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Combustion characteristics of diesel fuel on one cylinder diesel engine using clove oil, eugenol, and eugenyl acetate as fuel bio-additives

Asep Kadarohman [1], Hernani [1], Ijang Rohman [1], Ririn Kusrini [1], Rizki Maryam Astuti *

Indonesia University of Education, Faculty of Science Education, Dept. of Chemistry Education, Jl. Dr. Setiabudhi No 229, Bandung 40154, Indonesia

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ABSTRACT

The aim of this study was to analyze the fuel blend combustion characteristics on an engine. First, physical properties were obtained by measuring specific gravity, API gravity, aniline point, viscosity, density, flash point, cetane number and heating value. Subsequently, combustion analysis was carried out under laboratory condition using hydra one cylinder direct injection diesel engine, while the combustion characteristics tested in this study included cylinder gas pressure, total heat release and ignition delay. The performed research showed that terpene compounds content of clove oil acted as mediator agent between the bio-additive and base fuel resulting a perfect solution. Ultimately, it enhanced the process of mixing between clove oil fuel blend and air, promoted rapid combustion and lowered ignition delay. The highest total heat release was inferred to be oxygen content of the bio-additive, leading a decrease of smoke, CO and HC emissions. However, the improvement of combustion performance did not linear with the increase of the oxygen supply as shown by eugenyl acetate. NO_x emission, as an environmental consequence of an efficient process in combustion chamber, was strongly affected by the greater quantity of oxygen.

1. Introduction

A number of experimental investigations have formulated some blends of diesel fuel to meet the requirements of European Union Commission called for a 5.75% fuel replacement by bio-fuel in 2010 [1]. Bio-fuel (or biodiesel) is the most widely used alternative fuel that have been developed in recent times due to its cost and its particular characteristics including environmental friendly fuel, less polluting, and renewable [2–8]. Methanol and ethanol are good candidates as alternative fuel since they have several physical and chemical properties similar to diesel fuel [9]. Nevertheless, the production of biodiesel involves some processes which were complex and costly. In addition, the use of fossil fuel can not be entirely displaced by biodiesel to alleviate worldwide depletion of the fuel. Several ways in saving energy and reducing emissions have been improved such as engine modifications [10,11], aftertreatment devices technology [12,13] and elevation of diesel fuel properties by the use of additives.

Numerous studies on an increase diesel fuel quality by adding additives have been observed [14,15]. However, oxygenated additive was one that has been extensively discussed in previous reviews due to its high oxygen content [16–21]. Kadarohman [22] found that some essential oils as bio-additive could improve engine performance by reducing fuel consumption. This observation was supported by the finding of Butkus et al. [23] who reported that addition of 5% of turpentine oil on diesel fuel had a positive influence on the engine performance and exhaust emission. Pramanik [24] discovered that fuel blend containing 50% of jatropha oil could enhance thermal efficiency of the engine. Further research by Forson et al. [25] concluded that jatropha oil could be used as an ignition-accelerator additive for diesel fuel in proportion of 97.4%/2.6% by volume due to its ability to produce maximum values of the brake power and brake thermal efficiency as well as minimum value of the specific fuel consumption.

Extending the previous work, Kadarohman et al. [26] compared between turpentine oil and clove oil as the most potential bio-additives, and the result pointed out that clove oil bio-additive had a better performance than turpentine oil in increasing the process of fuel combustion reactivity. Further investigation, the research focused on clove oil. Clove oil is essential oil largely composed of eugenol as the main component [27]. Eugenol has a bulky structure and two oxygen atoms. It can also form eugenyl acetate by ester reaction. The study on clove oil, eugenol, and eugenyl acetate as diesel fuel bio-additives and their performance on one cylinder engine had been evaluated, and the finding displayed that at 0.2% of bio-additive, three of fuel blends could

* Corresponding author. Tel.: +62 85624508729; fax: +62 022 2001108.
E-mail addresses: kadar@upi.edu (A. Kadarohman), hernani_kimia@yahoo.com (Hernani), ijangrh@upi.edu (I. Rohman), nadzm_special@yahoo.com (R. Kusrini), rizki139@yahoo.com (R.M. Astuti).
[1] Tel./fax: +62 022 2001108.

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decrease Break Specific Fuel Consumption (BSFC) and reduce exhaust emissions of the engine as well as oxygen enrichment to eugenol by esterification helped in reaching optimal fuel combustion [28]. This research showed that at low percent of bio-additive, performance test did not indicate a significant decrease in BSFC. It means that these bio-additives could not save on fuel consumption. Nevertheless, the decreasing of BSFC in every formula exhibited that clove oil, eugenol, and eugenyl acetate had a great potential to reduce fuel consumption rate in a larger composition. Raslavicius and Bazaras [1] noted that diesel fuel containing 3–5% of biodiesel can fulfil the current fuel specification and be sold as general motor fuel.

The causative role of the bio-additives is unclear. Hence, it is necessary to fully evaluate a detailed mechanism of the use bio-additives. Combustion analysis can well describe the exact reason behind the observed phenomenon, so the bio-additive fuel blends can be reformulated in order to get the maximum performance in an appropriate ratio. Therefore, the aim of this study was to analyze the fuel blends combustion process on an engine.

