *M. oleifera* biodiesel blend on the performance of a four-cylinder diesel engine and emission at full load condition with different rpm. The results showed that the brake powers of MB10 and JB10 were 4% and 5% lower than those of diesel fuel, respectively; whereas the break powers of MB10 and JB10 of BSFC were 5% and 3% higher than those of diesel fuel, respectively. Compared with diesel fuel, the use of MB10 and JB10 reduced HC emission by 12% and 16%, respectively; CO emission was reduced by 11% and 14%, respectively; NO_x was increased by 9% and 10%, respectively; and CO_2 emission was increased by 5% and 7%, respectively.

2. Materials and methodology

2.1. Materials

Coconut oil and other chemicals such as KOH, Na_2OH, methanol, and ethanol were collected from Malaysia. PMA was obtained from Germany.

2.2. Biodiesel production

CB was produced in two steps, namely, esterification and transesterification, because the acid value was more than 4 mg KOH/g. In the esterification process, coconut oil with 50% (v/v oil) methanol and 1% (v/v oil) H_2SO_4 were allowed to react for 3 h in a reactor at 70 °C and 900 rpm stirring speed. The esterified oil was then extracted, and the lower part was placed in the evaporator to eliminate methanol and water. Afterward, the product was used for transesterification, where oil with 25% methanol and 1% (w/w) KOH was chemically reacted in a reactor for 2 h in 65 °C at 700 rpm stirring speed. The oil was then sent for separation and washing with 65 °C distilled water to remove soap, glycerol, and mono-, di-,