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Vibration, noise and exhaust emissions analyses of an unmodified compression ignition engine fuelled with low sulphur diesel and biodiesel blends with hydrogen addition

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ABSTRACT

Depletion thread of fossil fuels and emission regularities of countries enforce researchers to use alternative resources in diesel engines. Hydrogen and biodiesel are one of the most important alternative fuels. Therefore, all effect of them must be investigated on diesel engine. In this study, experimental investigation was conducted on an unmodified four-stroke four-cylinder compression ignition engine, in order to comprehend its noise and vibration characteristics when the engine was fuelled with sunflower, canola, and corn biodiesel blends with %20 and %40 volume ratio while H_2 injected through inlet manifold with 3 l/min and 6 l/min flow rates. The results revealed that changes of sound pressure level with H_2 addition depended on engine speed whereas vibration acceleration was decreased with addition of gas at all engine speeds. Furthermore, in this paper exhaust emission characteristic of the engine when it was fuelled with sunflower, canola, and corn biodiesel blends and H_2 gas addition was presented.

Introduction

Compression ignition (CI) engine that is widely used for power generation in transportation and heavy industrial is the most popular engine type since invention of them, principally, due to its advantages of high thermal efficiency and durability [1–6]. Although compression ignition engines mostly still rely on conventional diesel fuel, there are many researches about alternative fuels since the thread of depletion of fossil-based fuels and emission regulations in many countries [7–11]. Therefore, cleaner and sustainable fuels have been gained prominence in recent years [12,13]. Biodiesel (fatty acid methyl esters) that derived from vegetable oil or animal fat is one of the promising alternative fuel to use in compression ignition engines [14,15]. It can be used in compression ignition engines directly or with little modification [16–18]. Improving effect on exhaust emissions such as carbon monoxide (CO), hydrocarbon (HC), sulphur dioxide (SO_2) is another important advantage of using biodiesel [19–23]. However increment of NO_x emissions is the primary drawback of using it [24–27].

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Hydrogen (H_2) is another renewable alternative fuel. Performance and/or emission characteristics of compression ignition engines with H_2 addition has been studied by many researchers. On the studies, H_2 were mostly used with other fuel types due to high auto-ignition temperature of H_2 [28,29]. It has been reported by many researchers that carbon dioxide (CO_2), CO and HC emissions were reduced, whereas NO_x emissions increased with H_2 addition. On the other hand decrement at engine performance was also observed by researchers [30,31].

Noise and vibration characteristic of internal combustion engines with different fuels were also investigated by some researchers. How et al. (2014) investigated the effect of coconut biodiesel on engine vibration characteristic [32]. Nguyen and Mikami. (2013) studied combustion noise characteristic with addition of H_2 into intake air of a compression ignition engine [33]. Taghizadeh-Alisaraei et al. (2012) evaluated vibration characteristic of a compression ignition engine which is fuelled with diesel-biodiesel blend [34]. Gravalos et al. (2013) blended methanol and ethanol with gasoline in order to investigate vibration behaviour of a spark ignition engine and Redel-Macias et al. (2014) evaluated the sound quality inside a tractor cabin when their engine was fuelled with biodiesel-diesel blend [35,36].

Internal combustion engine is a significant source of noise and vibration in a vehicle thereby, considerable attention should be paid on them. Although in literature there are so many studies about performance and emission characteristic of H_2 addition, there is a gap about its noise and vibration effect on compression ignition engine. In this study, sound pressure level, vibration and exhaust emission characteristic of an unmodified compression ignition engine has been evaluated. Throughout the experiments, the engine was fuelled with sunflower, canola, and corn biodiesel blends with low sulphur diesel fuel. Furthermore H_2 at different flow rates was added into intake air.

Material and method

In this study, experiments were conducted in Petroleum Research and Automotive Engineering Laboratories of Automotive Engineering Department at Cukurova University.

Sunflower, canola, and corn biodiesels were prepared via transesterification reaction by using 6:1 methanol to oil molar ratio as reactant and 0.5% (by weight of oil) sodium hydroxide as catalyst. Before transesterification reaction, methanol and sodium hydroxide were mixed in order to obtain methoxide while the oil was heated up to 60 °C. After the oil and methoxide were blended, the mixture kept at this temperature for 90 min by stirring. At the end of transesterification, the crude methyl ester was waited at separating funnel for 8 h. And then, crude glycerine was separated from methyl ester. The crude methyl ester was washed by warm water until the washed water became clear and then it dried at 110 °C for 1 h. Finally, washed and dried methyl ester was passed through a filter.

Blends were prepared by volume ratio of 20% and 40% for each biodiesel with low sulphur diesel fuel. Properties of test fuels and pure biodiesel fuels were analyzed by Zeltex ZX 440 NIR petroleum analyzer for determining cetane number; Tanaka AKV-202 auto kinematic viscosity test for determining the viscosity; Kyoto electronics DA-130 for density measurement; IKA-Werke C2000 Bomb Calorimeter for lower heating value measurement and Tanaka APM-7 Automated Pensky-Martens Closed Cup Flash Point Tester was used for flash point determination.

Experiments were conducted on a four stroke, four cylinder, and direct injection Mitsubishi Canter diesel engine. Throughout the experiments test engine was fuelled with low sulphur diesel (D100), 20% and 40% sunflower biodiesel – low sulphur diesel fuel blend (SB20 and SB40, respectively) 20% and 40% canola biodiesel – low sulphur diesel fuel blend (CaB20 and CaB40, respectively), 20% and 40% corn biodiesel – low sulphur diesel fuel blend (CoB20 and CoB40, respectively), while the hydrogen was added into the intake manifold with various flow rates of 3 l/min and 6 l/min (H3 and H6, respectively). The energy substitution ratio of H_2 was calculated according to eq. (1) and in Table 1, the energy substitution ratio of hydrogen with diesel–biodiesel blends was given.

$$H_2\ energy\ substitution\ ratio = \frac{\dot{m}_{H_2} * LHV_{H_2}}{\dot{m}_{fuel} * LHV_{fuel} + \dot{m}_{H_2} * LHV_{H_2}} \quad (1)$$

where;

$\dot{m}_{H_2}$ = the mass flow rate of H_2
$\dot{m}_{fuel}$ = the mass flow rate of fuel blends
LHV = lower heating value

Table 1 – H_2 energy substitution ratio.

Fuel type	Engine speed (rpm)	H3 (%)	H6 (%)
D100	1200	4.36	8.36
	1500	3.03	5.89
	1800	2.10	4.12
	2100	1.66	3.26
	2400	1.54	3.03
SB20	1200	3.66	7.07
	1500	3.11	6.04
	1800	2.20	4.30
	2100	1.92	3.77
	2400	1.58	3.11
SB40	1200	3.51	6.78
	1500	2.94	5.72
	1800	2.07	4.06
	2100	1.80	3.53
	2400	1.49	2.94
CaB20	1200	4.01	7.70
	1500	3.13	6.07
	1800	2.13	4.17
	2100	1.70	3.35
	2400	1.57	3.09
CaB40	1200	3.68	7.10
	1500	2.77	5.39
	1800	1.98	3.88
	2100	1.69	3.32
	2400	1.42	2.80
CoB20	1200	3.62	6.99
	1500	3.04	5.90
	1800	2.14	4.19
	2100	1.86	3.65
	2400	1.54	3.04
CoB40	1200	3.44	6.65
	1500	2.85	5.54
	1800	2.00	3.93
	2100	1.73	3.40
	2400	1.45	2.85