2. Materials and methods

2.1. Materials

This experiment used clove oil taken from Mitra Pala Mas, Purwakarta Indonesia; whereas, eugenol and eugenyl acetate were purchased from Indesso Aroma Industry Cilengsi Bogor, Indonesia. According to the result mentioned in the previous study, clove oil, eugenol and eugenyl acetate as oxygenated bio-additives were individually dissolved to diesel fuel at volume percent level of 0.2% (Table 1). Their characterizations using FTIR and GCMS spectrophotometer have been determined in previous work [28]. Physical properties, however, were obtained by measurement of specific gravity, API gravity, aniline point, viscosity, density, flash point, cetane number and heating value. The derived data were compared with the standard of Directorate General of Oil and Gas specification Indonesia for diesel fuel [29]. Pure diesel fuel (S1, as a base fuel) and all the bio-additive fuel blends (S2, S3, S4) were examined on one cylinder direct injection engine to analyze their mechanism in combustion process.

2.2. Combustion analysis in one cylinder engine

Combustion analysis was carried out under laboratory condition using hydra one cylinder direct injection diesel engine in Thermodynamic Engine and Propulsion Laboratory BTMP Puspitek Serpong-Indonesia that had been ISO 17025 certified by National Accreditation Committee. The engine specifications and the experimental uncertainties are given in Tables 2 and 3, respectively. Engine speed was varied from 1500 rpm, 2500 rpm, 3000 rpm to 3500 rpm. The combustion characteristic tested in the study included cylinder gas pressure, total heat release, and ignition delay. In this stage, combustion analysis was performed using piezoelectric sensor assembled to a main combustion chamber. During the stand experiment, data were sent by the piezoelectric sensors and recorded by high speed data acquisition system. A schematic block diagram of the instrumental analysis is illustrated in Fig. 1.

Table 1
Formulation of tested fuels.

Formula	Notation
Pure diesel fuel	S1
Diesel fuel + 0.2% of clove oil	S2
Diesel fuel + 0.2% of eugenol	S3
Diesel fuel + 0.2% of eugenyl acetate	S4

Table 2
Engine specifications.

Bore × stroke	80.26 mm × 88.9 mm
Max. power	9 kW/3600 RPM
Compression ratio	20.3:1
Max. speed	4.500 rev/min
Fuel injection pump	VE 1/11 F2250 RV 14,061
Injector	Bosch KBEL 88PV 1 870 005 546
Nozzle	Bosch 4 × 4 × 0.25 × 160°
Nozzle operating pressure	250 bar

Table 3
The experimental uncertainties.

Measurements	Uncertainties
Inlet pressure	±0.3 kPa
Exhaust pressure	±0.3 kPa
Ambient pressure	±0.3 kPa
Oil pressure	±0.3 kPa
Fuel pressure	±0.3 kPa
Coolant temperature	±0.4 °C
Oil temperature	±1.4 °C
Exhaust temperature	±2.4 °C

3. Results and discussion

The performed research on physical properties showed that the bio-additive fuel blends were in full compliance with the standard of Directorate General of Oil and Gas specification for diesel fuel as shown in Table 4, summarizing the measurement of these properties. The combustion characteristics of bio-additive fuel blends could be compared with base fuel by means of cylinder gas pressure, total heat release and ignition delay (Table 5). Fig. 2a–d showed the comparison of the cylinder gas pressures for the test fuels at the engine speed of 1500 rpm, 2500 rpm, 3000 rpm and 3500 rpm, respectively. Based on the pressure profiles in Fig. 2a–d and Table 5, at 1500 and 3500 rpm, cylinder gas pressures were not decreased by the addition of the three substances. Moreover, these bio-additives increased the cylinder pressure at 3000 rpm. However, eugenyl acetate could decrease the pressure at 2500 rpm. Cylinder gas pressure data were analyzed to obtain heat

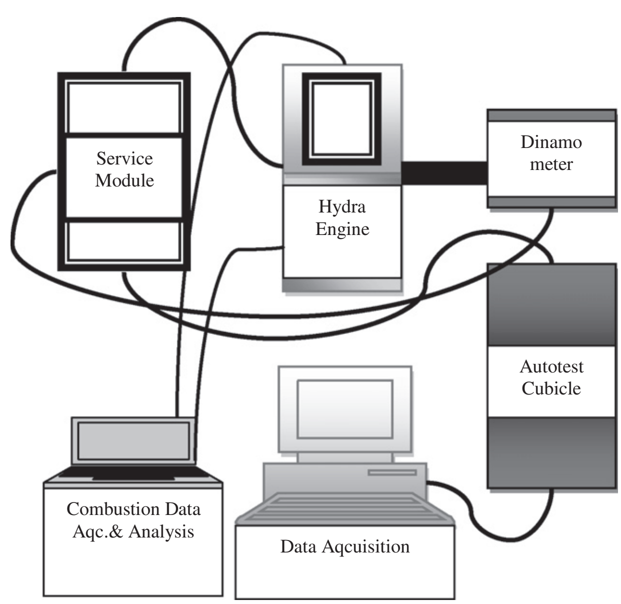

Fig. 1. Instrumental scheme for combustion analysis.